Accuracy and Reliability of a Wireless Skin Temperature Sensor (eTemp) Compared to a Thermistor-Based Reference (Physitemp SST-1) During Heat Stress

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Abstract

Introduction

Wearable skin temperature sensors are increasingly used to monitor thermoregulatory responses during exercise. Accurate measurement of skin temperature is essential for assessing heat strain and physiological responses, but wireless sensors require validation against established reference devices.

Purpose

To evaluate the agreement between the eTemp Performance sensor and the Physitemp SST-1 wired reference probe for the measurement of mean skin temperature during rest, exercise and recovery in a controlled thermal environment.

Methods

Fourteen participants (aged 18-35 yrs) completed a laboratory protocol consisting of 15 min rest, 30 min cycling exercise and 15 min recovery in a climate-controlled environment (35.02°C ± 0.49°C, 40.99% ± 1.48% relative humidity). Mean skin temperature was measured simultaneously using both sensors at multiple anatomical locations. Agreement was assessed using Bland-Altman analysis, with calculation of mean bias, 95% limits of agreement and 95% confidence intervals across the whole protocol and within each stage.

Results

Across the entire session (n = 794 paired observations), the eTemp sensor demonstrated a small positive bias of 0.27°C (95% CI: 0.26 to 0.28°C) relative to the Physitemp sensor, with 95% limits of agreement from -0.08°C to 0.62°C, and a mean absolute error of 0.27°C. Bias was highest during exercise (0.32°C, 95% CI: 0.30 to 0.34°C), and lowest during recovery (0.19°C, 95% CI: 0.17 to 0.21°C). This is within commonly accepted ranges for temperature sensor agreement, with bias < 0.3°C, and limits of agreement <1°C (Smith et al., 2010). Slight proportional bias was observed across the whole session, however, it was minimal and within an acceptable range.

Conclusion

The eTemp Performance sensor shows good agreement with the Physitemp SST-1 probe for measuring mean skin temperature across rest, exercise and recovery. These findings support the use of the eTemp sensor for continuous, practical monitoring of skin temperature in exercise and environmental physiology, offering a wireless alternative to conventional wired thermistors.

Introduction

Exercising in hot conditions leads to an increase in core body temperature, due to heat production from metabolic processes and environmental heat gain (Meade et al., 2024). Regulation of body temperature is primarily mediated by the skin through coordinated thermoregulatory responses, including vasodilation and sweating (Périard et al., 2021). Increased blood flow from the core to the skin's surface allows heat to be transferred from the body. This allows excess heat to be radiated into the environment, whilst secretions from sweat glands cause evaporative cooling (Havenith, 2005). These processes act together to limit extreme changes in core temperature.

During thermal stress, either induced from heat gain due to exercise or a hot environment, these physiological responses are especially important for maintaining thermal equilibrium (Meade et al., 2024). However, the rate of heat loss is limited by the temperature gradient that can be maintained between the skin and the environment (Koop & Tadi, 2025). As ambient temperature (and/or humidity) rises, evaporative, convective, conductive and radiative heat loss mechanisms become less effective (MacRae, Rossi, et al., 2018). When skin temperature reaches approximately 35°C-37°C, the body's capacity to lose heat is greatly diminished, and net heat gain may occur (Meade et al., 2024). Thus, accurate measurement of skin temperature will provide greater understanding of the body's thermoregulatory state, and risk of heat strain.

Heat strain has considerable impacts on human health, safety and performance, especially for athletes, occupational workers, military personnel and emergency responders working in hot environments (Périard et al., 2015). Inadequate monitoring of thermal responses during exercise or work may increase the risk of heat-related illnesses, including heat exhaustion and heat stroke (Varghese et al., 2023). Therefore, reliable measurement of skin temperature is a vital aspect of thermal monitoring protocols in both laboratory and practical settings (Aryal et al., 2017).

The current reference standard for skin temperature measurement is contact thermometry, where a temperature sensor is placed in direct contact with the skin (MacRae et al., 2018). Wired thermistors are able to sample the temperature through heat conduction between the skin, sensor and any overlying insulation or microclimate, and thus directly reflects the local thermal state, rather than any radiative surface effects (Xu et al., 2013). Compared to non-contact methods such as infrared thermography, thermistor readings are not strongly affected by ambient temperature and environmental conditions, thus providing accurate site-specific measurements (Bach et al., 2015). Despite their accuracy, the requirement for a wired connection to a data logger system limits its practicality during dynamic exercise, as cables can restrict movement, reduce comfort, and introduce errors due to motion.

