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Comparison of Rectal and Aural Core Body Temperature Thermometry in Hyperthermic, Exercising Individuals: A Meta-Analysis

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Objective: To compare mean differences in core body temperature (T_{core}) as assessed via rectal thermometry (T_{re}) and aural thermometry (T_{au}) in hyperthermic exercising individuals.

Data Sources: PubMed, Ovid MEDLINE, SPORTDiscus, CINAHL, and Cochrane Library in English from the earliest entry points to August 2009 using the search terms *aural*, *core body temperature*, *core temperature*, *exercise, rectal*, *temperature*, *thermistor*, *thermometer*, *thermometry*, and *tympanic*.

Study Selection: Original research articles that met these criteria were included: (1) concurrent measurement of T_{re} and T_{au} in participants during exercise, (2) minimum mean temperature that reached 38°C by at least 1 technique during or after exercise, and (3) report of means, standard deviations, and sample sizes.

Data Extraction: Nine articles were included, and 3 independent reviewers scored these articles using the Physiotherapy Evidence Database (PEDro) scale (mean = 5.1 ± 0.4). Data were divided into time periods pre-exercise, during exercise (30 to 180 minutes), and postexercise, as well as T_{re} ranges <37.99°C, 38.00°C to 38.99°C, and >39.00°C. Means and standard deviations for both measurement techniques were provided at all time intervals reported. Meta-analysis was performed to determine pooled and weighted mean differences between T_{re} and T_{au}.

Data Synthesis: The T_{re} was conclusively higher than the T_{au} pre-exercise (mean difference [MD] = 0.27°C, 95% confidence interval [CI] = 0.15°C, 0.39°C), during exercise (MD = 0.96°C, 95% CI = 0.84°C, 1.08°C), and postexercise (MD = 0.71°C, 95% CI = 0.65°C, 0.78°C). As T_{re} measures increased, the magnitude of difference between the techniques also increased with an MD of 0.59°C (95% CI = 0.53°C, 0.65°C) when T_{re} was <38°C; 0.79°C (95% CI = 0.72°C, 0.86°C) when T_{re} was between 38.0°C and 38.99°C; and 1.72°C (95% CI = 1.54°, 1.91°C) when T_{re} was >39.0°C.

Conclusions: The T_{re} was consistently greater than T_{au} when T_{core} was measured in hyperthermic individuals before, during, and postexercise. As T_{core} increased, T_{au} appeared to underestimate T_{core} as determined by T_{re}. Clinicians should be aware of this critical difference in temperature magnitude between these measurement techniques when assessing T_{core} in hyperthermic individuals during or postexercise.

Key Words: temperature assessment, tympanic membrane temperature, aural temperature, hyperthermia, exercise

Key Points

- Aural temperature underestimated core temperature as determined by rectal temperature.
- At the most extreme levels of hyperthermia, the relationship between rectal and aural temperatures is weakest.
- Recognizing this temperature difference is critical for clinicians assessing core temperature in hyperthermic individuals.

Since 1995, a total of 46 American football players have died from exertional heat stroke (EHS), 4 in 2010 alone.[1] This number does not take into consideration many of the other activities that are potential settings for this condition, such as soccer, wrestling, and running activities (eg, cross-country, road races, marathons).[2] The number may be even higher if we consider nonfatal cases of EHS, which often go unreported, and the misdiagnosis of many EHS-related deaths.[3,4] In other cases, organ failure is listed as the cause of death when EHS is the actual cause or there is a misdiagnosis. Research[3,4] supports an EHS incidence rate of 1 per 1000 participants who perform either athletic exercise or military activity in intense heat. Given this incidence of heat-related illnesses each year, certified athletic trainers and other sports medicine clinicians must be aware of the validity of different techniques to assess core body temperature (T_{core}), so that this key vital sign is obtained accurately and subsequent medical decisions are appropriate.

To distinguish a nonfatal condition such as heat exhaustion from potentially fatal EHS, T_{core} measurement is needed. An accurate T_{core} assessment may help to rule in EHS[5,6] over other emergency medical considerations, such as hyponatremia, cardiac emergency, diabetic emergency, head trauma, and exertional sickling, which can present with similar signs and symptoms. An athlete with a T_{core} ≥40°C who exhibits signs and symptoms of central nervous system (CNS) dysfunction is most likely suffering from EHS and must be cooled immediately.[5,6] Signs and symptoms of CNS dysfunction include but are not limited to disorientation, altered consciousness, hypotension, tachycardia, increased respiration rate, vomiting, diarrhea, dehydration, coma, and convulsions.[2,5] If cooling is not initiated promptly, physiologic complications may result: Of greatest concern are visceral organ failure and mortality. Therefore, a reliable and valid technique must be used to obtain accurate T_{core} in exercising individuals. For proper diagnosis of EHS, T_{core} must be greater than 40°C at the time of collapse and CNS dysfunction must be present.[6] Although the patient may have a lucid initial period, both criteria must be met for proper diagnosis, making the temperature assessment even more critical.[7] An accurate diagnosis is essential for appropriate treatment selection and duration. If the clinician is unaware of the starting core temperature, the treatment modality chosen may be less effective than necessary and the effective treatment time will be uncertain. Immediate cooling via ice-water immersion has shown a 100% survival rate[8,9]; however, before that treatment can be provided, the patient must first be properly diagnosed with EHS.[7,10] The inherent problem is the observed inaccuracy of temperature devices used during exercise sessions in hyperthermic individuals.[11,12]

To date, few reliable and valid methods for measuring T_{core} in hyperthermic, exercising individuals have been demonstrated.[11,12] Rectal, esophageal, and ingestible temperature assessment have the greatest validity in obtaining an individual's true core temperature.[11] Yet a plethora of other tools are used by health care professionals to assess T_{core}, such as aural, axillary, forehead, oral, and temporal artery measurements, as well as others.[11,12] These do not give accurate representations of actual T_{core}, and few have been tested for validity in hyperthermic, exercising individuals.[11–13]

Aural temperature (T_{au}) is commonly referred to as tympanic temperature, but this is a misnomer because the thermometer does not usually come into contact with the tympanic membrane. Devices that touch the tympanic membrane can cause extreme pain and damage the membrane (ie, perforation).[14] Many aural devices actually only detect auditory canal temperature[15] through infrared emission radiating from the tympanic membrane or auditory canal conduction via thermistors or thermocouples.[14] Measurement of T_{au} is popular because it is quick, noninvasive, and simple, but its efficacy in actually measuring T_{core} is debatable. In a clinical trial,[15] T_{au} and T_{re} in hospitalized patients undergoing surgical intervention showed a strong correlation. Other authors[16,17] have examined whether T_{au} can predict T_{core}, yet very few[17–19] have demonstrated a strong correlation between T_{au} and T_{re} in exercising individuals.[16]

Rectal temperature assessment has encountered scrutiny and has a negative perception within sports medicine.[13] It is viewed as an invasive and unnecessary technique. In a recent survey,[13] certified athletic trainers were asked which T_{core} assessment tool was most accurate and which tool they used. A total of 88% (119/136) reported the rectal thermometer was the proper assessment tool, yet only 4% (5/136) used T_{re} for T_{core} assessment.[13] According to the position statements of both the American College of Sports Medicine[10] and the National Athletic Trainers' Association,[7] it is vital to have an accurate T_{core}, and use of a rectal thermometer is recommended. However, T_{re} is not always used to diagnose an individual displaying a heat-related illness.

