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*Original Research*

# Non-invasive Measures of Core Temperature versus Ingestible Thermistor during Exercise in the Heat

DONOVAN L. FOGT‡[1], ANDREA L. HENNING†[2,3], ADAM S. VENABLE†[2,3], and BRIAN K. MCFARLIN‡[2,3]

[1]Department of Kinesiology, Health, and Nutrition, The University of Texas at San Antonio, San Antonio, TX, USA; [2]Department of Kinesiology, Health Promotion, and Recreation, University of North Texas, Denton, TX, USA; [3]Department of Biological Sciences, University of North Texas, Denton, TX, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

***International Journal of Exercise Science 10(2): 225-233, 2017*** The accuracy of core temperature ($T_c$) thermometry from temporal, tympanic, and oral thermometry devices has been variable during exercise in a hot, humid environment. The purpose of the present study was to cross-validate temporal, two tympanic devices, and oral devices compared to an ingestible thermistor during exercise in a hot, humid environment. Fourteen young, active adults (6 women) completed a graded exercise test until voluntary exhaustion in an environmental chamber (35.5 ± 0.6 °C, 53.9 ± 5.8 % RH). There was no statistical difference in mean temperature between tympanic device 1 and pill-based core temperature ($PBT_c$) measurements across all time points and were positively correlated (0.357; P<0.001). Temperatures of tympanic device 2 were statistically higher than $PBT_c$ (37.8 ± 0.7 ºC vs. 37.6 ± 1.0 ºC; respectfully) (P=0.008). At all time points, temperatures for the second tympanic device and $PBT_c$ were positively correlated (0.192; P=0.043). Temporal and $PBT_c$ values did not differ across time points and were positively correlated (0.262; P=0.005) across all time points. Mean oral temperature was significantly less than mean $PBT_c$ across all time points. (37.0 ± 0.4 ºC vs. 37.6 ± 1.0 ºC, respectively) (P<0.001). Across all time points, oral and $PBT_c$ were positively correlated (0.262; P=0.010). Tympanic and temporal devices can reflect $T_c$ while exercising in a hot, humid environment. However, care should be taken when selecting the tympanic or temporal measurement device and validation is advised prior to heat illness mitigation in the field.

KEY WORDS: Physical activity, monitoring, heat

## INTRODUCTION

Physical activity in hot, humid environments is common over a wide range of sports and conditioning settings. Some athletes may also purposefully train in hot, humid environments for the adaptations related to training acclimation and environmental acclimatization (23). In such, athletes, coaches, and sports medicine professionals alike are concerned with the development of heat-related illness during exercise. Tracking core body temperature ($T_c$) during exercise in hot and humid conditions can help mitigate the risk of heat illness (2). Traditionally, $T_c$ has been measured in environmental researchers by invasive probing of the esophagus (4, 9, 10, 27), nasal opening (8, 13, 26), or rectum (4, 10, 13, 20, 27). However, the aforementioned $T_c$ measures are not readily available to the public and are impractical during exercise outside of a laboratory setting.

Non-invasive temperature monitoring using relatively inexpensive temporal, tympanic, and oral measurement devices are adequate surrogates for $T_c$ at rest and during light activity in thermoneutral settings (14, 21). However, their usefulness as a $T_c$ monitoring tool during higher intensity exercise in a hot, humid environment is of question (10, 13, 23). Recent development of a small, single-use, ingestible $T_c$ thermistor for field use allows athletes and practitioners to circumnavigate logistical limitations associated with traditional invasive laboratory-based $T_c$ monitors. The ingested device transmits real time temperature information from the alimentary canal to an external monitor and has been validated independently (6, 22). However, the efficacy of measuring $T_c$ using superficial, non-invasive monitoring techniques relative to an internalized device has not been assessed during exercise in a hot and humid setting. The purpose of the present study was to evaluate four such alternate, non-invasive measurements of $T_c$ (temporal, two tympanic devices, and oral) compared to an ingestible thermistor during exercise in a hot, humid environment. By cross-validating using Bland-Altman analysis with these commonly available methods, we hope to gain insight regarding their potential to monitor heat illness risk in a sports conditioning setting.

## METHODS

*Participants*

This study was conducted in accordance with the guidelines outlined by the Declaration of Helsinki. Prior to any formal testing, this experiment was reviewed and approved by the University of North Texas (UNT) Institutional Review Board. Subjects gave written and verbal consent after a member of the study staff explained the risks and benefits related to participation in this study. A total of 14 young, active adults (8 men and 6 women) completed the study (Table 1).