To overcome these limitations, wireless skin temperature sensors have been developed and increasingly used in sport and exercise science research (Bandiera et al., 2025). One commonly used wireless device is the iButton Thermochron temperature logger (Maxim Integrated, 2015), which has been shown in previous studies to have good agreement with the wired thermistor reference, and is valid to use in exercise physiology (Smith et al., 2010). Despite this, the manufacturer states an accuracy of ±0.5°C, which does not meet ISO 9886 standards, which specifies performance requirements for physiological temperature sensors. According to the standard, temperature sensors must have an accuracy of ±0.1°C within the range of 25°C to 40°C, thus the iButton sensor is not compatible with the ISO specifications, despite their widespread use (ISO, 2004).

Recently, the eTemp Performance sensor (BodyCAP Medical, 2020) has come to market with a claimed accuracy of ±0.1°C by the manufacturer, which meets the ISO 9886 standard (ISO, 2004).

Figure 1 - eTemp performance sensor front, back, charging case

Although the eTemp sensor has clear practical advantages over both wired thermistors and other wireless devices, independent validation of its accuracy under controlled thermal and exercise conditions is necessary to confirm its performance in practical applications. Factors such as increased sweat rate, changes in cutaneous blood flow, and movement during exercise may affect sensor performance, especially across different anatomical sites. Thus, systematic comparison of eTemp measurements against an established reference device is necessary to determine its suitability for monitoring skin temperature during exercise-induced heat stress.

The aim of this study was to assess the accuracy of the eTemp Performance wireless skin temperature sensor by comparing its measurements to those obtained with a standard wired reference device during rest, exercise and recovery in controlled thermal conditions. It was hypothesised that mean skin temperature measured by the eTemp sensor would show close agreement with the reference device throughout the experimental protocol, with a mean bias within ±0.1°C, consistent with ISO 9886 and manufacturer specifications. Agreement was expected to vary slightly between rest and exercise stages due to increased skin blood flow, sweat production and dynamic changes in heat flux.

Materials and Methods

Study Design and Aim

The study employed a repeated-measures, within-subject experimental design to investigate the validity of the eTemp Performance sensor, by comparing its temperature measurements with those obtained from a wired reference temperature monitoring system. Measurements were obtained simultaneously from multiple anatomical locations while participants were exposed to controlled heat stress and exercise. This design allowed for direct comparison between devices under identical physiological and environmental conditions.

Participants

Fourteen participants (10 male, 4 female; n = 14), aged 18-35, were selected from a clinical and university-affiliated population. Inclusion criteria required participants to be adults who were able to safely tolerate moderate intensity cycling exercise and exposure to a warm environment. Participants were excluded if they had thermoregulatory disorders, taking medications that affect thermoregulation or cardiovascular function.

Ethical Considerations

The protocol for this study was reviewed and approved by the Griffith University Human Research Ethics Committee (HREC) (Reference Number: 2025/805) in accordance with the National Statement on Ethical Conduct in Human Research (2007). All experimental procedures were conducted in strict adherence to the ethical principles outlined in the Declaration of Helsinki.

Potential participants were provided with a comprehensive Participant Information Sheet, which detailed the study's aims, the nature of the physiological measurements (including the application of skin sensors), and the risks associated with exercise in a 35°C environment. Before the commencement of any data collection, participants were required to provide written informed consent. Participation was entirely voluntary and that individuals maintained the right to withdraw from the study at any point, including during the heat exposure, without penalty or the need for justification.

Instrumentation

SST-1 Skin Surface Probe

Skin temperature was measured using the SST-1 Skin Surface Probe (Physitemp), a wired contact thermometry device designed for direct skin application. It features a compact cylindrical shaped design (0.635cm diameter, 0.238cm thick), with a gold sensor disc for rapid heat transfer. The SST-1 uses a proprietary copper-constantan thermocouple wire, claiming a guaranteed accuracy of ±0.1°C within the physiological range. This type of contact thermometry provides the fastest response time, and has little perturbation in temperature, thus having the most accurate temperature measurement. The probe connects to a data logging system, and thus the amount of data it can record is only limited by the storage of the data logger.