Our purpose was to perform a meta-analysis to compare T_{au} with T_{re} core temperature measurement in hyperthermic individuals during exercise. We hypothesized that significant temperature differences between T_{au} and T_{re} would occur when T_{core} was assessed in hyperthermic, exercising individuals.

METHODS

Data Sources

We systematically reviewed the current literature to identify all studies that used T_{re} and T_{au} to assess T_{core} in hyperthermic individuals. PubMed, Ovid MEDLINE, SPORTDiscus, CINAHL, and Cochrane Library databases were searched from their earliest entry points to August 2009 using the search terms *aural*, *core body temperature*, *core temperature*, *exercise, rectal*, *temperature*, *thermistor*, *thermometer*, *thermometry*, and *tympanic* in various combinations. Previously identified articles, review articles, and reference lists of available studies were cross-referenced for possible articles that met the inclusion criteria. We limited our search to English-language research articles that involved human participants. A total of 2044 initial articles were identified via this search.

Study Selection

The specific inclusion criteria identified before data analysis included (1) hyperthermia $\geq$ 38°C (100.4°F) during exercise, (2) simultaneous T_{re} and T_{au} mean and standard deviation measurements, and (3) original research studies with human participants. Studies in which hyperthermia was induced via passive methods were excluded to better reflect a traditional exercise setting. A minimum mean T_{re} measurement of $\geq$38°C (100.4°F) was chosen because athletes' temperatures often exceed this value during exercise. Only measurements obtained via indwelling rectal thermistors were used to compare T_{re} with T_{au} devices. Animal studies and case reports were not included in the data analysis.

The titles of 1981 studies were reviewed and excluded based on irrelevance. Abstracts of the remaining 63 identified studies were reviewed and 32 were excluded. Of the 31 remaining studies, 22 were removed because they either did not involve hyperthermic individuals or did not use T_{re} or T_{au}. We manually cross-referenced the final 22 studies to look for other studies that should be included, but we did not find any additional relevant articles. This resulted in 9 articles for review[2,4,11,12,14,16–19] (Figure 1). When articles lacked the necessary data for extraction, we obtained the data through personal communication with the authors.[16–18]

Quality Assessment

All articles were rated using the Physiotherapy Evidence Database (PEDro) scale. The PEDro scale is a grading rubric that is widely used to determine the internal validity of clinical research studies. It consists of an 11-question, 10-point, *yes* or *no* questionnaire in which 1 point is awarded for each *yes* response and 0 points for each *no*

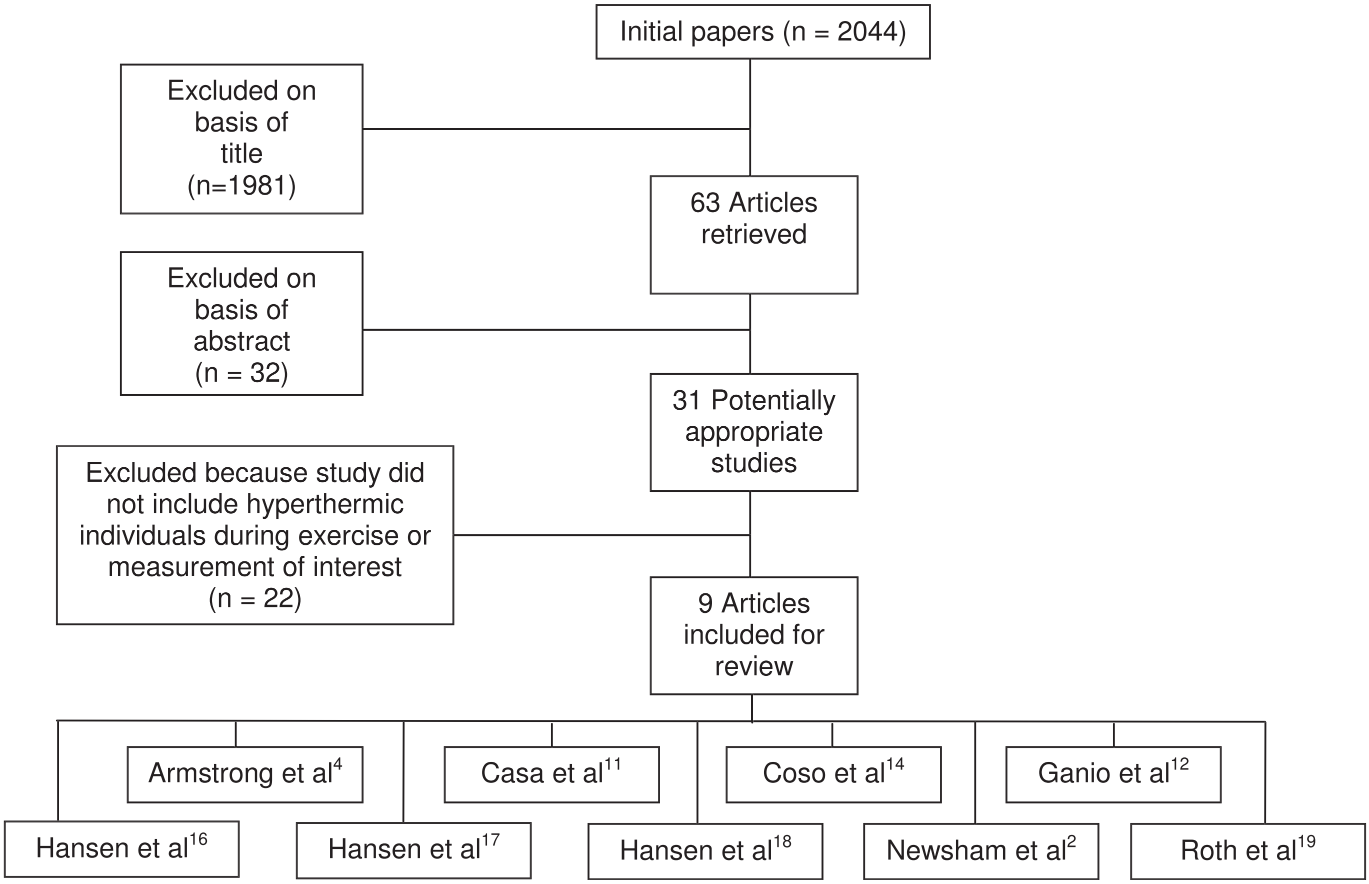

Figure 1. Selection process for articles included in the systematic review and the rationale for excluding the articles that were not included.

response. Question 1 of the PEDro scale determines only if the study is eligible to be scored, whereas questions 2 through 11 are included in the point total. Questions 2 and 3 examine the extent of the random and concealed allocation of the participants, and questions 4 through 7 identify the level of blinding within the study design. Questions 8 through 11 grade the outcome measures reported and the statistical comparisons via point estimates and measures of variability.

