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Research Article

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The Effect of Pre Exercise Carbohydrate Consumption on Cognitive Function

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Abstract

Objective: Glucose supplementation before exercise has been shown to improve exogenous glucose availability which may alter cognitive function. We tested the consumption of two carbohydrate containing drinks, Performance Drink® (PD) and Gatorade® (GA) prior to exercise to determine if they will result in a higher blood glucose level during prolonged exercise compared with a water placebo (PL). We hypothesize that in a hydrated state there will be a cognitive function decline after two hours of exercise on a cycle ergometer. This cognitive decline will be lessened with carbohydrate supplementation. Furthermore, work output will be highest with carbohydrate supplementation.

Methods: 12 (3 females, 9 males) highly trained cyclists were recruited, ages 19-45 with average VO_2 peak of 58 L/kg*min. Subjects exercised at 65% VO_2 peak for 2 hours on a cycle ergometer while heart rate, core body temperature, O_2, CO_2, RER, RPE, glucose and lactate data points were collected every 30 minutes starting at 30 minutes prior to exercise. An ANAM computerized cognitive function test was given prior to and post-exercise.

Results: Blood glucose averages at the start of exercise for PD and GA were significantly higher than PL (125, 131 and 86 mg/dL respectively) but were similar at the completion of exercise. Post-exercise simple reaction time lengthened and median reaction time for spatial processing decreased with PL compared to PD and GA. Energy output (Watts × Time) was not significantly different for either treatment.

Conclusion: PD and GA showed improvements in glucose availability that was not seen with PL. Some measures of cognitive function were decreased with hydration alone but were maintained when PD and GA was consumed.

Keywords: Endurance exercise; Cognitive function; Supplementation; Sports nutrition; Sports performance

Abbreviations: PL: Placebo; PD: Performance Drink®; GA: Gatorade®; ANAM: Automated Neuropsychological Assessment Metrics; SRT: Simple Reaction time; MATH: Mathematical Processing; SRT: Simple Reaction Time; MSP: Matching to Sample; SPD : Spatial Processing; PRO: Procedural Reaction Time; CDS: Code Substitution; CDD: Delayed Code Substitution; RPE: Rate of Perceived Exertion; RER: Respiratory Exchange Ratio

Background

The general physiology of exercise has been a very active area of research during the past 40 years, yet the neurobiology of exercise has been virtually absent from public health discourse [1]. Several metabolic and neurochemical pathways among skeletal muscle, the spinal cord and the brain suggest ways by which physical activity and exercise might influence CNS functions such as executive cognitive function and learning [2]. The types of changes on cognitive function from prolonged exercise have been varied. Research exists that promotes the idea of neuronal tissue competitiveness in the brain. Moderate physical workload is associated with increases in neuronal firing rates in large amounts of neuronal tissue at the expense of higher cognitive areas of the prefrontal cortex [3]. Other studies verify the impairment of higher cognitive function with prolonged exercise studied the sources of energy for neuronal tissue. Lactate produced in working muscle is usually shuttled to the brain but this action is limited during high-intensity exercise and changes in oxidative enzymes in skeletal muscle after exercise could have indirect effects on brain energy availability and metabolism [4]. The availability of energy substrates may also play a role in cognitive function performance. Research indicates that central executive function relies on a limited energy source [5]. When brain glycogen stores are low, executive functioning is impaired [6]. More specifically, low blood glucose is associated with the release of counterregulatory hormones such as cortisol and a concomitant impairment of cerebral function [7]. Therefore glucose supplementation may positively affect cognitive function, especially during endurance exercise when glucose availability is low and reaction time, spatial relations, and vital decision-making abilities crucial to performance may all be impaired. Previous research has shown that the influence of carbohydrate ingestion on cognition during prolonged exercise yielded varied results. One study showed that carbohydrate ingestion could be beneficial to cognitive performance during a 120-minute cycling task at 60% VO_2max [8]. These results were later confirmed by Collardeau et al. [9] that complex cognitive performance could be improved after a 2-hour run performed at 75% VO_2max by well-trained triathletes drinking a 5.5% carbohydrate/electrolyte solution (glucose, fructose, maltodextrins, sodium: 20 mEq, potassium: 5 mEq) every 15 minutes (2 ml/kg of body weight) [9]. Some research demonstrates a positive correlation with exercise and cognitive function performance. Indeed, increases in metabolic load associated with exercise duration can induce an increase in arousal level that would improve cognitive functioning [7]. Moreover, exercise duration and intensity has shown to be a key factor in the cognitive function performance changes [9]. Yet previous paradigms utilized only limited cognitive function test batteries and thus failed to fully identify variations in cognitive functioning [9,10]. Consequently, we aim to further elucidate and quantify these disparities by employing a more robust battery of tests. The supported evidence of cognitive decline with prolonged exercise provides a basis for our hypothesis. Carbohydrate supplements used in previous research have not been uniform in content or hydration status and with new carbohydrate supplements becoming available, evaluating the effectiveness of the ingestion of multiple drinks on cognitive function would add to the argument for carbohydrates being used not only to replace carbohydrates lost during exercise