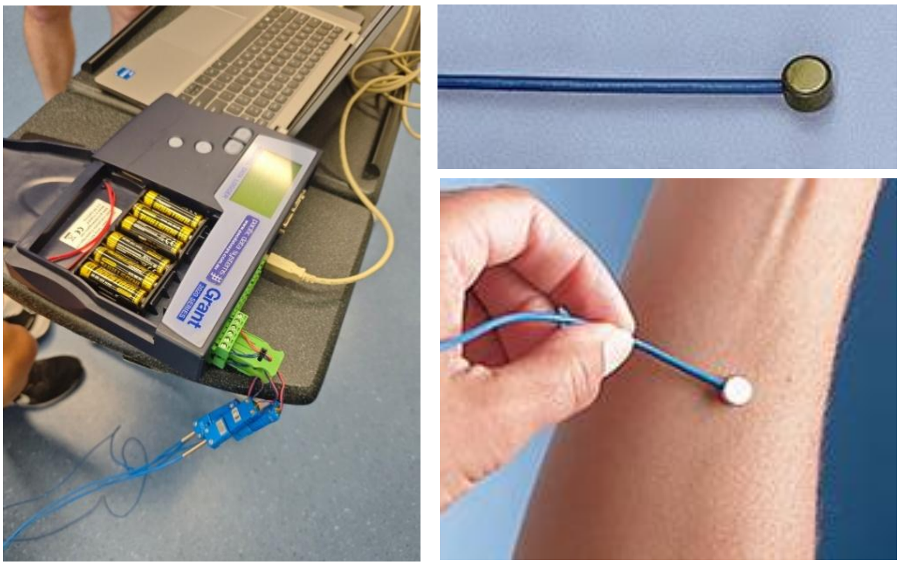


Figure 2 – Data logger (left) required for recording temperature measured by SST-1 Probe (right)

eTemp Performance Sensor

The eTemp Performance Sensor (BodyCAP Medical, 2020) is a compact wireless surface temperature sensor designed for continuous skin temperature collection. Its housing is made of waterproof plastic and is designed to be very compact (12.4 x 9.5 x 5.8 mm, 1.3g), improving comfort. The sensor can measure temperatures from -30–50°C, at an accuracy of ±0.1°C and resolution of 0.01°C. It transmits data to a computer using Bluetooth Low Energy at a minimum interval of 1s, with a recording capacity of 3600 data points. The configuration can be set using the eTemp Performance software, and the device can be activated and deactivated as needed. Data can be transmitted at a range of up to 5 metres and can also be configured for post event retrieval of collected data.

To investigate the validity of the eTemp device against the standard reference probe, the devices were applied to four anatomical locations on the test participants: the mid-sternal region of the right chest, the lateral aspect of the right upper arm (distal to the deltoid), the anterior right thigh, and the posterior aspect of the right calf. These locations were selected as they align with Ramanathan's formula for mean surface temperature estimation (Ramanathan, 1964):

$$Mean\ T_{skin} = 0.3 \times T_{chest} + 0.3 \times T_{arm} + 0.2 \times T_{thigh} + 0.2 \times T_{leg}$$

These regions also represent central and peripheral body regions, thus capturing potential regional variations in skin temperature. All sensors were attached according to the manufacturers' instructions and secured using adhesive dressings to minimise sensor displacement and data artefacts due to movement during exercise.

Despite this, during initial pilot testing, inadequate sensor adhesion was identified, as evidenced by visible sensor displacement and unstable skin temperature recordings. This was especially apparent in the chest and thigh positions, potentially due to the increased movement and sweat these areas would experience. To address this, a custom 3D printed housing was developed to hold the sensors, along with medical tape with stronger adhesive, improved proximity of the sensors to one another, unified contact pressure, and prevented loss of contact with the skin.

Figure 3 – 3D printed housing to hold eTemp, Physitemp sensors. Housing was designed so each sensor has the same height and thus equal skin adhesion

Environmental Conditions

All experimentation was conducted in a climate-controlled environmental chamber, in which ambient temperature and relative humidity were independently regulated (Figure 4C). Ambient temperature within the chamber was maintained at 35.02°C ± 0.49°C with relative humidity set at 40.99% ± 1.48%. The chamber HVAC system was set to maintain an ambient temperature of approximately 35°C. Relative humidity was maintained using a temperature and humidity sensor connected to both a humidifier and a dehumidifier (Figure 4A&B).