Three authors independently reviewed the 9 articles[2,4,11,12,14,16–19] with the PEDro scale. The PEDro scale has been commonly used in previous systematic reviews to assess the quality of included studies.[20–23] If a discrepancy existed among the scores, the reviewers met to achieve a consensus and to ensure that one had not missed or misinterpreted an aspect of the study. Initial κ statistics revealed agreement of 1.000. Final PEDro scale scores for the 9 articles are shown in Table 1. Eight articles[2,4,11,12,14,16–18] received a score of 5, and 1 article[19] received a score of 6.

Except for 1 study[19] that blinded the assessor of the aural reading to the rectal reading, none of the studies included blinding of participants, assessors, or researchers and none randomly allocated participants to groups. A total of 5 studies[2,12,14,17,18] were observational laboratory studies and 4 were observational field studies.[4,11,16,19] All studies included in Table 1 obtained simultaneous T_{re} and T_{au} measurements. In 2 studies,[11,12] T_{re} was compared with 9 other measurements, including T_{au}. For these studies, only T_{au} and T_{re} data were extracted. One article[4] contained data from 3 different studies, 2 of which (A and C) met our inclusion criteria. Study A could not be included because the standard deviation was not obtainable. Only Study C, an observational field study of individuals meeting heat stroke criteria in a medical tent at the end of a road race, was included.[4]

To categorize the mean differences between T_{re} and T_{au} more clearly, the results from the included studies were placed into 1 of 3 groups based on the time of measurement: (1) pre-exercise, (2) during exercise, or (3) postexercise. Additionally, pooled weighted-mean averages were grouped based on T_{re} assessment ranges: (1) <38.0°C, (2) 38.0°C to 38.99°C, or (3) >39°C.

Data Extraction and Management

The following information was extracted, when possible, from included studies: study design; number of participants; types of exercise; duration of exercise; T_{re} and T_{au} at pre-exercise, during exercise, and postexercise; environmental conditions; and manufacturers and models of the rectal and aural measurement devices. The primary outcome measure used by all studies was the comparison of T_{re} with T_{au}.

In this analysis, we examined only temperature assessment via rectal thermistor and aural thermometer. None of the other variables included in the studies were analyzed. This allowed us to focus specifically on the differences between the temperature assessment methods in hyperthermic individuals during exercise.

Table 1. Characteristics of the 9 Studies Included in Core Body Temperature Assessment Using Rectal and Aural Devices in Hyperthermic Exercising Individuals

Authors	Observational Design	Participants, N	Timing of Measurements	Types of Exercise and Settings	PEDro Score[a] (Range, 1–10)
Armstrong et al[4]	Field study	5	Postexercise	11.5-km road race	5
Casa et al[11]	Field study	25	Pre-exercise; during exercise at 60, 120, 180 min; postexercise at 20, 40, 60 min	Field games: soccer, Ultimate Frisbee, etc	5
Coso et al[14]	Laboratory study	9	During exercise at 15 and 90 min	Cycle ergometer at 90 min @ 63% $\dot{V}O_{2max}$	5
Ganio et al[12]	Laboratory study	25	Pre-exercise; during exercise at 30, 60, 90 min; postexercise at 20, 40, 60 min	Treadmill at 4 m/s @ 10% grade	5
Hansen et al[17]	Laboratory study	8	During exercise (30°C, 40°C)	Treadmill at 5 km/min @ 6% grade	5
Hansen et al[16]	Field study	12	Postexercise	14-km road race	5
Hansen et al[18]	Laboratory study	7	During exercise at 50 min	Cycle ergometer at 50 min @ 180 W	5
Newsham et al[2]	Laboratory study	10	Pre-exercise, during exercise at 36.5 min, postexercise at 5, 10, 15, 20 min	Stair climber at self-selected intensity	5
Roth et al[19]	Field study	37	Postexercise	26.2-mile road race	6

Abbreviation: PEDro, Physiotherapy Evidence Database.

Data Synthesis

For each individual comparison, the mean difference (MD) and associated 95% confidence interval (CI) was calculated. Additionally, *z* scores or effect sizes (ESs) for each of the comparisons were calculated using the following equation: ES = (T_{re} mean − T_{au} mean)/(T_{au} SD). Strength of the effect size was determined using the Cohen interpretation of effect size.[20]

Additionally, pooled weighted means from the data in each study were used to determine the pooled weighted MD pre-exercise, during exercise, and postexercise, as well as at T_{re} ranges of <38.0°C, 38.0°C to 38.99°C, and >39°C. The MD (and 95% CI) between pooled weighted-mean T_{re} and pooled weighted-mean T_{au} was calculated for all comparisons, as were *z* scores and their CIs.

Combined, all included studies[2,4,11,12,14,16–19] provided measurements for 138 physically active or highly trained participants. The selected studies used a variety of exercise types, intensities, durations, and environments. Five studies[2,12,14,17,18] conducted exercise in a climate-controlled chamber, whereas 4 studies[4,11,16,19] took place in outdoor settings. For the laboratory studies,[2,12,14,17,18] researchers instructed participants to run or walk on a treadmill, use a stair climber, or ride on a cycle ergometer. For the 4 outdoor field studies,[4,11,16,19] the participants ran on a field or road for different distances. The intensity of exercise was controlled in 4 laboratory studies,[2,12,14,17,18] but it was inconsistent in the field studies.[4,11,16,19] One laboratory study[2] allowed self-selected intensity. Exercise duration ranged from 20 to 180 minutes (Table 2). All researchers used a digital thermometer except for one who used a glass mercury thermometer, and they used a digital aural thermometer in all studies to measure T_{core}. Regardless of the specific exercise condition, 26 of the 28 measurements in all of the individual studies demonstrated a positive MD, with T_{re} consistently being reported as higher than T_{au} (Table 2).

Baseline Measurements

The authors of 5 studies reported baseline pre-exercise measurements,[2,4,11,12,17] but the authors of 2 studies did not provide standard deviations.[4,17] The other 3 studies[2,11,12] showed positive MD values, with T_{re} being consistently higher than T_{au} at baseline (Table 2). Casa et al[11] reported the highest MD at baseline in their field study (0.41°C, 95% CI = 0.25°, 0.57°C); Newsham et al[2] reported the lowest MD (0.04°C, 95% CI = −0.28°C, 0.36°C). Variability of the baseline measures between T_{re} and T_{au} pre-exercise across the 3 studies may indicate a small difference even at normal body temperature ranges. As shown in Table 2, the CIs of both Newsham et al[2] and Ganio et al[12] at baseline crossed zero into negative ranges, reflecting no difference, whereas the baseline point estimate and CI of Casa et al[11] suggested a difference. When the baseline measures were corrected for variance, the pooled weighted MDs resulted in a difference of 0.27°C (95% CI = 0.15°, 0.39°C), with T_{re} higher than T_{au}. Clinically, this difference is small and insignificant when differentiating between safe levels of hyperthermia.