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but also to assist in cognitive decline during the same endurance exercise. Performance Drink® is a newly available carbohydrate sports drink that we wanted to evaluate against Gatorade®, a sports drink that has been commercially available for decades and has research (Gatorade journal articles) showing its ability to enhance endurance exercise. We suggest that in a hydrated state there will be a decline in cognitive function performance. Furthermore in a hydrated state with carbohydrate supplementation, the decline in post-exercise cognitive function performance will be limited or suppressed.

Methods

Participants

12 participants (9 male and 3 female) age 18-45 were recruited from the local cycling community in Western New York (Table 1). Participants needed to be "healthy" as defined by having no signs or symptoms of cardiovascular and pulmonary disease according to the criteria for low-risk stratification for coronary artery disease (American College of Sports Medicine 2000) [11]. Participants were excluded for any of the following factors which could influence cognitive function performance: diagnosed learning disability, concussion within the previous 6 months, and the use of medication which could influence cognitive performance (e.g., antidepressants or pain medications). Participants fasted overnight for all laboratory visits to avoid gastrointestinal distress and potential interference with cognitive function due to digestion, varying caloric load between participants and factors such as alcohol or caffeine. In addition, subjects that smoked or had Level 1 hypertension were excluded. Female subjects were excluded if pregnant. Female subjects were also screened for menstrual status and excluded if they were amenorrheic. Female subjects were tested between days 4 and 11 of their menstrual cycle to limit any hormonal influence. This is the early follicular phase where female hormones such as estrogen and progesterone are at their lowest levels. The protocol was approved by the Health Sciences Institutional Review Board at the State University of New York at Buffalo. Each participant was informed of the experimental procedures before providing a written consent.

Procedure

Experimental participants completed four laboratory visits. All tests were conducted at the same time of day to avoid confounding factors associated with circadian variation [11].

Cognitive testing: The ANAM® (Centre for the Study of Human Operator Performance Norman, OK) is computerized, Windows PC-based, mouse-operated software for which scores have been correlated with scores on traditional neuropsychological tests and was created by the North Atlantic Treaty Organization and the U.S. Department of Defense as a rapid, reliable, easily repeatable neuropsychological test [12,13]. The ANAM® test battery is comprised of six modules for various cognitive domains (one module is repeated [14]. The battery takes approximately 15 minutes to complete on a desktop personal computer [14]. The test battery included the following modules: simple reaction time (SRT), mathematical processing (MATH), matching to sample (MSP), spatial processing (SPD), procedural reaction time (PRO) and code substitution (CDS) [14]. There was also a question asked about the sleepiness (sleep score) of the subject at the beginning of the test. The sleep score was based on a scale of 1 to 7 with 1 being very awake and 7 feeling sleepy. A test of Code substitution was also taken in the first part of the test (CDS) and was taken again later as delayed code substitution (CDD). The modules assessing reaction time (SRT and PRO), spatial processing and visuo-spatial working (SPD), visual-spatial working memory (MSP), concentration and working memory (MATH) and attention (CDS,CDD) [14]. Each subject performed an abbreviated ANAM® test battery upon first arriving at the lab to limit any potential learning effect. The abbreviated ANAM® contained the same type of questions as the full ANAM® but fewer questions were asked in each section. Subjects then completed the full ANAM® 90 minutes prior to exercise and then again following completion of exercise.

Table 1: Group Characteristics.

Measurements	Value		SD
Age (years)	26.0	±	7.0
Weight (kg)	167.2	±	9.2
Heart Rate (bpm)	70.2	±	11.6
Body Fat %	59.0	±	7.0
Total Cholesterol (mg/dL)	13.9	±	31.0
HDL Cholesterol (mg/dL)	149.0	±	12.0
Fasting Blood Glucose (mg/dL)	83.0	±	8.0
VO_2 Peak (mL/kg/min)	58.4	±	10.0

Note: Mean values ± SE of group characteristics for men and women at baseline.