**Table 1.** Participant characteristics. Means ± SD presented.

| Variable | Men (n=8) | Women (n=6) |
|---|---|---|
| Age (y) | 23.0±3 | 23.0±3 |
| Mass (kg) | 74.6±11.4 | 59.7±8.5 |
| Height (m) | 1.8±0.1 | 1.6±0.1 |
| BMI (kg/m$^2$) | 24.1±1.9 | 22.1±2.6 |
| Body fat (%) | 17.2±5.8 | 28.4±7.5 |
| VO2max (ml/kg/min) | 43.3±3.5 | 42.9±2.1 |

*Protocol*

All procedures were completed in an environmental chamber. Consented subjects underwent preliminary screening consisting of a medical history questionnaire and were excluded if they self-reported any contraindication to exercise (1). After completing the questionnaire, subjects underwent body composition analysis (%BF; Lunar Prodigy; Madison, WI) and a standard graded exercise test previously used in our laboratory (4). Briefly, subjects began the exercise test at 3.0 mph and speed was increased (men: 2.0 mph; women: 1.5 mph) every 3 minutes until voluntary exhaustion. Heart rate (Polar T31; Lake Success, NY) and oxygen uptake (Medgraphics Ultima CPX; St Paul, MN) were continuously monitored throughout the exercise test. Maximal oxygen uptake ($VO_2max$) was recorded for each individual participant.

Subjects reported to the laboratory one day prior to their exercise trial and were given a packaged thermometer pill (CorTemp Temperature Sensor; HQ, Inc.; Palmetto, FL). Subjects were asked to orally ingest the pill approximately 12 hours before reporting to the laboratory the following morning. Data recorders (CorTemp Data Recorder; HQ, Inc. City, State) logged and digitally stored values of heart rate and $T_c$ every 20 seconds. After exercise completion, subject data were downloaded to a PC in spreadsheet format for subsequent analysis. Telemetry pill measurement of core temperature has been established as representative of $T_c$ (6, 22).

Four additional temperature measurement devices were used during the exercise trial. Device measurement times coincided with the conclusion of each exercise stage. The devices were: tympanic 1 (T1) (Welch Allyn Braun Pro 4000; Skaneateles Falls, NY); tympanic 2 (T2) (Covidien Genius2; Mansfield, MA); temporal (Exergen Temporal Scanner; Watertown, MA); and oral (Welch Allyn Sure Temp Plus 690; Skaneateles Falls, NY). All devices were pre-warmed in the environmental chamber before each trial. All devices were used in accordance with the manufacturer instructions. A member of the study staff familiar with all devices recorded the temperatures at each site. Temporal temperature was taken on a towel-dried area. The measurement site was medial to the hairline at the anatomical temple for consistency within and across exercise tests. The other measurement devices were used according to manufacturer recommendations.

Subjects reported to the laboratory after a 12-hour exercise abstention and 8-hour fast and were instructed to hydrate with water prior to arrival. Upon arrival, subjects provided a urine sample for specific gravity assessment using a handheld meter (Atago 3741 PEN-URINE; Tokyo, Japan). Subjects were deemed euhydrated if urine specific gravity (USG) was <1.025 (normal range = 1.000-1.030). If the subject's USG was 1.025, then they consumed 500 mL of water and waited 30 minutes before providing another urine sample. This process repeated until urine specific gravity was <1.025.

After the subjects were confirmed to be euhydrated, they were escorted into a heated (35.5 ± 0.6 °C) and humidified (53.9 ± 5.8 % RH) environmental chamber and completed 45-minutes of staged treadmill exercise. The exercise trial was designed to cause a gradual rise in body temperature for 20 minutes, then a rapid increase through minute 45. This design was intended to roughly mirror what a runner might experience when warming up and competing in a hot, humid environment. As such, the exercise was comprised of seven stages (2 walking, 5 running; Figure 1). During the exercise trial, subjects were allowed to consume water (21±2 mL/kg body weight) immediately after each temperature data collection but were asked to refrain from pouring water on them, as this may have altered temperature measurements.