Measurements During Exercise

As exercise duration increased, both T_{re} and T_{au} increased. Exercise durations as short as 15 minutes[14] were associated with an MD of 0.80°C between T_{re} and T_{au}. When the exercise duration reached 60 minutes or longer, the MD ranged from 0.55°C to 1.70°C. Five studies[11,12,14,17,18] reported positive MDs, indicating that T_{re} was higher than T_{au} (Figure 2). Coso et al[14] demonstrated the highest MD in their field study at 90 minutes of exercise (1.70°C, 95% CI = 1.45°C, 1.95°C). Two groups reported negative MDs: Hansen et al[17] (−0.30°C, 95% CI = −0.63°C, 0.03°C) in their 30°C ambient heat chamber laboratory study at 120 minutes of exercise and Newsham et al[2] (−0.33°C, 95% CI = −0.67°C, 0.01°C) after 36.5 minutes of exercise. Pooled

Table 2. Analysis of Rectal (T_{re}) and Aural (T_{au}) Temperature Assessment in the 9 Included Articles

	$T_{re} - T_{au}$ at Baseline, During, or Postexercise, °C (Mean [95% CI])	Cohen d Effect Size (95% CI)[a]	Strength of Effect Size[c]
Armstrong et al[4]	Immediately postexercise = 3.90 (2.60, 5.20)	Immediately postexercise = 4.38 (1.82, 6.09)	Strong
Casa et al[11]	Baseline = 0.41 (0.25, 0.57)	Baseline = 1.44 (0.79, 2.03)	Strong
	60 min = 1.61 (1.27, 1.95)	60 min = 2.71 (1.91, 3.43)	Strong
	120 min = 1.44 (1.15, 1.73)	120 min = 2.85 (2.02, 3.58)	Strong
	180 min = 1.34 (1.10, 1.58)	180 min = 3.14 (2.26, 3.91)	Strong
	20 min postexercise = 0.97 (0.66, 1.28)	20 min postexercise = 3.23 (2.35, 4.01)	Strong
	40 min postexercise = 0.69 (0.54, 0.84)	40 min postexercise = 2.66 (1.87, 3.38)	Strong
	60 min postexercise = 0.53 (0.42, 0.66)	60 min postexercise = 2.34 (1.59, 3.02)	Strong
Coso et al[14]	15 min = 0.80 (0.64, 0.96)	15 min = 5.06 (2.89, 6.45)	Strong
	90 min = 1.70 (1.45, 1.95)	90 min = 6.67 (3.94, 8.37)	Strong
Ganio et al[12]	Baseline = 0.13 (−0.06, 0.32)	Baseline = 0.40 (−0.17, 0.95)	Small
	30 min = 0.45 (0.14, 0.76)	30 min = 0.82 (0.23, 1.38)	Strong
	60 min = 0.55 (0.17, 0.93)	60 min = 0.82 (0.23, 1.38)	Strong
	90 min = 0.60 (0.18, 1.02)	90 min = 0.82 (0.23, 1.39)	Strong
	20 min postexercise = 1.27 (0.98, 1.56)	20 min postexercise = 2.53 (1.75, 3.23)	Strong
	40 min postexercise = 1.01 (0.79, 1.23)	40 min postexercise = 2.66 (1.86, 3.37)	Strong
	60 min postexercise = 0.78 (0.59, 0.97)	60 min postexercise = 2.33 (1.58, 3.00)	Strong
Hansen et al[17]	During exercise at 30°C = −0.30 (−0.63, −0.03)	During exercise at 30°C = −0.97 (−1.92, 0.14)	Strong[b]
	During exercise at 40°C = 0.41 (0.07, 0.75)	During exercise at 40°C = 1.31 (0.14, 2.27)	Strong
Hansen et al[16]	Postexercise = 1.23 (−0.10, 2.56)	Post = 0.78 (−0.07, −1.59)	Moderate
Hansen et al[18]	50 min = 0.35 (−0.02, 0.72)	50 min = 1.11 (−0.09, 2.14)	Strong
Newsham et al[2]	Baseline = 0.04 (−0.28, 0.36)	Baseline = 0.12 (−0.79, 1.01)	Small
	36.5 min = −0.33 (−0.67, 0.01)	36.5 min = −0.95 (−1.82, 0.06)	Strong[b]
	5 min postexercise = 0.25 (−0.10, 0.60)	5 min postexercise = 0.69 (−0.29, 1.56)	Moderate
	10 min postexercise = 0.72 (0.35, 1.09)	10 min postexercise = 1.88 (0.68, 2.79)	Strong
	15 min postexercise = 1.58 (1.22, 1.94)	15 min postexercise = 4.28 (2.40, 5.49	Strong
	20 min postexercise = 1.53 (1.19, 1.87)	20 min postexercise = 4.41 (2.49, 5.64)	Strong
Roth et al[19]	Postexercise = 0.64 (0.14, 1.14)	Postexercise = 0.59 (0.12, 1.05)	Moderate

Abbreviations: CI, confidence interval; T_{au}, aural temperature; T_{re}, rectal temperature.

[a] Positive values indicate $T_{re} > T_{au}$.

[b] $T_{au} > T_{re}$ under these conditions.

[c] Small = 0.2 to 0.5, moderate = 0.5 to 0.8, strong = 0.8 to 1.0.

results for the weighted measures during exercise indicated that T_{re} was 0.96°C (95% CI = 0.84°C, 1.08°C) higher than T_{au} (Figure 2).

Measurements Postexercise

Six groups reported postexercise temperatures.[2,4,11,12,16,19] As the rest period increased, the reported T_{re} and T_{au} both gradually decreased (Figure 3). Armstrong et al[4] demonstrated the highest MD in their field study immediately after an 11.5-km race (3.90°C, 95% CI = 2.60°C, 5.20°C). Pooled results for the postexercise measures indicated that T_{re} was 0.71°C (95% CI = 0.65°C, 0.78°C) higher than T_{au} (Figure 3). Furthermore, data were extrapolated to reflect the pooled results for MD between T_{re} and T_{au} measurements at different T_{re} ranges: <38.0°C, 38.0°C to 38.99°C, and >39°C. As T_{re} measures increased, the magnitude of difference between the techniques also increased, with an MD of 0.59°C (95% CI = 0.53°C, 0.65°C) when T_{re} <38.0°C; 0.79°C (95% CI = 0.72°C, 0.86 °C) when T_{re} was between 38.0°C and 38.99°C; and 1.72°C (95% CI = 1.54°C, 1.91°C) when $T_{re} > 39.0$°C (Figure 4).

DISCUSSION

The results from our pooled data for the systematic review and meta-analysis indicate that T_{re} was consistently greater than T_{au} when T_{core} was measured in hyperthermic, exercising individuals. In 2 of the included studies[2,17] where T_{au} was greater than T_{re} during exercise, possible reasons as to why T_{au} was greater than T_{re} measures could be selective cooling of the CNS by the hypothalamus, a lag in T_{re} due to decreased blood flow to the rectum during exercise, or the type of sensor used in the specific aural device (eg, infrared, thermistor, or thermocouple). The data from 1 study[17] support the idea that T_{re} continues to rise after exercise stops and that the T_{re} device may not have given accurate readings due to decreased blood flow.

