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Effects of high-carbohydrate and high-fat dietary treatments on measures of heart rate variability and sympathovagal balance

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ABSTRACT

Aims: We tested the hypothesis that respiratory quotient (RQ) determines sympathovagal balance associated with metabolism of stored and dietary energy substrates.
Main methods: Six 18–20 year-old African-American males were studied after two control pretreatments of fasting and post-treatments of metabolizing high-fat and high-carbohydrate beverages. RQ, heart rate (HR), energy expenditure (EE) and blood pressure (BP) were recorded at rest and repeated 1 h–3 h after ingesting isocaloric high-carbohydrate and high-fat beverages. Sympathovagal modulation of HR was quantified by the low frequency/high frequency (LF/HF) ratio from fast Fourier transform (spectral) analysis of the electrocardiogram RR intervals during paced breathing at 0.2 Hz. Significance of differences of peak post-treatment values from controls was evaluated by analysis of covariance and of correlations by linear regression at $P<0.05$.
Key findings: The high-carbohydrate and high-fat treatments increased RQ, EE, HR and LF/HF with significant interactions between covariates. LF/HF values were not significant after eliminating covariance of RQ, EE and HR for the control vs. high-fat and for the high-fat vs. high-carbohydrate and after eliminating covariance of EE and HR for the control vs. high-carbohydrate treatments. Across the RQ values, correlations were significant for EE and LF/HF.
Significance: These findings imply that high RQ and sympathetic modulation produced by metabolizing carbohydrate is associated with high resting energy expenditure. We conclude that respiratory quotient may be an important determinant of the LF/HF ratio in the heart rate variability spectrum, likely, by a respiratory chemosensory mechanism.

Introduction

Interactions between dietary macronutrients, metabolic and autonomic balance are important in the regulation of energy substrate metabolism (Min et al. 2008) and age, gender, adiposity, ethnicity and dietary constituents may play roles in determining metabolic energy expenditure and cardiac autonomic balance. A high-fat diet increases susceptibility to “the metabolic syndrome” of obesity, diabetes and cardiovascular disease by increasing postprandial oxidative stress (Devaraj et al. 2008) and oxidative stress, in turn, alters cardiac sympathovagal balance (Kaufman et al. 2007a). In lean highly aerobically-fit cyclists, a high-fat diet is reported to increase sympathetic modulation of the heart rate more than an isocaloric high-carbohydrate diet (Havemann et al. 2006). In lean and obese adult females, cardiac sympathovagal balance appears to be unaffected by a high-fat meal but an isocaloric high-carbohydrate meal increases sympathetic modulation (Tentolouris et al. 2003). In healthy young Japanese men fed a high-fat meal, heart rate variability spectral power is reported to differ only with respect to an increase in the very low frequency component which is thought to represent sympathetic thermoregulation (Nagai et al. 2005a). In healthy young boys, the sympathetic thermoregulatory component also increases after eating but is not significantly different after a high-fat than after a high-carbohydrate meal (Nagai et al. 2005b). In lean healthy women, a high-carbohydrate meal is reported to increase thermogenesis more

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than a high-fat meal (Labayen et al. 1999) and a high-protein meal is shown to increase thermogenesis more than a high-fat meal in both lean and obese women (Tentolouris et al. 2008). A greater short-term weight loss is reported with a low-carbohydrate than with a low-fat diet in the absence of differences in caloric intake and resting energy expenditure (Brehm et al. 2005) and a greater short-term weight loss with a very low carbohydrate ketogenic diet than with a low-fat diet (Volek et al. 2004).

In a healthy adult male population, a high-fructose beverage is reported to increase sympathetic modulation of blood pressure more than an isocaloric high-glucose beverage (Brown et al. 2008). African-American males are at high risk for death associated with diseases such as obesity, diabetes, hypertension and heart failure (Martins et al. 2008). These diseases may be preventable by understanding the effects of dietary fat–carbohydrate balances on autonomic modulation of cardiovascular functions and resting energy expenditure in high risk groups. Respiratory quotient is a reliable physiological index of the oxygen consumption/carbon dioxide production rate known to vary with diet. However, the relationship between respiratory quotient and cardiac sympathovagal balance has not been systematically studied. The present study was, therefore, designed to test the hypothesis that differences in cardiac sympathovagal balance correlate with differences in respiratory quotient across a wide physiological range of metabolism of energy substrates. The study population consisted of an apparently healthy group of 18–20 year-old adolescent/young adult African-American males presumed to be at high risk for developing “the metabolic syndrome” in the future.

