Comparison of Esophageal, Rectal, and Gastrointestinal Temperatures During Passive Rest After Exercise in The Heat: The Influence of Hydration

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Abstract:

Context: It is unknown how valid esophageal, rectal, and gastrointestinal temperatures (T_{ES}, T_{RE}, and T_{GI}) compare after exercise-induced hyperthermia under different hydration states. **Objective:** To examine the differences between T_{ES}, T_{RE}, and T_{GI} during passive rest following exercise-induced hyperthermia under 2 different hydration states: euhydrated (EU) and hypohydrated (HY). **Design:** Randomized crossover design. **Setting:** Controlled laboratory setting. **Participants:** 9 recreationally active male participants (mean ± SD age 24 ± 4 y, height 177.3 ± 9.9 cm, body mass 76.7 ± 11.6 kg, body fat 14.7% ± 5.8%). **Intervention:** Participants completed 2 trials (EU and HY) consisting of a bout of treadmill exercise (a 10-min walk at 4.8-7.2 km/h at a 5% grade followed by a 20-min jog at 8.0-12.1 km/h at a 1% grade) in a hot environment (ambient temperature 39.3 ± 1.0°C, relative humidity 37.6% ± 6.0%, wet bulb globe temperature 31.3 ± 1.5°C) followed by passive rest. **Main Outcome Measures:** Root-mean-squared difference (RMSD) was used to compare the variance of temperature readings at corresponding time points for T_{RE} vs T_{GI}, T_{RE} vs T_{ES}, and T_{GI}vs T_{ES} in EU and HY. RMSD values were compared using 3-way repeated-measures ANOVA. Post hoc analysis of significant main effects was done using Tukey honestly significant difference with significance set at $P < .05$. **Results:** RMSD values (°C) for all device comparisons were significantly different in EU (T_{RE}-T_{GI}, 0.11 ± 0.12; T_{RE}-T_{ES}, 1.58 ± 1.01; T_{GI}-T_{ES}, 2.04 ± 1.19) than HY (T_{RE}-T_{GI}, 0.22 ± 0.28; T_{RE}-T_{ES}, 1.27 ± 0.61; T_{GI}-T_{ES}, 1.16 ± 0.76) ($P < .01$). Across the 45-min bout of passive rest, there were no differences in T_{RE}, T_{GI}, and T_{ES} between EU and HY trials ($P = .468$). **Conclusions:** During passive rest after exercise in the heat, T_{RE} and T_{GI} were in good agreement when tracking body temperature, with a better agreement appearing in those maintaining a state of euhydration versus those who became hypohydrated during exercise; however, this small difference does not appear to be of clinical significance. The large differences were observed when comparing T_{GI} and T_{RE} with T_{ES}.

Keywords: body temperature | thermoregulation | temperature device | validity

Article:

Esophageal temperature (T_{ES}), rectal temperature (T_{RE}), and gastrointestinal temperature (T_{GI}) have been shown to be valid measures of temperature assessment.[1,2] Although the gold standard for core-temperature assessment is in the pulmonary artery, its lack of practicality in exercise settings warranted identification of both viable and valid measures of body temperature.[3] Similarly, the use of T_{ES} in exercise settings lacks practicality due to the methods of obtaining the measurement. Therefore, T_{RE} and T_{GI} are often the methods of choice in monitoring body temperature during exercise.

It has been established that increasing levels of dehydration exacerbate thermoregulatory strain during exercise in the heat.[4] Evidence states that for every 1% increase in body-mass loss there is a 0.15°C to 0.23°C increase in body temperature.[4] However, there is a lack of evidence explaining the influence of dehydration on body temperature during recovery.

Although prior literature has validated the use of T_{ES}, T_{RE}, and T_{GI} during and immediately after exercise, limited research has investigated body temperature using these measurements during passive recovery.[5,6] In addition, little is known about whether hypohydration influences these body-temperature measurements during passive recovery. Thus, the purpose of our study was to examine the influence of hydration on changes in body temperature during passive rest using T_{ES}, T_{RE}, and T_{GI}. We hypothesized that hydration status would influence the way T_{ES}, T_{RE}, and T_{GI} track body temperature.