First laboratory visit of experimental groups: Subjects were well-trained cyclists capable of cycling for 2 hours at an intensity of 70% of their maximum aerobic capacity [11]. Fasting (12 hours) blood lipids and glucose was assessed using Cholestech LDX analyzer (Hayward, California), and ACCU-CHEK® Advantage® glucose analyzer (Roche Diagnostics, Basel, Switzerland) by a finger prick blood sample. Resting heart rate, blood pressure, height, and weight were also measured. Body composition was estimated by 3-site caliper skin-folds using Lange® skin calipers (Beta Technologies, Inc., Santa Cruz, California), and then calculated using equations derived by Jackson et al. [15] Once low cardiovascular disease risk had been established, each subject underwent a computerized VO_2peak cycling test using CompuTrainer Racermate 8002 (CT) (a computer aided load simulator) in the standard procedure of increasing workload. Subjects started out at 100 watts and workload was increased every 2 minutes by 50 watts until exhaustion [16]. This is similar to Cane et al. [16] who followed the same protocol except the stages were 3 minutes long. VO_2 peak achievement criteria included failure to increase O_2 uptake with increasing workload, attainment of age predicted heart rate max, or RQ greater than 1.10. Expired air analysis was performed using the Vacu-Med Mini CPX system (Vacumed, Ventura, CA). The cycling protocol was used to determine the level of exercise needed to exercise at 70% of VO_2peak (Figure 1).

Second, third and fourth experimental visits: The study was a randomized double blinded cross-over design. Experimental participants arrived at the laboratory after an overnight fast having avoided exercise for 24 hrs [17]. Subjects were instructed in recording their food intake, and completed three day diet records were reviewed by a registered dietician. These were analyzed using Nutrition Pro® Version 5.0 (Axxya Systems, Houston, TX) (Table 1). Subjects were required to keep a similar diet before each testing. The lab-controlled training and food diaries were administered to ensure similarities in glycogen status prior to each performance test [17]. Each subject completed a GI distress questionnaire upon arrival to the lab, post-exercise, and 48 hours post-exercise [18].

Exercise protocol: The subjects rested for 30 minutes after the first blood sample (Time 2), then drank 500 mL of a predetermined

Stage	1	2	3	4	5	6	7	8	9	10	11	12	13
Time (min)	2	2	2	2	2	2	2	2	2	2	2	2	2
Watt	100	150	200	250	300	350	375	400	425	450	475	500	525

Figure 1: VO_2 Peak Protocol
This graph represents a modified Bruce VO_2 max test of increasing workload used.

solution at room temperature (Time 3) which was either Placebo (PL), Performance Drink® (PD) or Gatorade® (GA). All subjects received each treatment; the visit order for which treatment was ingested was randomized. The subjects also consumed a small VitalSense® capsule to measure core body temperature (Mini Mitter, Bend OR). Thirty minutes after ingesting the drink, subjects started cycling on the bicycle at a speed/resistance (workload) that required 70% of their specific, predetermined VO_2 peak for 120 minutes [19]. Expired air was collected continuously with the Vaccumed MINI CPX® during the endurance cycling to assure 70% VO_2 peak was maintained. (Vaccumed, Ventura, Ca). Heart rate, core body temperature, and (RPE) rate of perceived exertion, a measure of perceived effort during exercise based on the Borg scale with 6 being the lowest effort and 20 being the highest effort experienced were recorded prior to exercise and every half hour until completion of exercise. Heart rate was recorded using a Polar Heart Rate Monitor (S410 heart rate monitor, Polar USA, Lake Success, NY). 150 mL of water (at RT) was given every half hour during exercise, maintaining and matching hydration status across all treatment conditions. Finger prick blood samples for glucose and lactate were taken after 1 and 2 hours of exercise. Blood lactate concentration was determined using an ACCUTREND® lactate autoanalyzer (Sports Resource Group, Hawthorne, NY). Blood Glucose concentration was determined using an ACCU-CHEK® glucose monitor (Roche Diagnostics, Basel, Switzerland). The beverages consumed were all 500 mL, at room temperature, and double blinded to the researcher and subject. PL consisted of commercially available lemon lime flavored water, $Fruit_20$®. The PD beverage is a lemon-lime flavored, hypo-osmotic carbohydrate-electrolyte solution which was gender specific for the subject. The GA beverage is Gatorade *Rain lime*® and consisted of a 6% carbohydrate-electrolyte solution.

Statistical analysis

The design is that of a single-center, three-treatment, and three period cross-over trials with repeated measurements within period with the purpose of assessment of mean drink differences. Numeric variables were summarized using simple descriptive statistics such as the mean, standard deviation, and range. A variety of graphical techniques were also used to display data. To describe the observed variability in the data and test for differences between drinks, a linear mixed model was fit to each considered endpoint. Each endpoint was fit as a function of the fixed effects of drink, time treated as a categorical variable, a drink by time interaction, and period. A complete lack of carry-over effects was assumed. To account for the within-subject dependence structure, random effects of subject and period were included and the model assumed that the distribution of the error terms subject to be multivariate normal with zero mean and an unstructured covariance structure. Once a model was fit, specific linear contrasts based on the estimated model parameters were constructed and used to test hypotheses of interest. All tests were two-sided and tested at a 0.05 nominal significance level. No method of imputation was used for missing data and standard diagnostic plots were used to assess model fit. All statistical tests were carried out using SAS version 9.2 statistical software (Cary,NC).