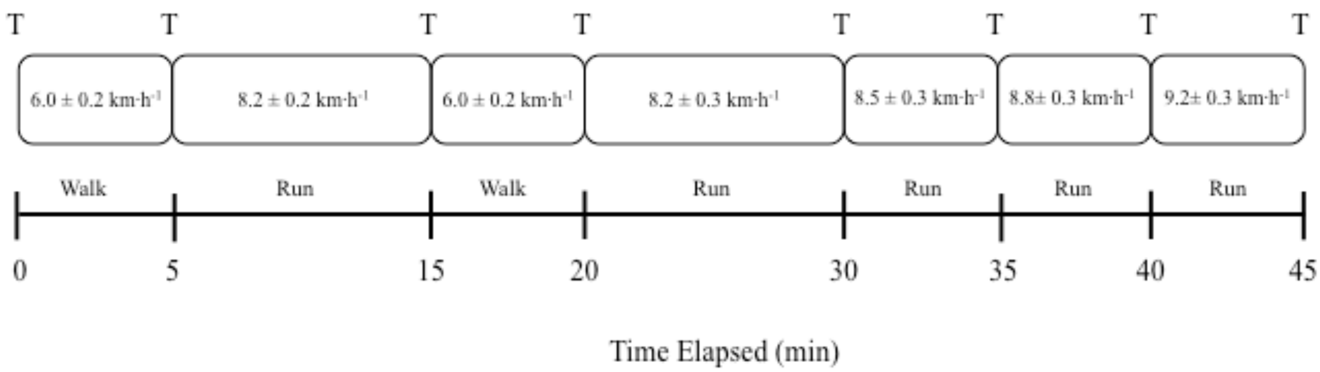


**Figure 1.** Timeline depicting the exercise protocol for the current study. T – indicates time point at which secondary measurements of temperature were taken. Speed presented as mean ± SD.

## RESULTS

The limits of agreement for the T1 Bland-Altman plot were ± 1.90 ºC (Figure 2A). Review of the plot revealed that: 1) T1 temperature tended to be lower than the $PBT_c$, but were within the limits of agreement; 2) the distribution of the differences shifted to negative above 38.0 ºC; and 3) more (5.4%) values were above the upper limit of agreement compared to the number below (1.8%) the lower limit of agreement.

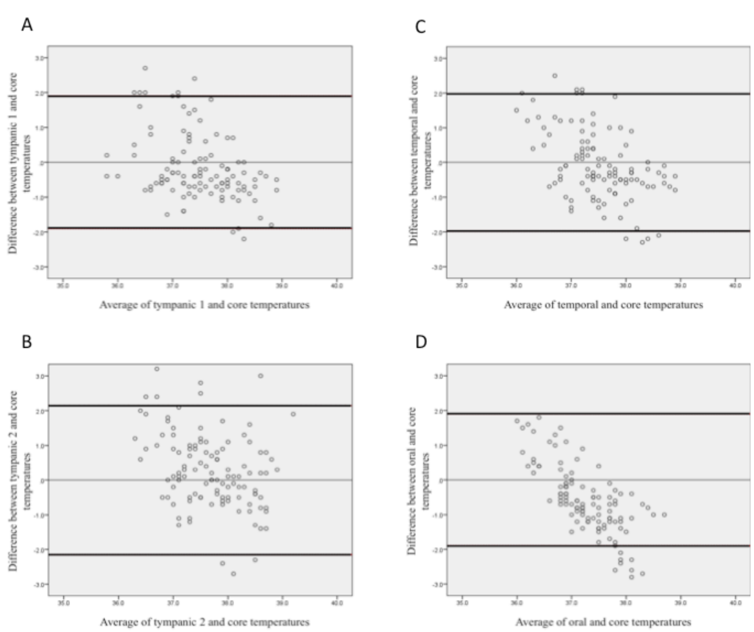


**Figure 2.** Bland-Altman Plots for tympanic devices 1 (**A**) and 2 (**B**), temporal (**C**) and oral (**D**) devices vs. Pill-based core temperature ($PBT_c$) during incremental treadmill exercise at 35.5 ± 0.6 °C and 53.9 ± 5.8 % RH. Difference between respective device and $PBT_c$ (y-axis) plotted against the average of combined respective device and $PBT_c$ (x-axis). Center lines represent complete agreement (zero difference) between respective device and $PBT_c$. For A: Bold lines represent the upper (+1.9 ºC) and lower (-1.9 ºC) limits of agreement. For B: Bold lines the upper (+2.15 ºC) and lower (-2.15 ºC) limits of agreement. For C: Bold lines represent the upper (+1.98 ºC) and lower (-1.98 ºC) limits of agreement. For D: Bold lines represent the upper (+1.90 ºC) and lower (-1.90 ºC) limits of agreement.

There was no difference in mean temperature between T1 and $PBT_c$ measurements across all time points. Results from the paired t-tests at individual time points are summarized in Table 2.