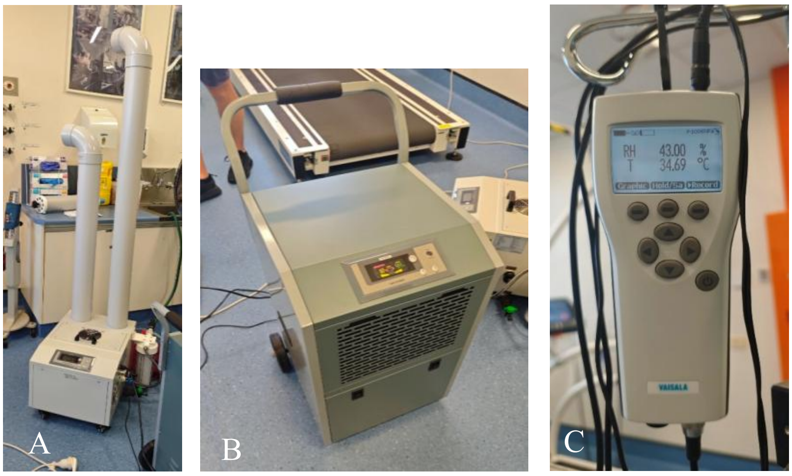


Figure 4 – (A) Humidifier to increase chamber humidity, (B) dehumidifier to decrease chamber humidity, (C) temperature and humidity sensor to monitor and regulate humidity

These environmental conditions were selected to induce thermal stress while remaining within safe limits for supervised exercise testing.

Experimental Protocol

The sensors were attached to the bracket and adhered to the skin using medical tape on the four sites. The data logger was left in the chamber to prevent changes in ambient temperature affecting the calibration of the sensor. Each participant completed a single testing session consisting of three sequential stages.

Upon entering the chamber for the first stage, participants completed a 15-minute acclimatisation period while seated at rest. This period allowed participants' physiological responses to stabilise in response to the warm environment prior to the commencement of exercise.

Following acclimatisation, participants completed 30 min of continuous cycling exercise, using a stationary cycle ergometer (Lode BV, 2026). Oxygen uptake was measured continuously using indirect calorimetry, and metabolic heat production was calculated as the difference between metabolic energy expenditure and external work rate. Cycling intensity was adjusted to maintain a target heat production of 7 $W \cdot kg^{-1}$, to standardise the exercise intensity, in accordance with the approach of Cramer and Jay (2014).

Afterwards, participants were allowed to recover in the room for 15 minutes to measure how skin temperature changes as physiological variables return to baseline levels.

Data Collection

Temperature data from the eTemp device and wired reference standard were collected continuously throughout all stages of the protocol, including acclimatisation, exercise and recovery. Data was time-synchronised so that point by point comparison could be accurately performed between the devices.

In the pilot trials, data artefacts were noticed with the wired thigh sensor, resulting in intermittent connection loss, so adjustments to sensor fixation were implemented prior to experimental trials to eliminate these effects.

Data Analysis

Temperature data were analysed separately by experimental stage (rest, exercise, recovery) and altogether. Agreement between the eTemp device and the wired reference standard system was assessed using Bland-Altman analysis. For each analysis, the mean bias (eTemp–Physitemp) and 95% limits of agreement (mean bias ± 1.96 SD of the differences) were calculated. 95% confidence intervals were also computed for the mean bias and limits of agreement.

Bland-Altman plots were constructed to visually assess agreement and to inspect for proportional bias by examining whether differences varied systematically with temperature across the measurement range.

Descriptive statistics (mean ± standard deviation) were calculated for temperature values and device differences. Mean absolute error (MAE) was also calculated as a complementary measure of average absolute deviation between devices. All statistical analyses were performed using Jamovi v2.6. Statistical significance was set at an alpha level of 0.05.