As T_{re} increases with exercise, the discrepancy between T_{au} and T_{re} increases. Measuring T_{re} is the method recommended by the National Athletic Trainers' Association and the American College of Sports Medicine for assessing T_{core}.[7,10] Clinicians should be aware of the critical difference in temperature magnitude between these measurement techniques when assessing T_{core} as determined by T_{re} assessment in hyperthermic individuals during or postexercise. Based on the results of the meta-analysis, as T_{core} increased based on T_{re}, the difference between T_{re} and T_{au} also increased (Figure 4). In other words, the more hyperthermic an exercising individual was, the greater the discrepancy between the measures. This finding is of particular importance for those clinicians who use T_{au} devices and believe that adding 1°C or any other correction factor can account for the difference in T_{core} as determined by rectal thermometry. This misconception may result in a crucial error in the care of a patient with exercise-induced hyperthermia, especially at higher T_{core} levels.

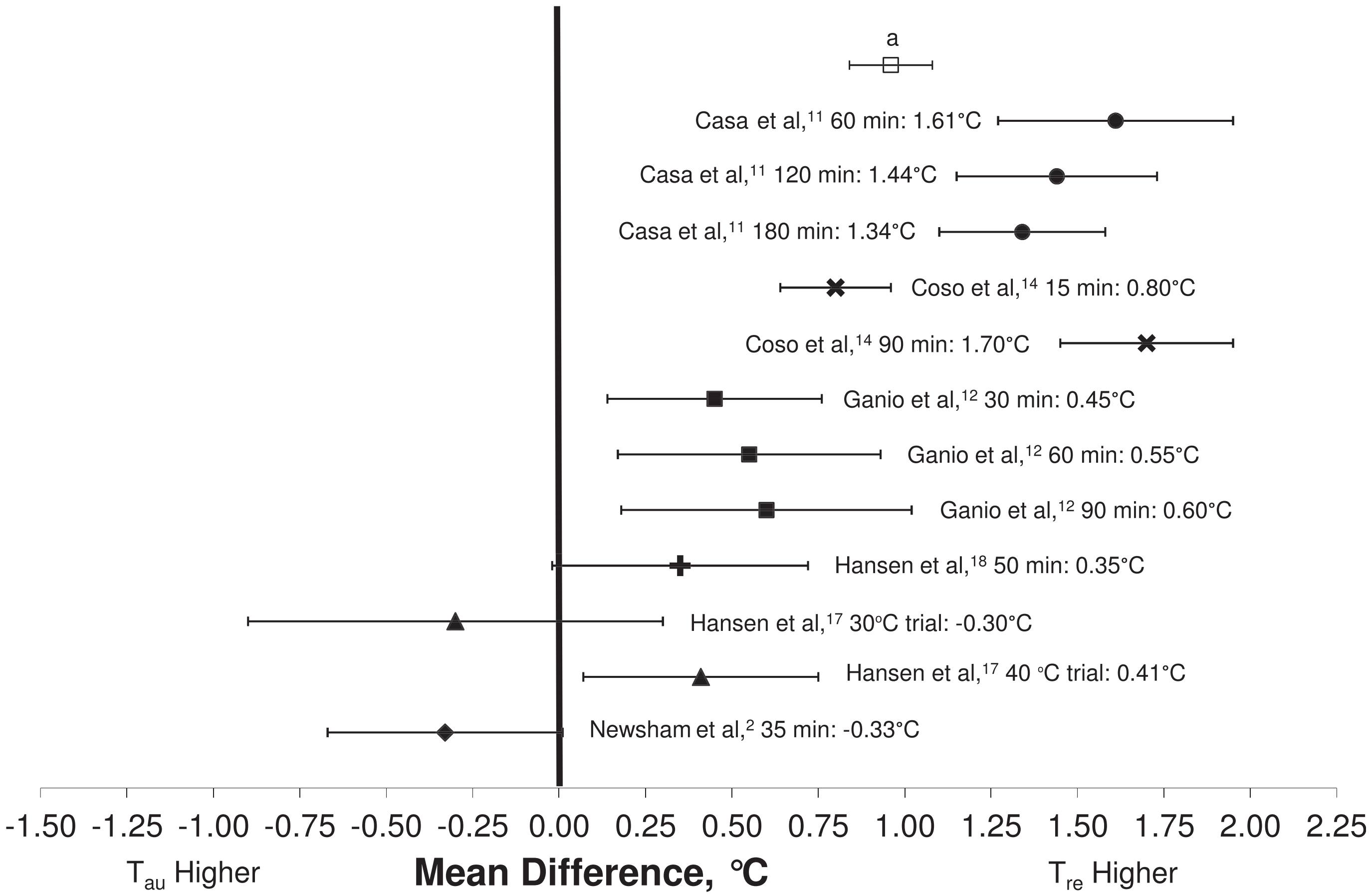

Figure 2. Mean difference (±SD) between rectal (T_{re}) and aural (T_{au}) temperatures during exercise in hyperthermic individuals. Pooled weighted mean difference reflects all included articles. [a] Pooled weighted mean ($T_{re} - T_{au}$) = 0.96°C.

At rest, an individual's core temperature should be less than the common resting temperature of 38.0°C. This was true at all baseline measurements, and the difference between T_{re} and T_{au} was approximately 0.5°C. This difference was consistent with previous systematic reviews[24] that examined T_{re} and T_{au} in individuals at rest. Thus, clinicians may consider T_{au} an accurate measure when compared with T_{re} during the general medical assessment of nonexercising patients. Our meta-analysis specifically examined studies of hyperthermic exercising individuals, and we determined that as an individual's temperature increased to the 38°C to 38.99°C range via rectal thermometry, the difference between T_{re} and T_{au} was approximately 0.8°C. The greatest difference between devices was identified when an individual's T_{re} was greater than 39°C, with a difference of 1.7°C. If an individual has a core temperature of 40°C as assessed by rectal thermometry, an aural device should theoretically display a temperature of 38.3°C. This point is of vital importance to medical personnel evaluating an individual who might have hyperthermia and not a potentially fatal case of EHS. Furthermore, an individual may present with an initial lucid period, which is why accurate T_{core} assessment is so necessary.[7,10] If the temperature difference between devices increases as an individual's core temperature increases, the clinical consequences are very concerning once the true T_{core} is greater than 40°C.[5–7,10] This possibility cannot be examined via clinical studies because institutional review boards understand the danger of a T_{core} at that high level.

Core Body-Temperature Assessment Devices

As assessed by medical professionals, true T_{core} often refers to pulmonary artery or esophageal temperature. Devices to obtain these measurements are considered the criterion standard, yet their clinical use is limited for the athletic trainer in the on-field assessment of a patient with a heat-related illness. Based on this practical restriction, other devices (eg, rectal, ingestible, aural, oral, and infrared thermometry) were developed. These devices only partially addressed the invasiveness concern, but their inherent limitation is that they measure only the anatomical region in which they are placed. Some have demonstrated more validity than others,[11,12,34,36] yet even with measurement differences of more than 1°C during exercise, their use continues due to their simple operation and reduced cost. We recognize that T_{re} is a measure from the rectum and T_{au} from the aural canal and that differences exist based on anatomical location. Within the literature, the measurements have yet to be compared in a systematic fashion in athletes exercising in the heat, which is key to the practicing clinician.