Results

Physiological measures

Subjects consuming GA (134.7 ± 25.7) had a lower heart rate after 60 minutes of exercise than subjects consuming PL (157.2 ± 14.5, P=0.007) or PD (151.5 ± 15.1, P=0.04). Rate of perceived exertion rose significantly higher for each treatment from beginning of exercise to end of exercise (P<0.001). After 30 minutes of exercise, subjects consuming PL had a significantly higher body temperature (101.2 ± 0.4) compared to subjects consuming PD (100.0 ± 0.6, P=0.003)) or GA (99.8 ± 0.2, P=0.003). During PD and GA exercise bouts, glucose levels initially decreased yet stabilized after 30 minutes (Figure 2). Conversely, during PL exercise blood glucose concentrations increased at the outset but steadily declined after 30 minutes of exercise. At the completion of exercise, subjects who drank PL (80.7 ± 6.4) had significantly lower blood glucose levels than subjects who drank GA (95.1 ± 5.3, P=0.03) (Figure 3) Respiratory values of oxygen and carbon dioxide expressed as respiratory quotient were not significantly different for any treatments upon completion of exercise, PL (0.72 ± 0.02), PD (0.68 ± 0.02), and GA (0.68± 0.02). Subjects did not report any gastrointestinal distress for either of the treatments (data not shown).

Exercise completion

Failure to complete the two hour cycling protocol only happened once for subjects who drank GA and once for subjects who drank PD. Total energy output (minutes multiplied by watts) for subjects drinking PD (21519.0 ± 2634.4) was 36.1% greater than PL (15808.1 ± 1787.4), and GA (19652.1 ± 2420.5) was 24.3% greater than PL, but neither were significant (P=0.6).

Cognitive function

There were significant differences in portions of the ANAM® test batteries between the three treatment groups.

Sleep score: Subjects who consumed PD had a 21.1% increase in post-exercise sleep score (4.0 ± 1.1) compared to pre-exercise (1.62 ± 0.7) (P=0.001) (Table 2). Subjects who drank GA had a post-exercise sleep score of (4.3 ± 1.1) which was 9.3% worse than subjects who

Table 2: Nutritional Intake.

Drink	Mean Kcal Intake		SE	Mean CHO %		SE	Mean Protein %		SE	Mean Fat %		SE
Placebo	2208	±	700	52	±	7	17	±	4	29	±	6
Performance Drink	2296	±	612	55	±	10	24	±	10	28	±	6
Gatorade	2553	±	613	46	±	7	18	±	5	30	±	6

Note: Mean values for Kilocalorie intake and percent carbohydrate, protein and fat intake showing nutritional status.