Results

Participant Characteristics

	n =	Age (years)	Height (cm)	Mass (kg)	VO_2 max ($ml{\cdot}kg^{-1}{\cdot}min^{-1}$)
male	10	25.5 ± 5	177 ± 4.0	82 ± 20.0	46.1 ± 9.2
female	4	24.3 ± 3.8	164 ± 3.0	60 ± 5.0	44.3 ± 7.0
all	14	25.1 ± 4.6	173 ± 7.0	76 ± 20.0	45.6 ± 8.4

*Table 1 - **Participant characteristics for male, female, and combined groups (mean ± SD).** Age, height, body mass, and maximal oxygen uptake (VO_2 max) are presented separately for males, females, and the total sample (n = 14).*

Fourteen participants (10 males, 4 females) completed the study. The mean age was 25.1 ± 4.6 years, with a mean height of 173 ± 7 cm and body mass of 76 ± 20 kg. Mean maximal oxygen uptake of the participants was 45.6 ± 8.4 $ml \cdot kg^{-1} \cdot min^{-1}$, indicating a moderately trained cohort (Heyward, 2010). Participant characteristics stratified by sex are presented in Table 1.

Mean Skin Temperature Responses

	eTemp Sensor			
Period	**T_{skin} mean**	**T_{skin} SD**	**95% CI Lower**	**95% CI Upper**
Rest	34.63	0.59	34.32	34.94
Exercise	36.52	0.52	36.25	36.79
Recovery	36.21	0.44	35.98	36.44
	Physitemp SST-1 Sensor			
Period	**T_{skin} mean**	**T_{skin} SD**	**95% CI Lower**	**95% CI Upper**
Rest	34.42	0.51	34.15	34.69
Exercise	36.21	0.47	35.96	36.46
Recovery	35.98	0.42	35.76	36.20

Table 2 - ***Mean skin temperature (T_{skin}) measured by the eTemp and Physitemp SST-1 sensors across experimental periods (mean ± SD, 95% confidence interval).*** *Mean T_{skin} values are shown for rest, exercise, and recovery periods for each device.*

Mean skin temperature increased from rest to exercise and remained elevated during recovery for both devices (Table 2). During rest, mean T_{skin} was 34.63 ± 0.59°C for the eTemp sensor, and 34.42 ± 0.51°C for the Physitemp sensor. During exercise, mean T_{skin} was increased to 36.52 ± 0.52°C (eTemp) and 36.21 ± 0.47°C (Physitemp), before decreasing slightly during recovery (36.21 ± 0.44°C and 35.98 ± 0.42°C, respectively). Across all periods, mean skin temperature values were consistently higher for the eTemp sensor compared to the Physitemp reference.

Overall Sensor Agreement

		95% Confidence Interval	
	Estimate	**Lower**	**Upper**
Bias (n=794)	0.27	0.26	0.28
Lower Limit of Agreement	-0.08	-0.10	-0.06
Upper Limit of Agreement	0.62	0.60	0.64
Mean Absolute Error	0.27	N/A	N/A

Table 3 – ***Bland-Altman analysis of agreement between eTemp and Physitemp SST-1 sensors for mean skin temperature across the entire testing protocol.*** *Bias and 95% limits of agreement (LoA) with corresponding confidence intervals are presented for paired measurements across the whole session.*

Across the entire session (n = 794 paired observations), the eTemp sensor demonstrated a mean positive bias of 0.27°C relative to the Physitemp SST-1 sensor (95% CI: 0.26°C to 0.28°C). The 95% limits of agreement ranged from -0.08°C (95% CI: -0.10°C to -0.06 °C) to 0.62°C (95% CI: 0.60°C to 0.64°C), reflecting narrow dispersion of differences between devices across the full measurement range. Agreement across the whole protocol is illustrated in Figure 5. Visual inspection of the Bland-Altman plot indicated minimal evidence of proportional bias, with only a slight positive trend evidenced by a greater clustering of points above the mean bias line at higher temperatures.