Materials and methods

This study was designed to test the hypothesis that differences in cardiac sympathovagal balance correlate with differences in respiratory quotient across a wide physiological range of metabolism of stored and food energy substrates. This protocol was approved by the Howard University Institutional Review Board. To limit variability in metabolism of food energy substrates related to gender, age, health and lifestyle, six 18–20 year-old male university students were used as subjects. Exclusion criteria were smoking, taking of any medications and diagnosis with or treatment for any disease or medical condition. The participants were recruited via personal interaction, fliers distributed on campus and word-of-mouth from previous study participants. Age was verified by government issued driver's license. The study participants came into the Howard University Exercise Science Laboratory for an assessment of the percentage of total body fat. To maximize variability in metabolism of food energy substrates related to body composition, no limit was placed on the percentage of total body fat. On two separate days, each participant came to the General Clinical Research Center at the Howard University Hospital between 8:00 and 10:00 AM for evaluation of the effects of high-fat and high-carbohydrate test beverage treatments on resting heart rate variability, blood pressure, body temperature and energy expenditure after an unsupervised self-reported period of overnight fasting.

Anthropomorphic, cardiovascular and metabolic measurements

Table 1 summarizes the relevant anthropomorphic characteristics of the study population. Body weight and height were measured (Detecto scale) and these values were used to compute body mass index as the quotient kg body weight/m^2 height. Axillary body temperature was measured by a digital thermometer. Blood pressure was determined using an automated sphygmomanometer (Criticare Systems Model 506DXNT, Waukesha, WI). Baseline metabolic and heart rate variability measurements were made, over a period of 30 min, after overnight fasting. After stabilization (20–25 min), a paced breathing maneuver at 0.2 Hz was performed for 5 min to limit the effect of respiratory frequency on the spectral analysis of heart rate variability. The subjects were instructed to follow a bar on a computer monitor that maintained a rhythmic pace of 2.5 s for each inspiration and expiration. Respiratory quotient and energy expenditure were measured by indirect calorimetry using an isolated flow-directed breathing chamber (Deltatrac, SensorMedics, Yorba Linda, CA). The percentage of total body fat was measured by Dual Energy X-ray Absorptiometry (DEXA) whole body scanning (LUNAR Model DPX-L DEXA, Madison, WI).

Table 1
Characteristics of study population.

Characteristic	Range	Mean ± SD
Age (years)	18–20	19 ± 1.0
Body mass index (kg/m^2)	23.0–43.2	29.5 ± 6.9
Total body fat (%)	14.4–45.6	27.1 ± 11.7

SD = standard deviation, n = 6.

Heart rate variability measurements

Electrocardiogram (ECG) data were recorded using a BIOPAC data acquisition system (BIOPAC Systems Inc., Santa Barbara, CA) comprised of a single-channel differential input amplifier and signal conditioning module (ECG100A) with an analog-to-digital converter module (MP100). Data were recorded at a sample rate of 500 Hz and at a breathing pace of 12 breaths per min for 5 min. Electrodes were placed at the right arm, left arm, and V_6 location of each subject and interfaced with the ECG100A amplifier to collect the ECG data. Frequency domains of heart rate variability were analyzed in accordance with the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996) guidelines on 5 min of ECG data collected during paced breathing. Frequency domain analysis was done by applying the fast Fourier transform to quantify the beat-to-beat variations into an index of autonomic activity. HRV analysis was based on the following natural peak frequencies: High frequency (0.15–0.40 Hz) and low frequency (0.04–0.15 Hz) using specialized autonomic neural software (Nevrokard, Version 6.3, Ljubljana, Slovenia). The low frequency/high frequency ratio of heart rate variability power was used as an index of sympathovagal balance. The very low frequency band (0.001–0.04 Hz) was ignored because, according to the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996) guidelines, contribution of this frequency band may be too small to be a reliable indicator during short-term recordings.

Isocaloric high-carbohydrate and high-fat test beverage treatments

The high-carbohydrate treatment consisted of 900 Cal of pure fruit juice containing 30 mg sodium whereas the high-fat treatment was a 900 Cal half-and half dairy mixture made of 67% fat, 23% carbohydrate and 10% protein containing 320 mg sodium. Subjects were administered either the high-carbohydrate or the high-fat test beverage treatment randomly, over a period of 20–30 min, on two separate days after overnight fasting (11–16 h) and performance of the pre-treatment measurements.

Statistical analyses

The study design consisted of measurements of resting heart rate variability, blood pressure, body temperature, energy expenditure, and respiratory quotient variables after overnight fasting (pretreatment) and peak values observed during a 3 h postprandial period (post-treatment) after ingesting either the high-carbohydrate or the high-fat test beverage. To determine the effects of feeding, comparisons were made between the pretreatment (fasting) and post-