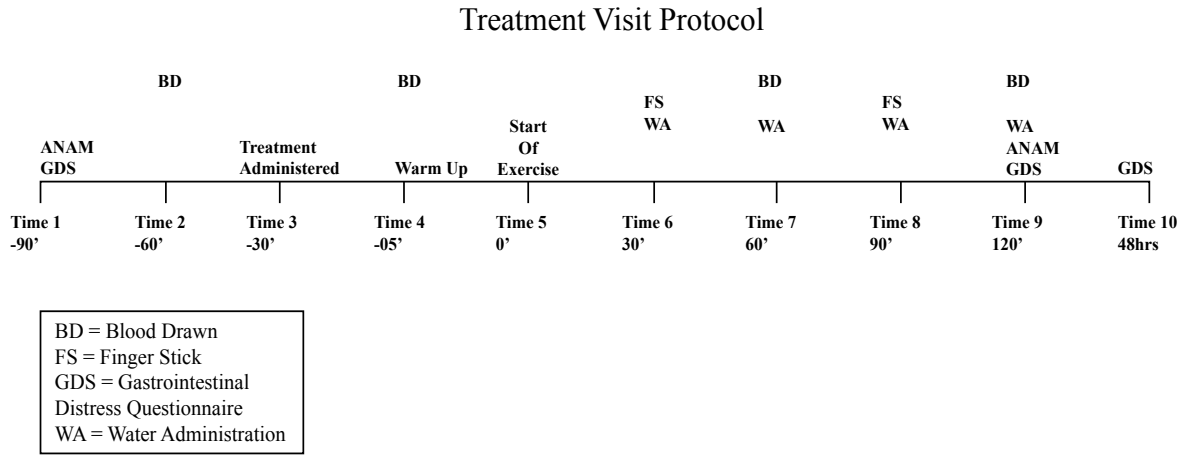

Figure 2: Treatment Visit Protocol. Time Trial Protocol

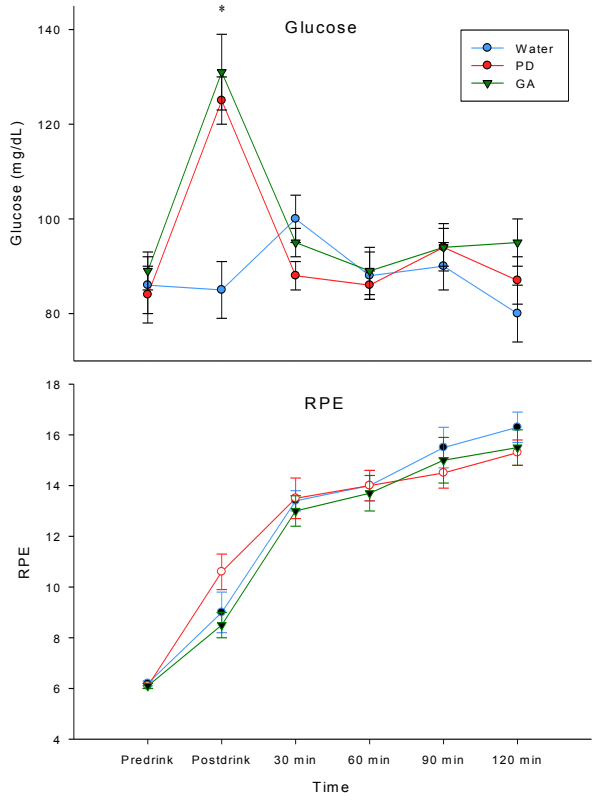

Figure 3: Blood Glucose and Rate of Perceived Exertion
Note: Blood glucose and RPE mean value ± SE at 6 time points during the rest and exercise portion of the study protocol. * P<0.05

consumed PL (3.0 ± 1.6, P = 0.01) (Table 3).

Simple reaction time: Post exercise, minimum reaction time for PL (186.1 ± 8.9) was degraded 2.9% lower than PD (165.8 ± 6.4, P=0.03) and 2.3% lower than GA (169.6 ± 6.1, P=0.05) reaction times. The impulsivity of reaction time degraded 27.8% slower for subjects who drank PL (0.2 ± 0.1 to 0.7 ± 0.3, P=0.05) compared to subjects who drank PD (0.1 ± 0.1 to 0.3 ± 0.1, P=0.3) or GA (0.3 ± 0.2 to 0.2 ± 0.2, P=0.2) from pre-exercise to post-exercise.

Code substitution: Subjects who drank PD had an improved 2.2% more in correct answers from pre-exercise to post-exercise that was approaching significance (P=0.7) (Table 4). As expected from the change in correct answers, there was a 47.7% decrease in incorrect answers in tests of code substitution for subjects consuming PD in pre-exercise to post-exercise scores that was approaching significance (P=0.07) (Table 4). The throughput, a measure of total score (correct answers and time to complete the questions) for subjects consuming PD was higher (2.2%) than those consuming PL (-0.3%) or GA (1.2%) in pre-exercise to post-exercise tests (Figure 4).

Delayed code substitution: A measurement of short term memory, showed that cyclists drinking PD improved their throughput scores (16.4%, P=0.01) pre-exercise to post-exercise. PL had a (-1.9%) decrease in scores and GA (3.5%) increase, both of which were not significant (Figure 4).

Procedural reaction time: The standard deviation of correct answers in the Procedural Reaction Time battery post-exercise for subjects consuming GA was significantly lower than those consuming PL or PD compared to pre-exercise (Table 4). The standard deviation of correct answers in the same Procedural Reaction Time battery for subjects consuming PD was had less variation from pre-exercise to post-exercise tests (Table 4).