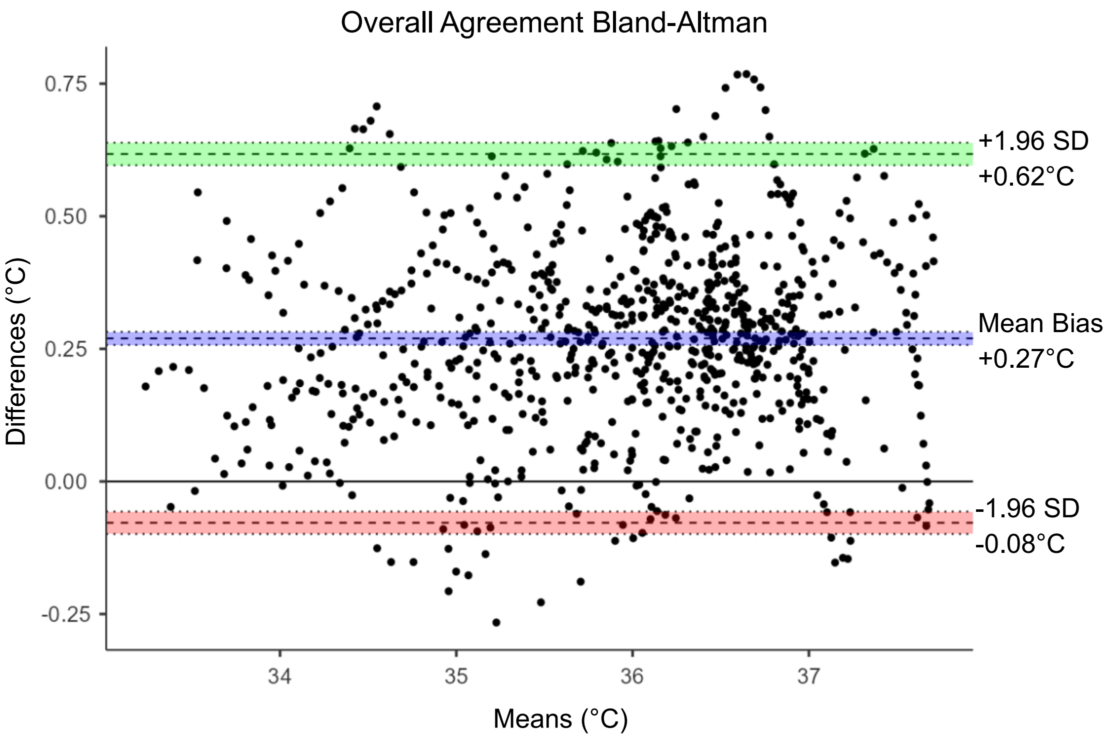


*Figure 5- **Bland–Altman plot showing agreement between the eTemp and Physitemp SST-1 sensors for mean skin temperature across the whole testing period.** The dotted blue line represents the mean bias (eTemp - Physitemp), and the dashed green and red lines represent the upper and lower 95% limits of agreement respectively. Shaded areas indicate the 95% confidence intervals for the bias and limits of agreement. The thin blue line represents the proportional bias, with grey shaded regions representing the 95% proportional bias line confidence intervals.*

Stage Specific Analysis

To investigate whether agreement between sensors varied across different physiological and thermal states, Bland-Altman analyses were performed separately for the rest, exercise and recovery stages of the protocol.

Stage	Bias	Lower LoA	Upper LoA	n =
Rest	0.25	-0.06	0.57	209
Exercise	0.32	-0.03	0.67	389
Recovery	0.19	-0.12	0.50	196

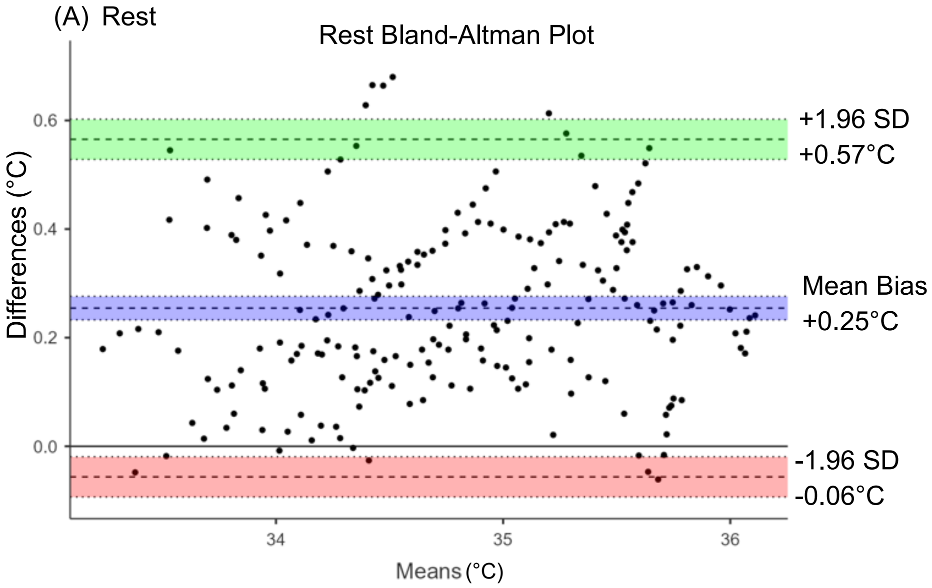
*Table 4 – **Bland-Altman analysis of agreement between eTemp and Physitemp SST-1 sensors for mean skin temperature stratified by stage.***

