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Effects of glucose ingestion on autonomic and cardiovascular measures during rest and mental challenge

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ABSTRACT

Background: High levels of dietary sugar consumption may result in dysregulated glucose metabolism and lead to elevated cardiovascular disease risk via autonomic nervous system and cardiovascular dysfunction. Altered cardiovascular function can be examined using perturbation tasks such as mental challenge. This study examined the effects of controlled glucose intake on cardiovascular measures at rest and in responses to mental challenge in a laboratory setting.

Method: Using a double blind within-subjects design, participants were monitored at baseline, following ingestion of a glucose or taste-control solution, during structured speech (SS), anger recall (AR) and recovery ($N = 24$, 288 repeated measures; age $= 21 \pm 2$ years). Pre-ejection period (PEP), heart rate (HR), stroke index (SI), cardiac index (CI), blood pressure and total peripheral resistance (TPR) were measured throughout the protocol.

Results: Glucose resulted in sustained decreased PEP levels compared to control condition ($\Delta = 11.98 \pm 9.52$ vs. 3.27 ± 7.65 m·s, $P < .001$) and transient increases in resting HR ($P = .011$), CI ($P = .040$) and systolic blood pressure ($P = .009$). Glucose did not result in increased cardiovascular reactivity to mental challenge tasks, but was associated with a delayed HR recovery following AR ($P = .032$).

Conclusion: Glucose intake resulted in a drop in PEP indicating increased sympathetic nervous system activity. No evidence was found for glucose-related exaggerated cardiovascular responses to mental challenge. Dysregulated glucose metabolism may result in elevated cardiovascular disease risk as a result of repeated glucose-induced elevations of sympathetic nervous system activity.

Introduction

The consumption of foods containing high levels of sugar is correlated with cardiovascular disease risk factors, including impaired glucose metabolism, obesity, dyslipidemia, Type 2 diabetes, and hypertension [1–3]. Multiple biological pathways are involved in these adverse outcomes, including glucose related dysregulation of vascular biology and function. Most research addressing sugar intake and cardiovascular risk is cross sectional and based on self-reported usual dietary habits. Little is known about the effects of systematically controlled glucose ingestion on autonomic nervous system and cardiovascular function.

Previous investigations of the effects of acute glucose ingestion on resting cardiovascular function have demonstrated potent hemodynamic effects characterized by increases in cardiac output (CO), heart rate (HR), systolic blood pressure (SBP), and superior mesenteric artery flow and decreases in diastolic blood pressure (DBP) and total peripheral resistance (TPR) [1,4]. These glucose-induced hemodynamic alterations reflect, at least in part, increased demands from the gut for blood for digestive activities.

Evidence suggests that acute ingestion of glucose results in increased mental challenge-induced hypothalamic–pituitary–adrenal (HPA) axis activity [5,6], as well as TPR and attenuated challenge-induced elevation of CO [1]. Other research indicates that ingestion of a gelatin-based drink containing "complex carbohydrates" is associated with increased CO and SBP and decreased TPR at baseline and increased HR reactivity to mental challenge [7]. These studies are clinically important because elevated autonomic nervous system and cardiovascular responses to mental challenge and delayed recovery have been linked to cardiovascular disease risk factors [8,9]. However, these studies did not control for perceived sweetness and the possibility for subsequent cephalic phase insulin release in responses to oral glucose intake. In addition, these investigations have used mental arithmetic and reaction time tasks and such tasks may have limited generalizability to real life stressors [10].

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The present study examined the effects of standardized oral glucose ingestion versus a taste-based control condition (i.e., sucralose) on cardiovascular responses to standardized mental challenge tasks in a laboratory setting. The control solution was used to ensure comparability in the perceived sweetness of the glucose and control solutions. The mental challenge protocol involved personally relevant structured speech tasks to evoke robust emotional and cardiovascular responses [10]. Using a fully counter-balanced within-subject design we tested the hypothesis that: (1) oral glucose results in altered resting levels of cardiovascular measures. Specifically it was expected that glucose would result in a reduction of the pre-ejection period (PEP), an indicator of sympathetic nervous system activity [11–14], (i.e., and increases in other cardiovascular measures associated with increased cardiac demand (HR, CO, SBP, DBP and TPR)). (2) Oral glucose results in exaggerated mental challenge-induced cardiovascular responses. We also explored whether glucose resulted in delayed recovery from the mental challenge tasks.