Table 3: Physiological Measurements

Measurement	-30	-5	30	60	90	120
Body Temperature						
Placebo	98.7 ± 0.2	98.1 ± 0.2c	101.3 ± 0.4ab	100.8 ± 0.2ab	100.7 ± 0.1b	100.3 ± 0.1a
Performance Drink	96.0 ± 1.9	97.8 ± 0.4c	100.02 ± 0.6a	100.8 ± 0.1b	100.9 ± 0.1b	100.6 ± 0.1bc
Gatorade	98.4 ± 0.2	98.3 ± 0.2a	99.8 ± 0.2b	100.1 ± 0.3b	100.1 ± 0.3b	100.4 ± 0.3b
Systolic						
Placebo	113.0 ± 4.2	117.2 ± 4.2a	133.2 ± 9.1b	131.4 ± 8.1b	117.0 ± 5.7a	122.1 ± 7.0ab
Performance Drink	116.4 ± 4.9	116.1 ± 5.3a	132.0 ± 8.1cd	141.3 ± 9.4d	129.3 ± 6.9bc	119.3 ± 5.0ab
Gatorade	114.8 ± 5.9	116.2 ± 6.6a	129.6 ± 6.6a	128.3 ± 7.2a	121.0 ± 6.2a	119.8 ± 9.4a
Diastolic						
Placebo	65.5 ± 2.9	66.8 ± 2.8a	73.2 ± 3.2b	67.8 ± 2.9ab	68.3 ± 3.3ab	62.6 ± 4.1a
Performance Drink	68.3 ± 3.6	65.8 ± 2.7a	72.5 ± 3.9b	70.0 ± 3.1a	66.7 ± 2.0a	69.4 ± 3.8a
Gatorade	64.8 ± 3.1	66.7 ± 3.1a	72.8 ± 3.7a	68.2 ± 2.8a	68.2 ± 3.2a	65.6 ± 3.4a
Heart Rate						
Placebo	60.3 ± 3.2	62.3 ± 3.3a	150.0 ± 5.3b	157.4 ± 4.6b	146.0+7.0b	151.8 ± 5.4b
Performance Drink	62.8+3.2	61.0+2.8a	146.0+5.7b	151.5+5.0b	146.0+7.0b	155.7+4.6b
Gatorade	63.2 ± 3.0	62.6 ± 3.8a	136.5 ± 9.2b	134.7 ± 9.0c	143.5 ± 8.7b	152.0 ± 5.4b
RPE						
Placebo	6.2 ± 0.1	9.0 ± 0.8b	13.4 ± 0.4c	14.0 ± 0.6c	15.5 ± 0.8d	16.3 ± 0.6d
Performance Drink	6.1 ± 0.1	10.6 ± 0.7b	13.5 ± 0.8c	14.0 ± 0.6c	14.5 ± 0.6c	15.3 ± 0.5d
Gatorade	6.1 ± 0.1	8.5 ± 0.5b	13.0 ± 0.6c	13.7 ± 0.7c	15.0 ± 0.9c	15.5 ± 0.7d
Glucose						
Placebo	86 ± 2	85 ± 3.ab	102 ± 4c	89 ± 4bc	91 ± 5bc	81 ± 6a
Performance Drink	83 ± 5	126 ± 0c	90 ± 4a	86 ± 3a	93 ± 6a	86 ± 7a
Gatorade	89 ± 4	131 ± 8b	95 ± 3a	89 ± 5a	94 ± 4a	95 ± 5a
Lactate						
Placebo	6.2 ± 0.1	9.0 ± 0.8b	13.4 ± 0.4c	14.0 ± 0.6c	15.5 ± 0.8d	16.3 ± 0.6d
Performance Drink	6.1 ± 0.1	10.6 ± 0.7b	13.5 ± 0.8c	14.0 ± 0.6c	14.5 ± 0.6c	15.3 ± 0.5d
Gatorade	6.1 ± 0.1	8.5 ± 0.5b	13.0 ± 0.6c	13.7 ± 0.7c	15.0 ± 0.9c	15.5 ± 0.7d

Note: Mean values ± SE of Body Temperature °F, Blood Pressure, Heart Rate and Lactate at baseline, rest and exercise. Same letter signifies no significant difference.

Table 4: Cognitive Function

	Placebo		**Performance Drink**		**Gatorade**	
	Pre SE	Post SE	Pre SE	Post SE	Pre SE	Post SE
Simple Reaction Time						
SRT MIN	172.7 ± 9.2ab	186.1 ± 8a	179.1 ± 12ab	165.9 ± 6bc	178.9 ± 8ab	169.6 ± 6bc
Procedural Reaction Time						
Correct%	29.7 ± 0.1a	29.4 ± 0.7a	29.6 ± 0.2a	29.6 ± 0.1a	29.3 ± 0.2a	29.2 ± 1.1a
Correct, RT-SD	121.0 ± 31a	96 ± 26bc	118.0 ± 31ab	114.0 ± 33abc	99.1 ± 20c	109 ± 16abc
Spatial Processing						
Correct%	18.0 ± 0.3a	18.5 ± 0.6a	19.2 ± 0.3a	19.1 ± 0.2a	19.3 ± 0.3a	18.8 ± 0.5a
Correct, RT-SD	1404.5 ± 357a	1324.4 ± 328a	1643.1 ± 371a	1518.4 ± 400a	1561.2 ± 347a	1366.4 ± 272a
Code Substitution						
Correct%*	70.2 ± 0.04ab	70.0 ± 0.04ab	68.7 ± 0.07a	70.2 ± 0.04b	69.2 ± 0.09ab	70.0 ± 0.6ab
Correct,RT-SD	287.9 ± 38.8a	297.1 ± 34.3a	263.3 ± 33.8a	256.6 ± 34.6a	279.3 ± 59.6a	256.1 ± 56.1a
Mathemeatical Processing						
Correct%	19.0 ± 0.3a	19.3 ± 0.2 a	19.1 ± 0.8a	18.8 ± 0.3a	18.7 ± 0.5a	18.7 ± 0.4a
Correct, RT-SD	618.0 ± 51a	702.1 ± 90a	791.4 ± 114a	638.7 ± 102a	767.5 ± 92a	681.7 ± 109a
Matching to Sample						
Correct %	18.8 ± 0.4a	19.3 ± 0.3a	18.8 ± 0.4a	19.3 ± 0.2a	19.2 ± 0.3a	19.6 ± 0.7a
Correct, RT-SD	474.8 ± 112a	554.4 ± 104a	540.8 ± 150a	460.5 ± 82.1a	514.8 ± 110a	495.0 ± 116a
Delayed Code Substitution						
Correct	34.5 ± 0.4a	33.2 ± 1.4a	33.3 ± 0.78a	33.7 ± 0.84a	34.5 ± 0.62a	33.2 ± 0.92a
Correct, RT-SD	331.2 ± 70ab	320.5± 45ab	540.1 ± 142a	339.9 ± 126b	347.4 ± 94ab	319.9 ± 115ab
Summation						
Correct	191.2 ± 0.9ab	189.4 ± 2.9ab	189.0 ± 1.7ab	191.0 ± 1.9a	191.0 ± 1.7ab	189.7 ± 2.2b