During rest (n=209), the eTemp sensor had a mean positive bias of 0.25°C (95% CI: 0.23°C to 0.28°C), with limits of agreement between -0.06°C and 0.57°C. In the exercise period (n=389), bias increased to 0.32°C (95% CI: 0.30°C to 0.34°C) with wider limits of agreement (-0.03°C to 0.67°C), indicating greater variability between sensors during exercise. During recovery (n=196), bias decreased to 0.19°C (95% CI: 0.17°C to 0.21°C) with narrower limits of agreement (0.16°C to 0.30°C).

Stage	Bias 95% CI	Lower LoA 95% CI	Upper LoA 95% CI
Rest	(0.23, 0.28)	(-0.09, -0.02)	(0.53, 0.60)
Exercise	(0.30, 0.34)	(-0.07, 0.00)	(0.64, 0.70)
Recovery	(0.17, 0.21)	(-0.16, -0.09)	(0.46, 0.54)

*Table 5 – **95% Confidence intervals for each stage of Bland-Altman analysis shown in Table 4.***

Agreement between sensors across each stage of the protocol is illustrated in Figure 6.



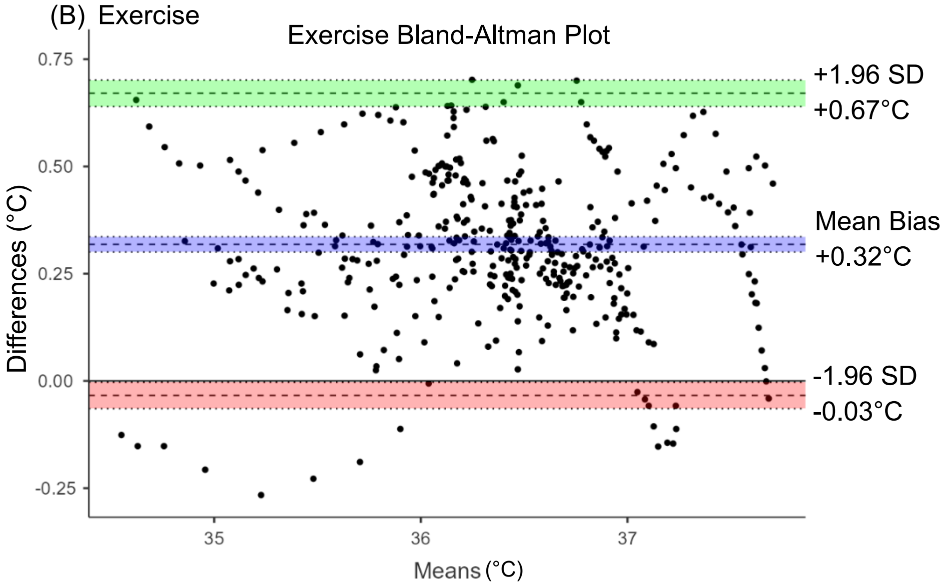


Figure 6 Cont.