Methods

Nine recreationally active men (mean ± SD age 24 ± 4 y, body mass 76.7 ± 11.6 kg, height 177.3 ± 9.9 cm, body fat 14.7% ± 5.8%) participated in this study. All tests were conducted in an environmental chamber (Minus-Eleven Inc, Weymouth, MA) that was set at ambient temperature 39.3°C ± 1.0°C, relative humidity 37.6 ± 6.0%, and wet bulb globe temperature (WBGT) 31.3°C ± 1.5°C. All trials occurred at the same time of day ± 1 hour to control for circadian changes in body temperature. Trials were separated by at least 1 day to allow for full recovery from each trial.

Before the exercise sessions, participants' sweat rate was assessed in the environmental chamber (ambient temperature 37.9°C ± 1.1°C, relative humidity 35.4% ± 8.3%, WBGT 29.6°C ± 2.5°C). All participants arrived in a euhydrated state (urine specific gravity [USG] ≤1.020) (Atago Model N-1, Tokyo, Japan) and were restricted from fluid consumption during exercise. Nude body mass (Defender 5000, Ohaus, Parsippany, NJ), height, and body-fat percentage using 3-site skinfolds (Lange skinfold caliper, Cambridge, MD) were obtained.[7] Participants inserted a rectal thermometer (Model 401, Measurement Specialties, Hampton, VA) 10 cm past the anal sphincter. They completed a 30-minute bout of exercise on a motorized treadmill, performing a 10-minute walk (4.8–7.2 km/h) at a 5% grade followed by a 20-minute jog (8.0–12.1 km/h) at a 1% grade. Participants were allowed to self-select their pace as the goal was to achieve a hyperthermic state. To familiarize participants with the T_{ES} measurement, an esophageal probe (Model 402AC, Measurement Specialties, Hampton, VA) was inserted through a nostril at a depth defined by previous literature.[8]

For exercise sessions, participants ingested a T_{GI} pill (HQ, Inc, Palmetto, FL) 6 to 8 hours before their arrival at the laboratory. Participants consumed an extra 500 mL of water the night prior and the morning of their trial for euhydrated (EU) trials and were restricted from fluids for 14 hours before the hypohydrated (HY) trials. Fluid consumed during exercise either matched sweat rate or was 10% of sweat rate for EU and HY, respectively. Preexercise USG was measured to ensure an appropriate hydration status for the designated trial (EU, USG ≤1.020; HY, USG >1.020).[9] Participants provided a nude body mass, inserted a rectal thermometer, and donned a thermal long-sleeve shirt and leggings (Under Armour, Baltimore, MD) to accelerate the rise in body temperature during exercise. The same exercise protocol from the sweat-rate assessment was repeated. Exercise was continued until the participants' T_{RE} reached 39.75°C or on volitional exhaustion, with T_{RE} and T_{GI} being measured every 10 minutes.

Once exercise was terminated, participants changed into shorts and a T-shirt and sat in the environmental chamber to begin passive rest. The T_{ES} probe was inserted and passive rest continued until $T_{RE} \leq 38$°C while T_{RE}, T_{GI}, and T_{ES} were measured every 3 minutes. On completion, postexercise USG and nude body mass were obtained to examine hydration status and body-mass loss.

Statistical Analysis

All statistical analysis was performed using SPSS version 21 (IBM, Armonk, NY). Root-mean-square difference (RMSD) was calculated to examine the variance between T_{RE} and T_{GI}, T_{RE} and T_{ES}, and T_{GI} and T_{ES}, where a RMSD of 0 depicts a perfect agreement between the measurement devices. To determine if hydration affected the agreement between T_{RE}, T_{GI}, and T_{ES}, RMSD values were compared using a 3-way (measurement × trial × time) repeated-measures analysis of variance (ANOVA). A repeated-measures ANOVA was also used to compare measurements over time across the resting period. Tukey post hoc analysis was used to determine where significant differences occurred. The data were reported in mean ± SD, and significance was set at .05 a priori.