Note: Values ± SE for cognitive function battery at pre and post exercise for each condition. P ≤ 0.05, Same letter signifies no significant difference. *P=0.05-0.07

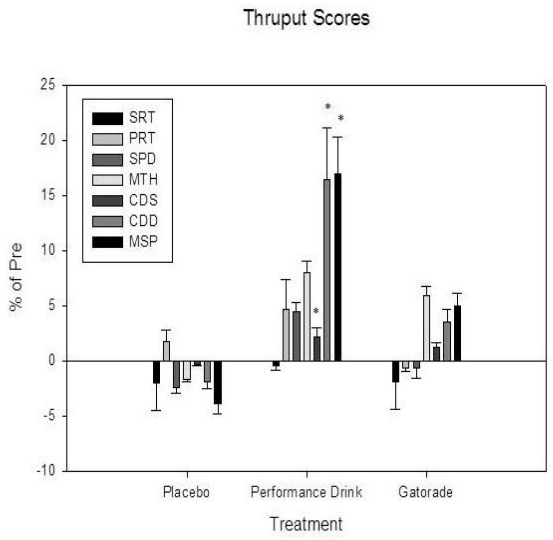

Figure 4: ANAM Throughput percent change
Note: Percent change of throughput scores from pre-exercise to post-exercise. *P<0.05

Spatial processing: The median reaction time to select a correct answer increased in tests of spatial processing when comparing pre-exercise to post-exercise tests for subjects consuming PD was 7.6% faster (P=0.02) and GA was 12.5% (P=0.001) faster (Table 4). The mean reaction time to get a correct answer in Spatial Processing tests was slower for subjects consuming GA pre-exercise (1610.2+114 ms) compared to post-exercise (1460.5+101ms, P = 0.008).

Matching to sample: The pre-exercise (38.9 ± 4.2) versus post-exercise (45.5 ± 5.3) throughput scores for matching to sample tests improved by 17.0 % for subjects consuming PD (P=0.03) (Figure 4).

Summation scores: The summation of correct answers from all of the test batteries was higher for subjects consuming PD compared to those drinking GA but not for those consuming PL when comparing pre to post-exercise (Table 4).

Throughput summation: While not all cognitive function test batteries showed a significant improvement for subjects consuming PD, six of the seven tests showed an improvement from pre-exercise (Figure 4).Throughput scores for subjects consuming GA improved for four of the seven batteries (Figure 4). Subjects consuming PL had a decline in throughput scores for all but one of the seven tests (Figure 4).

Discussion

This study was designed to investigate the effect of exercise and liquid carbohydrate supplementation on cognitive function and performance. Even with a low statistical power as a result of the relatively small subject numbers, the effect of ingesting Performance Drink® and Gatorade® compared to water was sufficient to observe a significant increase in performance.