Methods

Participants

Participants aged 18–26 years were enrolled from a university-based community. Exclusion criteria were current use of medications known to alter cardiovascular function, body mass index (BMI) >30 kg/m^2, self-reported history of cardiovascular disease, diabetes, asthma, recent surgery/medical procedure, and any other major medical disorder. The sample was restricted to men only because adequate control for menstrual cycle variations was not feasible given the within-subjects design and the overall scope of the study. Participants with valid data for HR, blood pressure and impedance derived variables were included (N = 24/26; 92%). Demographic and average baseline cardiovascular indices are displayed in Table 1. The protocol was approved by the University of Maryland, Baltimore County's Institutional Review Board. All participants provided written informed consent and were paid $80 for taking part in the study.

Procedures

The protocol involved two testing sessions (one oral glucose administration and one control administration) separated by one week ($\pm$3 days). The glucose vs. control conditions were administered in a double-blind fashion and the order of administration (i.e., whether the first session involved glucose administration and the second session the control condition, or the reverse order) was randomized across participants. Participants were asked to fast overnight and abstain from caffeine and alcohol consumption for 24 h prior to the study. Two mental challenge tasks were used during each session (structured speech and anger recall).

Table 1
Participant characteristics

	Mean $\pm$ S.D. or N (%)
Demographic measures	
Age (years)	20.9 $\pm$ 2.4
Race	
Caucasian	16 (66.7%)
African American	5 (20.8%)
Asian	1 (4.2%)
Latino	2 (8.3%)
BMI (kg/m^2)	24.5 (2.2)
Baseline physiological measures	
PEP (m·s)	129.9 $\pm$ 12.1
HR (bpm)	63.4 $\pm$ 9.6
SI (mL/beat/m^2)	45.7 $\pm$ 15.7
CI (L/min/m^2)	2.7 $\pm$ 0.72
TPR (dyn/cm^2/s)	1300.0 $\pm$ 326.8
SBP (mm Hg)	114.4 $\pm$ 5.8
DBP (mm Hg)	58.5 $\pm$ 6.5
MAP (mm Hg)	80.6 $\pm$ 6.6

All experimental sessions started between 0800 and 1200 h and times of testing were kept consistent within participants ($\pm$1 h). Assessments were obtained in a sound-attenuated, climate controlled room. Participants provided written informed consent prior to being instrumented with the physiological monitoring equipment.

The protocol for each of the two sessions (glucose or control) consisted of six phases: (I) pre-ingestion of glucose or control: "baseline"; (II) post-ingestion resting levels; (III) SS; (IV) recovery SS; (V) AR; and (VI) recovery AR. Thus, data were collected at 12 time-points for each participant during two separate sessions (six glucose ingestions and six control-solution ingestions). During the pre-ingestion baseline period, participants remained quietly seated for 10 min after which participants completed baseline questionnaires. The oral test solution (glucose or control) was then administered. Participants were allowed 1 min to consume all of the test solution. Then, the 30-min post-ingestion resting period was started. The timing of physiological measures was based on prior results indicating that serum glucose and insulin levels are at their highest elevations after 30–60 min post glucose ingestion [1].

Physiological measures were obtained during the last 6 min of the baseline and post-ingestion (glucose or control), resting periods, continuously throughout the mental tasks, and during the 5 min immediately following the tasks (recovery periods). Task evaluation questionnaires were completed prior to and following each mental task.

Glucose and control conditions

A 20% glucose solution was presented at a dose of 1 g glucose per kg of body weight (Now Foods, Bloomingdale, IL). This dose yields significant changes in hemodynamic function [1].

The control condition consisted of a 2.5% sucralose solution (McNeil Nutritionals, Fort Washington, PA) at a volume matching that of the glucose test solution (1 mL of solution per 200 g of body weight). This 2.5% sucralose concentration was chosen based on pilot testing, indicating that participants could not discriminate this control solution from the glucose solution in terms of sweetness or palatability.

The glucose and control solutions were flavored with cherry sugar free Kool-Aid™ (2 g/L) (Kraft Foods, Rye Brook, NY). This flavor concentration was chosen because it was preferred from higher and lower concentrations in pilot testing. The test solutions were prepared by a research technician other than the experimenter prior to each experimental session and served chilled in a 16 oz. plastic cup. The test solution administrations were double blind and coded. Test solution codes were revealed to the experimenter only after all data collections of the project were completed.

Mental challenge tasks

Structured speech (SS)

The speech task involved presenting a speech in front of the experimenter. Speeches involved providing a convincing defense in a hypothetical scenario where the participant was falsely accused of a crime. Because of the repeated measures design, two scenarios were used (one scenario during each session and the presentation order of the scenarios was random and counterbalanced). One scenario involved being falsely accused of shoplifting by a plain-clothed policeman. The second scenario involved being stopped for speeding after running a stop sign that was not visible due to vegetation overgrowth. Participants were instructed to read the scenario, then prepare and recite a speech defending themselves to an imaginary