Pros and Cons of T_{re} and T_{au}

Previous researchers[2,4,15,24,25,29,33] have stated the advantages and disadvantages to T_{re} and T_{au}. Considered invasive by some, T_{re} creates a privacy concern, and patient cooperation may be lacking.[2] In 1 report,[25] T_{re} had a temperature lag during rapid changes in core temperature

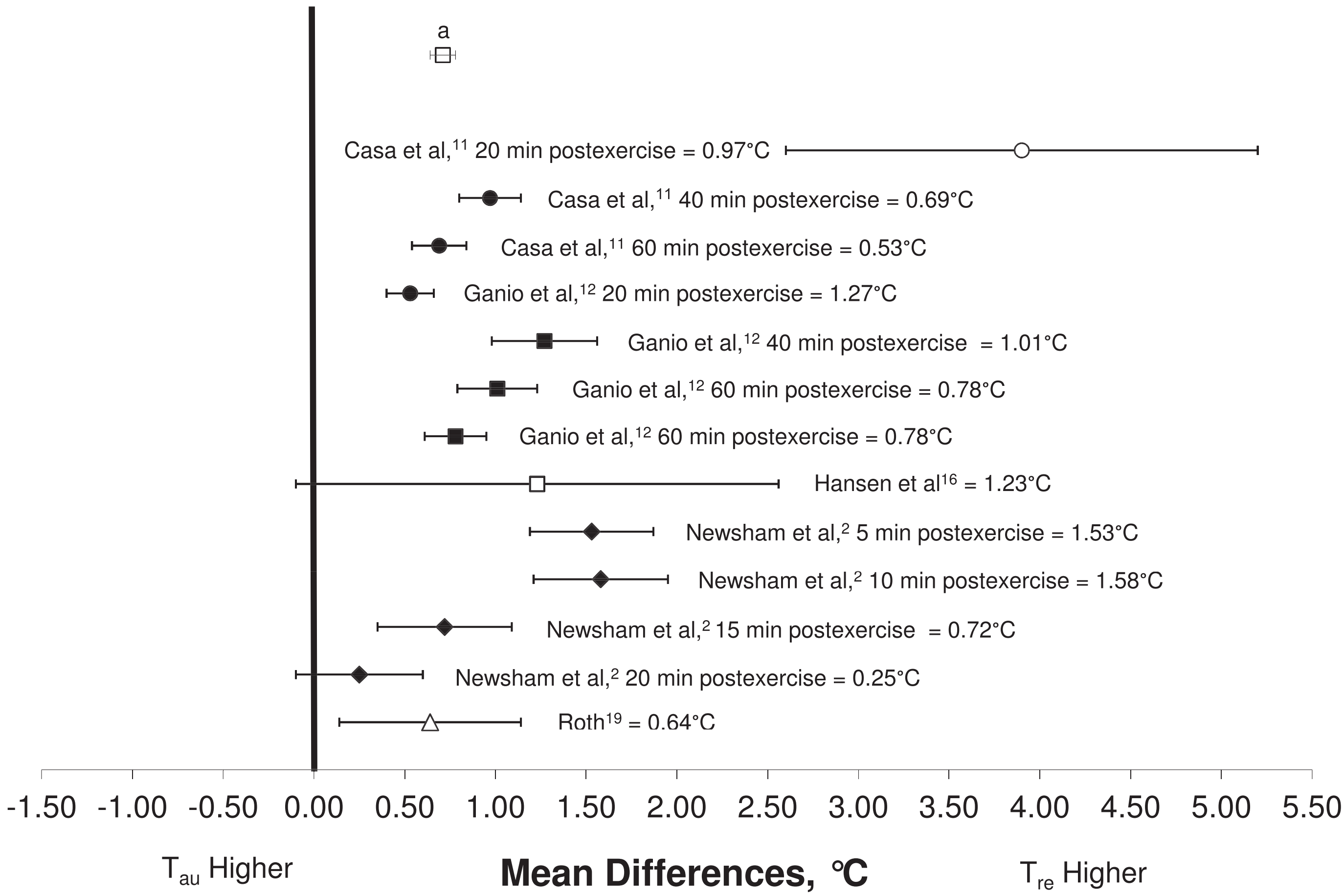

Figure 3. Mean difference (±SD) between rectal (T_{re}) and aural (T_{au}) temperatures after exercise in hyperthermic individuals. Pooled weighted mean difference reflects all included articles. [a] Pooled weighted mean ($T_{re} - T_{au}$) = 0.71°C.

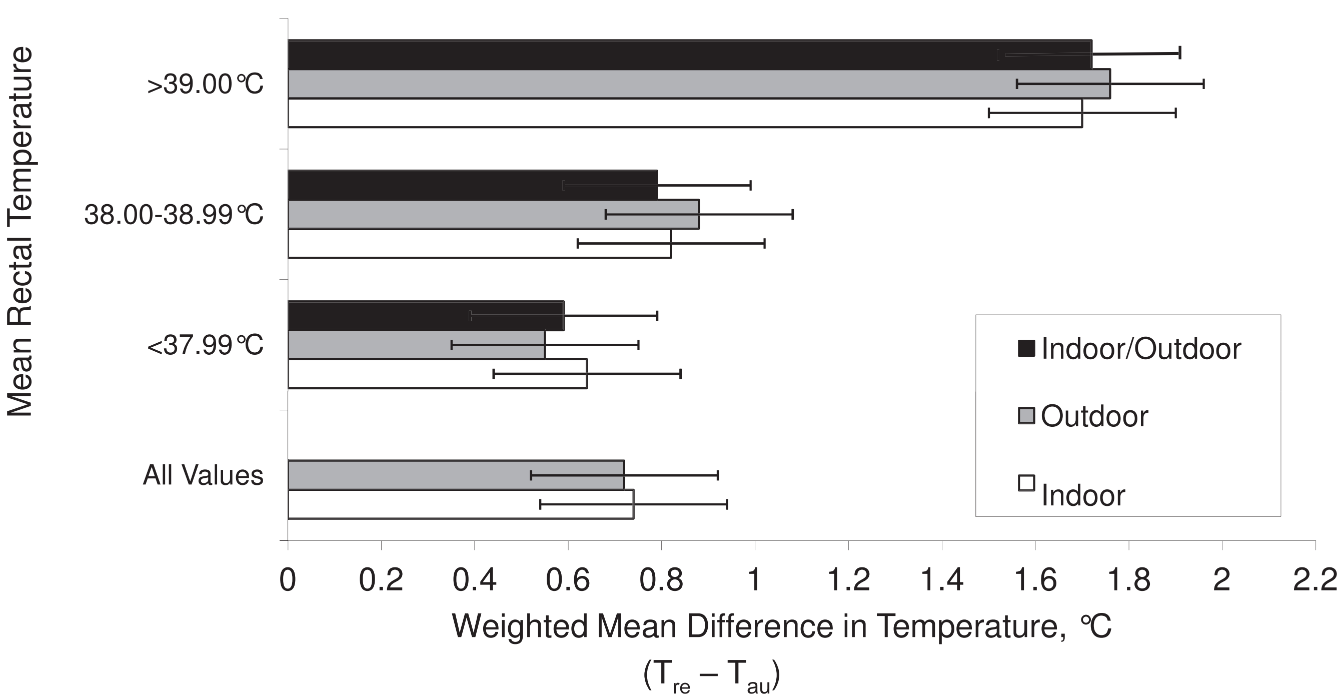

Figure 4. Pooled weighted mean difference between rectal (T_{re}) and aural (T_{au}) temperatures at various temperature ranges based on rectal temperatures for studies conducted in a climate chamber (indoor), field setting (outdoor), and all studies combined.