Results

Percentage of body-mass loss, pretrial and posttrial USG, total exercise time, and postexercise T_{RE} and T_{GI} are summarized in Table 1.

Table 1. Hydration Markers and Exercise Time for Euhydrated and Hypohydrated Trials

	Body-mass loss (%)	Pretrial USG	Posttrial USG	Total exercise time (min)	Postexercise T_{RE} (°C)	Postexercise T_{GI} (°C)
Euhydrated	1.5 ± 0.5	1.012 ± 0.006	1.018 ± 0.005	46.8 ± 7.1	39.48 ± 0.28	39.41 ± 0.40
Hypohydrated	3.2 ± 0.8[a]	1.021 ± 0.004[b]	1.027 ± 0.003[b]	45.3 ± 11.5	39.47 ± 0.28	39.24 ± 0.65

Abbreviations: USG, urine specific gravity; T_{RE}, rectal temperature; T_{GI}, gastrointestinal temperature.
[a] Significantly different from EU trial ($P < .001$). [b] Significantly different from EU trial ($P < .01$).

RMSD for T_{RE} and T_{GI}, T_{RE} and T_{ES}, and T_{GI} and T_{ES} are presented in Table 2. The RMSDs between EU and HY trials were different between T_{RE}-T_{GI}, T_{RE}-T_{ES}, and T_{GI}-T_{ES} ($P < .01$). The RMSD for T_{RE}-T_{GI} was lower (better agreement) than T_{RE}-T_{ES} and T_{GI}-T_{ES} in both EU and HY trials ($P < .001$). The RMSD was higher (worse agreement) for EU T_{GI}-T_{ES} than for EU T_{RE}-T_{ES} ($P < .01$).

Table 2. Root-Mean-Square Difference Between Temperature Devices and Hydration Status

	T_{RE}–T_{GI}	T_{RE}–T_{ES}	T_{GI}–T_{ES}
Euhydrated	0.11°C ± 0.12°C	1.58°C ± 1.01°C	2.04°C ± 1.19°C
Hypohydrated	0.22°C ± 0.28°C [a]	1.27°C ± 0.61°C [a,b]	1.16°C ± 0.67°C [a,b]

Abbreviations: TRE, rectal temperature; TGI, gastrointestinal temperature; TES, esophageal temperature. Root-mean-square difference was calculated from the average of all measurement time points during the passive rest.
[a] Significantly different from euhydrated trial ($P < .01$). [b] Significantly different from T_{RE}-T_{GI} ($P < .001$).
[c] Significantly different from T_{RE}-T_{ES} ($P < .01$).

During passive rest, there were no differences between EU and HY trials for T_{RE}, T_{GI}, and T_{ES} ($P = .468$). Measures of T_{ES} during the 45-minute bout of passive rest were significantly lower than T_{RE} and T_{GI} at all time points during both EU and HY (Figure 1) ($P < .05$). Due to the time it took for the T_{ES} to provide reliable values, comparisons between T_{ES} and T_{RE} and T_{GI} were taken starting at minute 9.

