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ORIGINAL RESEARCH

The Effect of Environmental Temperature on Glucose and Insulin After an Oral Glucose Tolerance Test in Healthy Young Men

Charles L. Dumke, PhD; Dustin R. Slivka, PhD; John S. Cuddy, MS; Walter S. Hailes, MS; Shawn M. Rose, RN; Brent C. Ruby, PhD

From the Department of Health and Human Performance, Montana Center for Work Physiology and Exercise Metabolism, University of Montana, Missoula, MT (Drs Dumke and Ruby, and Messrs. Cuddy, Hailes, and Rose); and the School of Health, Physical Education and Recreation, University of Nebraska at Omaha, Omaha, NE (Dr Slivka).

Objective.—The purpose of this study was to compare glucose and insulin responses during an oral glucose tolerance test (OGTT) in cold (C), neutral (N), and hot (H) environments.

Methods.—Eleven males completed three 4-hour climate-controlled OGTT trials (C, 7.2°C; N, 22°C; and H, 43°C). Participants remained semireclined for 60 minutes before ingesting a 1.8 g/kg glucose beverage. Skin and rectal core temperatures were continuously monitored. Blood was collected just before glucose ingestion (time 0) and at 15, 30, 60, 90, 120, and 180 minutes, and analyzed for serum glucose, insulin, hematocrit, and hemoglobin. Expired gases were collected upon entering the chamber (−60 minutes), before glucose ingestion (0 minutes), and at 60, 120, and 180 minutes to determine Vo_2 and respiratory exchange ratio.

Results.—Rectal core temperature was greater in the H condition compared with both C and N ($P < .001$). Rectal core temperature was not different between C and N, whereas skin temperature was different across all trials (H greater than N greater than C). The Vo_2 was greater in C than in both H and N during all time points. Carbohydrate oxidation was greater in C compared with H and N ($P < 0.001$). Glucose was higher during H compared with C and N ($P \leq 0.002$). Glucose was elevated in C compared with N. Insulin was higher in H compared with C ($P = 0.009$). Area under the curve for serum glucose was greater in H compared with C and N ($P \leq 0.001$); however, there was no significant difference in area under the curve for insulin.

Conclusions.—These data indicate that after an OGTT, glucose and insulin are elevated in a hot environment.

Key words: oral glucose tolerance test, heat, cold, environmental stress

Introduction

Many persons, such as athletes, military personnel, and firefighters, are exposed to adverse environments in which their fuel utilization and ability to recover is affected by thermoregulatory stress.[1,2] The effect of environmental temperature on substrate oxidation has been studied extensively; however, much of this work has been under the stress of exercise.[3] There is a paucity of research on the direct effect of both hot and cold environments on the glucose and insulin response to an oral glucose tolerance test (OGTT) at rest.

Hot environments typically result in elevated blood glucose compared with thermoneutral environments; however, that is thought to be a result of elevated hepatic glucose output due to increased sympathetic drive.[3] A study done at rest compared four environmental temperatures—20°C, 25°C, 30°C, and 35°C—during a standard OGTT and found that glucose remained elevated 2 hours after consumption at the two higher temperatures.[4] This result is supported by others,[5] and appears to be amplified in subjects with diabetes mellitus.[6] However, none of these studies also examined the effects of cold in the same set of subjects.

We have demonstrated impaired glycogen synthesis while recovering in the heat compared to a thermoneutral

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Corresponding author: Charles L. Dumke, PhD, University of Montana, Department of Health and Human Performance, 32 Campus Drive, 103 McGill Hall, Missoula, MT 59812 (e-mail: charles.dumke@umontana.edu).

environment.[7] In this study, blood glucose was elevated in the heat after postexercise feeding; thus, it was not apparent what mechanism drove the attenuation of glycogen synthesis while recovering in the heat. Core temperature was elevated during recovery in the heat, but skin temperature was not measured;[7] however, subsequent work by our laboratory demonstrated that skin temperature would be elevated under similar conditions in the heat.[8] This finding suggests that despite elevated blood glucose in the heat, and thus apparent increased glucose availability, that may not be manifest as increased glucose uptake into muscle. It remains unclear whether that is due to decreased glucose transport or to a redistribution of blood flow away from muscle.