due to the lack of blood supply to the rectum. When compared with pulmonary artery measurement,[25,26] T_{re} accurately predicts T_{core} and may be a better predictor of EHS due to its ability to detect systemic heat stress and potential organ damage. Rectal temperature has also been described as a valid device to measure T_{core}.[27–29] Research has supported T_{au} as providing an accurate assessment of an individual's T_{core}.[30,31] Advantages included its ease of use and noninvasive nature and patient compliance. However, these authors examined the devices in nonhyperthermic exercising individuals.[30,31] Most of the research was conducted in pediatric and hospital patients, whose temperatures were usually lower or indicated a slight fever.[16,32] In addition, environmental factors such as fanning one's face, sweating rates, metabolic rates, and exposure to wind or colder air can influence the device's accuracy.[16,28] Also, T_{au} underestimates T_{core} and does not reflect changes during exercise.[33]

The Importance of a Valid T_{core} Measurement

It is imperative to use an accurate and reliable method to assess T_{core} in hyperthermic individuals suspected of having EHS. To diagnose an individual with EHS, 2 specific criteria must be met: T_{core} $\geq$40°C and CNS dysfunction. An improper assessment of T_{core} can lead to misdiagnosis of EHS and possible fatality. A vital distinguishing criterion between nonfatal heat exhaustion and the medical emergency of EHS is T_{core} $\geq$40°C. The position statements of both the National Athletic Trainers' Association[7] and American College of Sports Medicine[10] recommend obtaining T_{re} when assessing T_{core}.

The validity of devices that assess T_{au} as an estimate of T_{core} must be questioned. In exercising, hyperthermic individuals, T_{re} was consistently higher than T_{au}. Clinicians should be aware of discrepancies when assessing T_{core} in hyperthermic individuals during or postexercise with various devices. The T_{au} devices are not in direct contact with the tympanic membrane; therefore, they may not assess true T_{core} but T_{au}. Although some device manufacturers take this information into consideration and add a correction factor, those corrections are not clinically validated when assessing temperatures near 40°C. In addition, the correction factor differs with each device. Using an aural device and adding a correction value does not always provide a valid T_{core} measurement. Furthermore, manufacturers that recommend correction factors do not adjust for the growing disparity between T_{au} and T_{re} as T_{core} increases. Aural devices vary in their technological designs, which may be a source of inaccuracy when measuring T_{core} in hyperthermic patients. If reliable alternative aural thermometers that are in direct contact with the tympanic membrane (without causing damage) are developed, tympanic core temperature may accurately assess elevated T_{core}. Future research in the validity and reliability of T_{au} devices is needed.

The validity of alternative T_{core} measurements has been tested in hyperthermic patients.[11,12] The ingestible telemetric pill shows promise in the assessment of T_{core} due to its noninvasive nature and continuous monitoring abilities,[11,12,34–39] but 3 aspects of this device must be considered. First, the CorTemp (HQ, Inc, Palmetto, FL) ingestible T_{core} sensor costs approximately $30.00, and the CorTemp data recorder device costs $2000.00. Although many levels (eg, youth, high school, and some college) of sport programs may not be able to accommodate the cost of ingestible pills, the athletes' health and safety is a priority, and these devices should be used whenever possible. Second, the ingestible pill can take 1 to 8 hours to enter the lower gastrointestinal tract, and at that time, it must be in a location where neither food nor liquid is present.[11] However, recent original research[40] has shown no difference in pill effectiveness when ingested at 24 hours and 40 minutes pre-exercise. Third, younger patients and those who have difficulty swallowing pills can find ingesting the device challenging. The ingestible pill can be used as a suppository, but then invasiveness becomes a concern. However, it may be difficult to use the ingestible pill in a patient with an emergent heat-related illness.

Limitations

A limitation of the included studies was that different T_{au} devices were used: Thermoscan Pro 1 tympanic thermometer (Braun, South Boston, MA) by Newsham et al,[2] Thermoscan ExacTemp (model IRT 4520; Braun) by Casa et al[11] and Ganio et al,[12] First Temp (model 2000A; Intelligent Medical Systems, Inc, Carlsbad, CA) by Hansen et al,[16,18] Genius 300A (Intelligent Medical Systems, Inc) by Roth et al,[19] Ototemp (model 3000; Exergen Corporation, Newton, MA) by Armstrong et al,[4] and YSI-402 (YSI Inc, Yellow Springs, OH) by Coso et al.[14] One group[17] did not report the device used. Different T_{re} devices were also used: Blanketrol Hypo-Hyper Temperature Control Unit (Cincinnati Sub-Zero, Cincinnati, OH) by Newsham et al,[2] YSI-401 (YSI Inc) by 5 groups,[4,11,12,14,18] and IVAC model 2080A (IVAC Corporation, Naperville, IL) by Roth et al.[19] Hansen et al[17] omitted the model and manufacturer of their rectal device. Six groups[11,12,14,16,17,19] specifically stated that their rectal devices had been calibrated before data collection, but the remaining authors did not mention calibration of the devices. We did not include a threshold for the reported reliability estimates of each measurement in the included studies.

Another limitation to the study was the use of the 10-point PEDro scale to determine the internal validity of our articles. A score of 10 signifies a high-quality study. All of our articles achieved scores of 5 or 6, which are not ideal scores for study quality. The PEDro scale is often used to determine the internal validity for randomized controlled trials. The articles included in this study had low scores due to the absence of blinding and random allocation. However, all the studies were observational, and it is extremely difficult to blind a patient in such a study from the interventions. The PEDro scale may not be the ideal reflection of study quality for these articles, but we are unaware of a better scoring tool that has been validated in the literature.

The participants in the study may also be considered a limitation, but they should not affect the validity of a device used to track temperature changes. Participants ranged from the physically active within the general population[2,12] to marathon runners[4,16] to moderately trained college students.[14] This wide range is associated with a great deal of variance in exercise training and heat acclimation. Being well trained or acclimated to the heat allows the body to more efficiently dissipate heat and cool itself, which may have affected the data. Coso et al[14] openly stated that their participants were not heat acclimated.