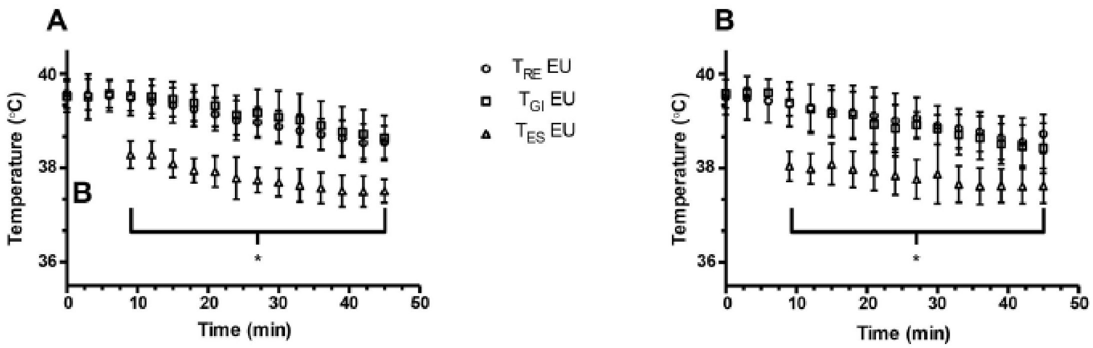

Figure 1. Rectal temperature (T_{RE}), gastrointestinal temperature (T_{GI}), and esophageal temperature (T_{ES}) in (A) the euhydrated trial (EU) and (B) the hypohydrated trial (HY) during passive rest. *Significant differences between T_{ES} and both T_{RE} and T_{GI} ($P < .05$).

Cooling rates for T_{RE}, T_{GI}, and T_{ES} during the EU trials were 0.02°C/min ± 0.01°C/min, 0.02°C/min ± 0.01°C/min, and 0.02°C/min ± 0.01°C/min, respectively ($P > .05$). The cooling rates for T_{RE}, T_{GI}, and T_{ES} during the HY trials were 0.03°C/min ± 0.01°C/min, 0.03°C/ min ± 0.02°C/min, and 0.02°C/min ± 0.01°C/min, respectively ($P > .05$).

Discussion

The purpose of our study was to investigate the influence of hydration on temperature measures using T_{ES}, T_{RE}, and T_{GI} after exercise in the heat. Previous literature[1,6] has compared the aforementioned temperature devices during exercise and found good agreement between devices (RMSD 0.13–0.23°C). Our results suggest that T_{RE} and T_{GI} are in good agreement during passive rest; however, there were large differences observed between T_{ES} and the other measures (T_{RE} and T_{GI}). The differences observed when compared against T_{ES} are largely different from that observed in the study by O'Brien et al[1] (T_{GI} vs T_{ES}, 0.23°C ± 0.04°C). The higher RMSD value observed in our study might be attributed to the distribution of blood immediately postexercise, where body-temperature changes in T_{RE} are delayed due to the greater perfusion of blood to the periphery than the splanchnic region during exercise.[10] Furthermore, the lower T_{ES} in our study may be reflective of circulating blood returning to the heart from the periphery, which may dissipate heat more rapidly than the organs and tissues in the gut.

O'Brien et al[1] examined the RMSD between T_{ES}, T_{RE}, and T_{GI} at rest and during exercise while participants were immersed in water at 2 different temperatures (18°C and 36°C). They found no significant differences between temperature devices in either condition even though the magnitude difference in RMSD between devices ranged from 0.01°C to 0.29°C. The differences in our study for T_{RE} versus T_{GI} and T_{RE} versus T_{ES} were 0.11°C and 1.58°C during EU, respectively. However, when these 2 comparisons were examined between EU and HY, the observed RMSD had opposite trend; T_{RE} versus T_{GI} had better agreement in the EU trial while T_{RE} versus T_{ES} and T_{GI} versus T_{ES} showed better agreement in the HY trial. While it is unclear why this difference in agreement was observed between EU and HY with the aforementioned comparisons, a plausible reason could be the decreased potential for heat dissipation in HY compared with EU.

There were several limitations to the study. The relatively small sample size may have increased the variability in the data we observed. The large variation in humidity in the environmental chamber may have affected the magnitude of evaporative heat loss. In addition, the self-regulation of exercise intensity may have influenced the magnitude of hypohydration achieved. Finally, our study design did not account for the T_{ES} during exercise, resulting in missing data points during the initial 6 minutes of passive rest since the thermistor required time to equilibrate.

Conclusions

During passive rest after exercise in the heat, T_{RE} and T_{GI} were in good agreement when tracking body temperature, with a better agreement appearing in those maintaining a state of euhydration versus those who became hypohydrated during exercise; however, this small difference does not appear to be of clinical significance. The large differences observed when comparing T_{GI} and T_{RE} with T_{ES} may be due to T_{ES} being more sensitive to temperature changes after exercise in the heat.

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