**Table 2.** Mean temperatures for a given time point during incremental treadmill exercise at 35.5 ± 0.6 ºC and 53.9 ± 5.8 RH. Differences between thermometry device and pill-based core temperature ($PBT_c$) means were compared using a paired t-test. Means ± SD; *Indicates p<0.05; **Indicates p<0.001.

| Time Point | PBTc | Tympanic 1 | Tympanic 2 | Temporal | Oral |
|---|---|---|---|---|---|
| 0 min | 37.0 ± 0.6 | 36.3 ± 0.4** | 37.3 ± 0.4 | 37.2 ± 0.3 | 36.6 ± 0.1* |
| 5 min | 37.0 ± 0.6 | 36.8 ± 0.3 | 37.8 ± 1.1* | 37.1 ± 0.5 | 36.6 ± 0.2* |
| 15 min | 37.2 ± 1.0 | 37.4 ± 0.3 | 38.0 ± 0.9* | 37.2 ± 0.5 | 36.8 ± 0.2 |
| 20 min | 37.4 ± 0.9 | 37.3 ± 0.4 | 37.8 ± 0.9 | 37.1 ± 0.5 | 36.8 ± 0.2 |
| 30 min | 37.7 ± 1.0 | 37.6 ± 0.3 | 37.9 ± 0.6 | 37.6 ± 0.5 | 37.1 ± 0.2* |
| 35 min | 37.9 ± 1.0 | 37.8 ± 0.4 | 37.9 ± 0.4 | 37.7 ± 0.4 | 37.2 ± 0.3 |
| 40 min | 38.0 ± 1.1 | 37.9 ± 0.4 | 38.0 ± 0.6 | 37.8 ± 0.5 | 37.2 ± 0.4* |
| 45 min | 38.3 ± 1.0 | 38.2 ± 0.3 | 38.0 ± 0.4 | 38.1 ± 0.5 | 37.4 ± 0.4* |

Across all time points, T1 and $PBT_c$ temperatures were positively correlated (0.357; P<0.001). At 0 minutes, T1 and $PBT_c$ temperatures were positively correlated (0.677; P=0.008). There were no correlations at any other time point.

The limits of agreement for the T2 Bland-Altman plot were ± 2.15 ºC (Figure 2B). The plot showed that: 1) T2 temperature tended to be greater than $PBT_c$ across the temperature range; 2) the distribution of the differences was unchanged across the temperature range; and 3) more (5.4%) values were above the upper limit of agreement compared to the number below the lower limit of agreement (2.7%).

Across all time points, the mean temperature for T2 was statistically greater than the mean $PBT_c$ (37.8 ± 0.7 ºC vs. 37.6 ± 1.0 ºC; respectfully) (P=0.008). Results from the paired t-tests at individual time points are summarized in Table 2. Across all time points, T2 and $PBT_c$ were positively correlated (0.192; P=0.043). There were no correlations at any individual time point.

The limits of agreement for the temporal Bland-Altman plot were ± 2.98 ºC (Figure 2C). Review of the plot showed that: 1) temporal measurements were generally lower than $PBT_c$, although the difference is not apparent until temperatures reach 38.0 ºC; 2) the distribution of the differences shifted to primarily negative above 38.0 ºC; and 3) more (5.4%) values were above the upper limit of agreement compared to the number below the lower limit of agreement (3.6%).

No statistically significant differences were observed in the means of temporal and $PBT_c$ measurements across time points. Results from the paired t-tests at individual time points are summarized in Table 2. Temporal and $PBT_c$ were positively correlated (0.262; P=0.005) across all time points. At 0-minutes, temporal temperature and $PBT_c$ were positively correlated (0.570; P=0.033). There were no correlations at any other time point.

The limits of agreement for the oral measure Bland-Altman plot were ± 1.90 ºC (Figure 5). Review of the plot revealed that: 1) oral measurements were lower than $PBT_c$; 2) the distribution of the differences shifted exclusively lower when $PBT_c$ rose above 37.6 ºC; and 3) values were all below the upper limit of agreement compared to 7.2% below the lower limit of agreement.

Mean oral temperature was significantly less than mean $PBT_c$ across all time points. (37.0 ± 0.4 ºC vs. 37.6 ± 1.0 ºC, respectively) ($P<0.001$). Results from the paired t-tests at individual time points are summarized in Table 2. Across all time points, oral and $PBT_c$ were positively correlated (0.262; $P=0.010$). At 0-minutes, oral temperature and $PBT_c$ were positively correlated (0.597; $P=0.024$). There were no correlations at any other time point.