Study design and mode of exercise also varied among studies. Casa et al[11] and Hansen et al[16] performed observational field studies that required participants to run at various speeds for 65 to 180 minutes, whereas Ganio et al,[12] Hansen et al,[17,18] and Newsham et al[2] performed observational laboratory studies within an environmental heat chamber. Hansen et al studied members of the Australian Army for 100 minutes of exercise in 1 study[17] and healthy adults in another.[18] Newsham et al[2] investigated physically active individuals on a stair climber at self-selected intensities for an average of 36.5 minutes, and Ganio et al[12] tested physically active individuals on a treadmill for 90 minutes. Roth et al[19] and Armstrong et al[4] measured T_{au} and T_{re} in runners at the end of a road race. Armstrong et al[4] assessed core temperature after an 11.5-km foot race in participants who displayed CNS dysfunction and were suspected of having EHS. Roth et al[19] tested patients admitted to the field hospital at the end of a marathon. Although we note these discrepancies in the modes of exercise, we primarily compared T_{au} and T_{re}. In order to properly perform this comparison, we could not exclude the studies based on mode of exercise.

The T_{core} of the hyperthermic individuals also differed. For the purpose of this review, participants needed to reach a mean T_{core} of 38°C to be considered hyperthermic. In some studies,[2,11,12,16,14,17–19] a mean of 38°C was reached; another group[4] recorded values as high as 41.7°C. Safety precautions played a role in limiting the surpassing of a T_{core} of 40°C, as in the Casa et al[11] and Ganio et al[12] studies, whose institutional review board required participants to cease exercise if they reached a T_{core} of 40°C.[11,12] The advantage of the investigations by Armstrong et al[4] and Roth et al[19] was that the data were collected in runners immediately after the completion of a road race and, thus, the T_{core} was greater than in the other studies. Notably, Armstrong et al[4] also found the greatest mean difference (3.9°C) between devices immediately after the race.

The fact that we drew our conclusions from 9 studies may be considered a limitation. The 28 total data points used may be fewer than in previous meta-analyses, but they were the only values available at the time of the search. More data on T_{au} and T_{re} may be needed in the future to support or strengthen the conclusions found in this meta-analysis.

CONCLUSIONS

In conclusion, T_{re} measures were consistently greater than T_{au} measures when assessing T_{core} in hyperthermic, exercising individuals. As determined by T_{re}, T_{au} appeared to underestimate T_{core}. Clinicians should be aware of this critical difference in temperature magnitude between these measurement techniques when assessing T_{core} in hyperthermic individuals during or after exercise. If the device used does not provide an accurate, valid, and precise measurement of an individual's T_{core}, the diagnosis of EHS may be delayed. To date, a minimal amount of research has compared T_{re} with T_{au} in hyperthermic, exercising individuals. Based on the data we examined, we strongly support using T_{re} as the temperature assessment method for hyperthermic, exercising individuals.

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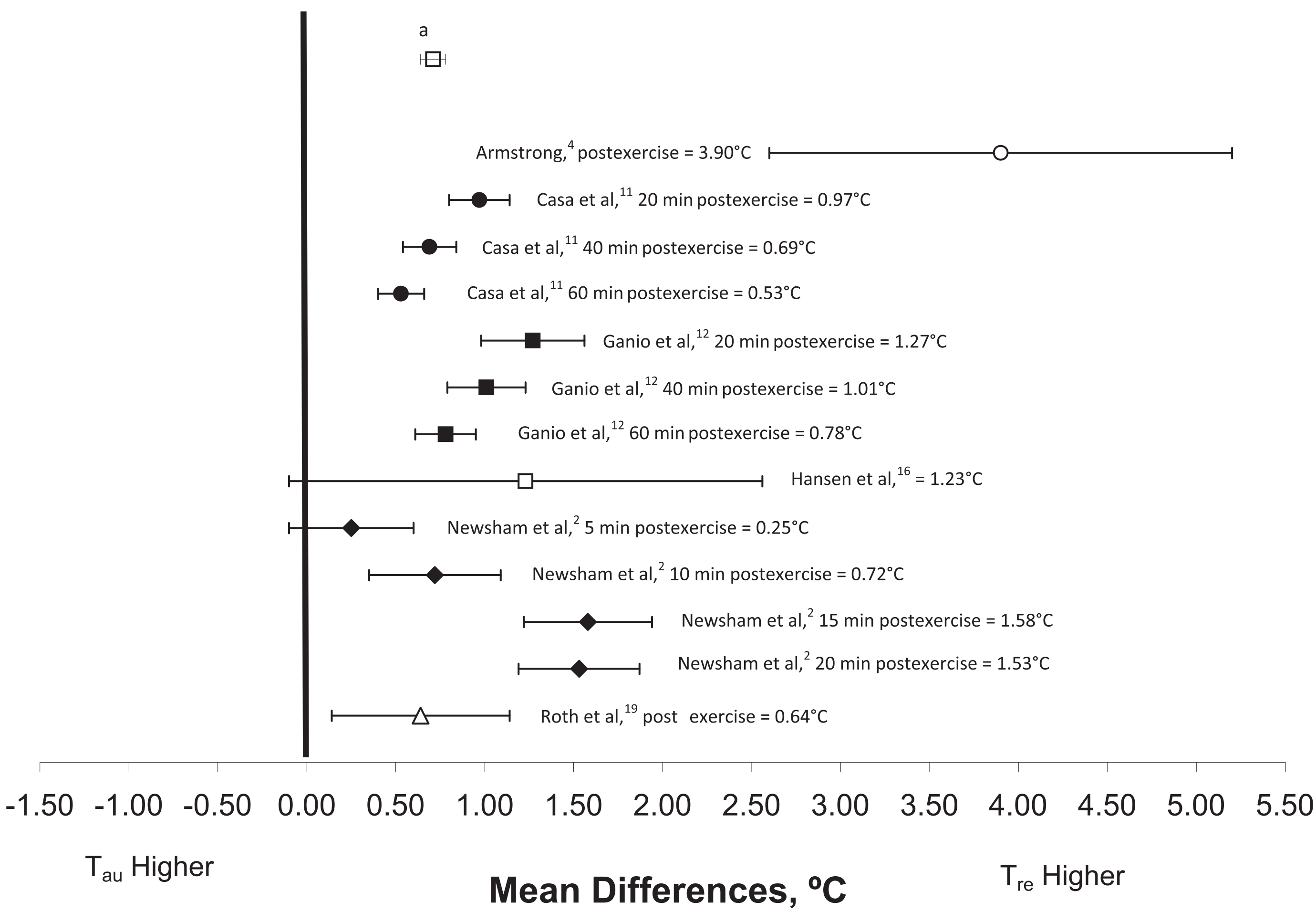
correction

Huggins R, Glaviano N, Negishi N, Casa DJ, Hertel J. Comparison of rectal and aural core body temperature thermometry in hyperthermic, exercising individuals: a meta-analysis. *J Athl Train*. 2012;47(3):329–338.

Figure 3 was incorrect. Please see the correct Figure 3 below. We regret the error.



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