Exercise performance

Respiratory gas did not reveal any significant difference in proportional substrate selection during the time trial exercise. Thus, the ergogenic effects of Performance Drink® or Gatorade® were not due to the reduced carbohydrate utilization of the muscle. It is possible that during the test, intensity was such that muscle glycogen remained the primary substrate so that increasing circulating plasma glucose did not alter oxidation. Previous work has shown that only when muscle glycogen stores become low does changing the availability of circulating substrate (plasma glucose or free fatty acids) alter substrate selection [20]. It is then also possible during the time trial that increased circulating glucose availability via PD and GA may have enabled the higher power outputs compared to PL, given the equivalent hydration status across treatments. Blood glucose concentration was significantly higher for PD and GA at the onset of exercise despite plunging below PL concentration after 30 min of exercise. This phenomenon known as rebound hypoglycemia occurs when a high glucose carbohydrate is ingested prior to the onset of exercise and results from the addition of insulin-mediated glucose uptake and contraction-mediated glucose uptake by muscle [17]. While PD is considered a hypo-osmotic solution, (Performance Drink, Ontario, Canada) subjects consuming it had blood glucose levels suggesting there were no differences in gastrointestinal absorption compared to the isosmotic solution of GA. The glucose level of GA and PD is concurrent with findings by Kellet et al. [21] who showed that with increases in glucocorticoids such as cortisol during exercise, the GLUT2 translocation to the apical membrane for glucose transport into the cell was decreased [21]. This decrease in glucose transport across the apical membrane may explain why the osmolality of either glucose carbohydrate supplements PD or GA did not differ in their glucose absorption. There were no complaints of gastrointestinal distress during or after any trials, suggesting that the rate of carbohydrate administration did not exceed absorption. Average heart rate was lower for GA during exercise compared to PD or PL, however this did not relate to work output or RPE and may be due to random occurrence.

Cognitive function

Sleep score: Post-exercise subjects consuming PD felt more sleepy and tired than prior to exercise. The sleepiness recorded may be a result of the higher average power output performed by subjects consuming the PD treatment.

Code substitution: The tests for attention and working memory showed subjects consuming PD scored better than those consuming PL and GA when comparing pre to post-exercise tests. This is similar to other research [22] which suggested that a low blood glucose level as seen in the PL treatment is associated with the release of counterregulatory hormones that could impair cerebral function [22].

Spatial processing: We saw no significant change between either treatment or time point. **Simple reaction time:** Subjects consuming PD and GA both had faster reaction times to get the correct answer in tests of Spatial Processing than those consuming PL. The variation in time to get the correct answer significantly narrowed in tests of reaction time from pre to post for subjects consuming PD. The same variation in time for correct answers was smaller in pre-exercise Spatial Processing tests for those drinking GA compared to drinking PL or PD. This is concurrent with other studies showing that exercise may influence the speed of decision making [23]. Post-exercise tests for subjects consuming PL had a lengthened reaction time compared to those drinking PD and GA. The decline in reaction time after 120-min of exercise for subjects consuming PL is different than other research that showed a significant improvement after 40-min of exercise without carbohydrate supplementation [9]. The debate on cognitive function improvement without supplementation may still exist but carbohydrate supplementation potentially improves

cognitive performance following exercise. **Matching to sample:** Throughput scores improved for subjects consuming PD in tests of working memory. This is contrary to previous research that showed endurance exercise has a detrimental effect on working memory and attention [3].

Correct answer summation: A summation of all correct scores from each test battery showed that PD performed better than GA (Table 4).

Throughput summation: Overall Throughput scores showed that subjects consuming PD improved cognitive function performance after 120 minutes of endurance exercise in all but one test battery. Subjects consuming PL had declines in cognitive function performance for all but one test battery after 120 minutes of exercise. Subjects consuming GA improved throughput scores for four batteries while declining in the other three batteries.

Summation

Cognitive function tests revealed significant differences for all three treatments. Two main significant factors of cognitive function found in this study were reaction times and correct answers. These two factors are combined to yield a throughput score. This may be explained by Arcelin et al. [24] who suggested that exercise improves performance directly by affecting motor-preparation functions and indirectly by preparing the individual to respond to incoming sensory information [24]. The increase in throughput score does not explain why PL did not have increased reaction times after exercise. Exercise may heighten your ability to respond to stimuli but there also needs to be a cause to the increased correct answers as well.

Tests of reaction time showed that subjects taking the placebo had slower reactions after endurance exercise. Performance Drink® and Gatorade® yielded more correct answers and faster reaction times to get the correct answer after exercise in multiple test batteries compared to placebo. The throughput for Performance Drink® was higher than Gatorade® and Placebo in multiple batteries. This is in part due to the summation of all correct answers for all test batteries being higher post-exercise for Performance Drink®. Exercise improved some tests of cognitive function performance, while carbohydrate supplementation with exercise showed increased cognitive function performance in additional tests. The additional glucose supplied by GA and PD may explain the improved cognitive functioning during those treatment conditions. Indeed, these results are in agreement with Reilly [8] and Collardeau et al. [9] who reported improved complex cognitive performance following endurance events when carbohydrate ingestion had occurred. These results indicate carbohydrate supplementation may not only limit the decline in cognitive function, but may actually help improve cognitive performance following glycogen-depleting endurance exercise. Hence, endurance athletes whose performance depends upon rapid reaction time, precise spatial relations, and high executive functioning (e.g., biathletes, racecar drivers) may benefit most from the consumption of specialized carbohydrate beverages through a potential competitive advantage gained by possible cognitive improvements. Further testing is required to determine the mechanism for the differences seen between PD and GA.

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