Cold exposure, conversely, is well known to elevate energy expenditure by both shivering and nonshivering thermogenesis.[8–10] The elevation of metabolic rate with shivering is thought to cause an increase in glucose uptake and carbohydrate oxidation.[8–10] In the most relevant study to date, Vallerand et al[10] found that intravenous, but not oral, intake of glucose resulted in attenuated plasma glucose and insulin responses when humans were exposed to cold (10°C) compared with warm (29°C) environments. In a subsequent study,[9] the investigators found that cold exposure (10°C) elevates plasma glucose oxidation, resulting in attenuated plasma glucose after an intravenous glucose tolerance test. However, both of these studies compared infused glucose during cold exposure (10°C) compared with a warm environment (29°C), which may ignore the environmental effects on the gastrointestinal tract, as well as negating a thermoneutral control environment.

There remains a paucity of research demonstrating a clear effect of environmental temperature on blood glucose after an oral ingestion in the absence of exercise. The purpose of this investigation was to compare glucose, insulin, core and skin temperatures, energy expenditure, and fuel utilization during an OGTT in healthy males in cold (C [7.2°C]), thermoneutral (N [22°C]), and hot (H [43°C]) environments (33% relative humidity) at rest.

Methods

SUBJECTS

Eleven healthy males volunteered for participation in the study (Table 1). Before testing, participants read and signed an informed consent form approved by the University of Montana Institutional Review Board.

EXPERIMENTAL DESIGN

A week after preliminary descriptive testing of height, weight, body composition, and Vo_2max (Table 1), participants (n = 11) completed three trials of an OGTT under three different environmental conditions: cold (C) at 7.2°C; neutral (N) at 22°C; and hot (H) at 43°C, all at 33% relative humidity in a climate-controlled chamber (Tescor, Warminster, PA). Trials were performed in a randomized and counterbalanced manner and separated by at least 1 week. Subjects were instructed to do no more than 30 minutes of exercise in the 48 hours before a trial and no exercise the day before. Subjects recorded diet and exercise for 48 hours before the day of the first trial and were instructed to replicate this exact diet and exercise pattern before the subsequent trials. No alcohol was allowed for 24 hours before a trial. Before the start of the trials, adherence to the diet and exercise instructions was verified by the researchers.

On the morning of the trials, subjects arrived after a 12-hour fast and were asked to void their bladders, after which nude body weights were taken. The subjects wore a standardized cotton T-shirt and shorts during all trials. Core and skin temperature was continually monitored using a data acquisition system (Physitemp Instruments, Clifton, NJ) with a rectal thermistor inserted 15 cm past the anal sphincter, and a skin temperature patch placed on the chest halfway between the nipple and the acromion process. Subjects then entered the climate-controlled chamber and remained semireclined for 60 minutes before ingesting a 1.8 g/kg bodyweight glucose beverage. During this time, a catheter was inserted in the antecubital vein with patency maintained by a saline drip. At a minimum of 15 minutes after catheter insertion, blood was collected just before glucose ingestion (time 0) and at 15, 30, 60, 90, 120, and 180 minutes after consumption. Participants remained in the environmental chamber for 4 hours, during which they were allowed to read, watch movies, or listen to music while remaining semireclined. Water was allowed ad libitum, with intakes recorded. Voided urine was collected, and 4 hours after environmental exposure, nude body weights were measured to estimate

Table 1. Subject characteristics (n = 11)

Characteristics	*Mean ± SEM*
Age, years	22.2 ± 0.8
Height, cm	179.5 ± 1.8
Weight, kg	75.2 ± 2.6
Body mass index, $kg \cdot m^{-2}$	20.9 ± 0.6
Body surface area, m^2	1.93 ± 0.04
Body fat, %	11.8 ± 0.9
Vo_2 max, $mL \cdot kg^{-1} \cdot min^{-1}$	49.7 ± 1.7
Maximum watts	255 ± 13