## DISCUSSION

The purpose of the present study was to cross-validate four non-invasive $T_c$ alternates to $PBT_c$ during intermittent exercise in a hot, humid environment using the methods of Bland-Altman. This study will help inform athletes, coaches, and sports medicine practitioners monitoring body temperature during physical activity in hot, humid environments. We have shown that tympanic, specifically T1, and temporal temperatures provided the best representation of $PBT_c$.

Tympanic temperature monitoring is relatively easy to perform in a field setting. Nagano et al. (16) used an earplug containing a thermocouple during exercise in 35 ºC, observing that this method differed from rectal temperature by >0.5 ºC. However, another exercise investigation in hot, humid conditions indicated that tympanic might, in fact, correlate with $T_c$ as assessed by rectal probe (17). The present study was designed with normal exercise clothing in a carefully controlled (heat and humidity) environment. Of the two tympanic devices tested in the present study, T1 best-matched $PBT_c$ throughout the heat-stressed exercise challenge. The T2 measure was statistically greater than mean $PBT_c$, which could initiate premature field-based heat illness preventative care. Considering previous literature and the results of the present study, care should be taken when choosing tympanic measurement devices to estimate core body temperature when exercising in hot, humid environments.

Methodological differences may account for the inconsistent findings of temporal tracking of $T_c$ during exercise in previous investigations (11, 14, 15, 24). For example, Low et al. (15) concluded that $T_c$ and temporal temperatures were statistically different during whole-body passive heat stress while wearing a 34 ºC water-perfused suit. Interestingly, in that study temporal temperature was lower than $PBT_c$. Using an exercise protocol in typical clothing similar to that in the present study (36.4 ºC, 52% RH), Ganio et al. (12) found that temporal temperature was 0.63 ºC lower than rectal $T_c$. Temporal measures failed to track rectal $T_c$ during hyperthermia in marathon runners compared to rectal $T_c$ in a study by Ronnenberg and colleagues (25). In the present study, temporal temperatures correlated with $PBT_c$ throughout the exercise session. This finding is promising as temporal measures could be performed easily in the field.

Oral temperature has failed to match rectal or esophageal $T_c$ during exercise in the heat in numerous studies (7, 12, 18). A literature review by Mazerolle and colleagues (19) concluded that oral temperature could not replicate rectal or esophageal $T_c$ measures. This conclusion is supported by results from males and females during indoor (12) and outdoor (7) exercise in a hot and humid environment. In the present study, oral temperature was lower than $PBT_c$ at 0 minutes and at $T_c$ ≥37.6 ºC. In the current protocol, $T_c$ of 37.6 ºC was achieved after 30 minutes of exercise. Taken together, oral temperatures underestimate $T_c$ and should not be relied on for tracking heat illness risk during exercise.

The present study is not without limitations. Ingestible thermistors are an established surrogate for $T_c$ (6, 22) and were chosen for this study as esophageal and rectal $T_c$ assessments were not available for this investigation. Oral temperatures could have been affected by respiration and cooling of the mouth through convection (19). However, there were no measurable air currents on the exercising subjects that might have influenced the temporal and oral readings via face cooling (28). Subjects were allowed to drink a prescribed volume of water *ad libitum* during exercise. It is possible that water consumption was increased in subjects when exercising beyond thirty minutes compared to the first stages of exercise when average $T_c$ reached 37.6 ºC. Water consumption was not allowed the minute prior to each measurement time point, but it is possible that the water temperature still influenced temperature measurements. Similar results have previously been demonstrated (3, 7, 12, 19) and, although this is a limitation in the present study, it still represents an obstacle experienced both on the field and on job sites when body temperature is a concern and fluid intake is not monitored. Additionally, we cannot discount the possible effects of water ingestion on $PBT_c$ during our protocol.

In summary, the key finding of the present study is that tympanic (Welch Allyn Braun Pro 4000 model) and temporal (Exergen Temporal Scanner) devices can be used as alternate measures $T_c$ while exercising in a hot, humid environment. Such surrogates are helpful in hot athletic or workplace environments when rectal, esophageal, and $PBT_c$ are not available. These measures are relatively inexpensive and easily administered during exercise. However, care should be taken when practitioners select a tympanic or temporal measurement device as accuracy can vary. Furthermore, careful sport- and environment-specific validation of any individual device is prudent prior to heat illness mitigation in the field. Since temperature measurement is often used to reduce risk of heat-related illness during training and competition, use of the wrong device may increase one's risk of serious and possibly life-threatening complications. The present findings have practical and clinically relevant implications providing athletes, coaches, and sports medicine practitioners with information to select an alternate measurement of $T_c$ to guard against heat-related illness.

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