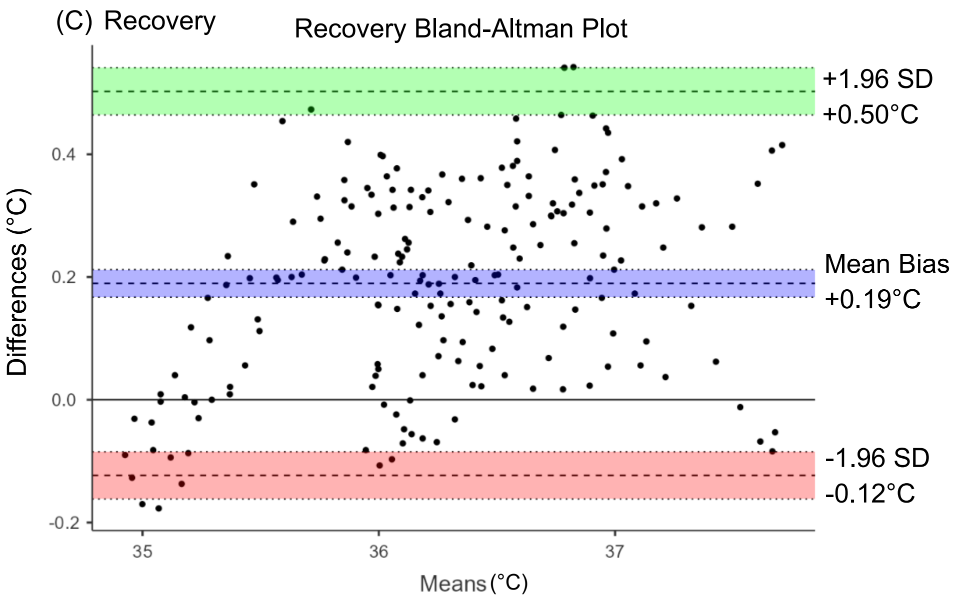


*Figure 6 - **Bland–Altman plot showing agreement between the eTemp and Physitemp SST-1 sensors for mean skin temperature during (A) rest, (B) exercise, and (C) recovery.** The dotted blue line represents the mean bias (eTemp - Physitemp), and the dashed green and red lines represent the upper and lower 95% limits of agreement respectively. Shaded areas indicate the 95% confidence intervals for the bias and limits of agreement.*

During rest, (Figure 6A), mean bias is low (0.25°C), with a large range for the limits of agreement, from -0.06°C to 0.57°C. Visual inspection of the Bland-Alman plot indicates minimal evidence of proportional bias in the rest stage, with largely random distribution of differences and no meaningful increase in differences at higher skin temperatures. Most of the data points clustered around the mean bias line, with the majority below the line, indicating relatively consistent differences throughout the rest stage.

In contrast, during exercise, (Figure 6B), mean bias increased compared to rest, alongside a widening of the limits of agreement. The Bland-Altman plot demonstrates a broader dispersion of differences, with greater frequency of negative values and increased spread across the temperature range. Despite this increased variability, no systematic proportional bias evident, as differences do not increase progressively with higher mean skin temperatures.

During recovery, (Figure 6C), mean bias and limits of agreement decreased relative to both rest and exercise conditions. The distribution of data points became sparser and more spread out away from the mean bias line, with greater spread and less clustering compared to exercise. An increased amount of negative difference values can be observed, and there is no proportional bias can be observed across the range of skin temperatures.

Discussion

The study evaluated the agreement between the eTemp Performance sensor and the Physitemp SST-1 standard reference sensor for the measurement of mean skin temperature during rest, exercise and recovery. Across the entire testing period, agreement between the sensors was strong, with a small systematic positive bias relative to the Physitemp sensor, indicating that the eTemp sensor consistently reported slightly higher skin temperatures than the Physitemp SST-1 probe.

Across the whole testing session (n = 794 paired observations), the eTemp sensor demonstrated a mean bias of 0.27°C relative to the Physitemp sensor, with 95% limits of agreement between -0.08°C to 0.62°C. This magnitude of bias is small and lies within commonly accepted limits for skin temperature measurement in exercise physiology. Systematic reviews of contact skin temperature measurement generally report that mean differences of less than 0.5°C and limits of agreement <1°C are generally considered acceptable for monitoring thermal responses during exercise (Smith et al., 2010), (Bandiera et al., 2025), (Bartman et al., 2025). The mean absolute error of 0.27°C further supports the close agreement between devices, indicating that typical measurement error was minimal across the physiological temperature range examined.

Although the eTemp sensor did not meet the ±0.1°C accuracy criterion outlined in ISO 9886 when compared against the Physitemp SST-1 reference, this standard represents ideal laboratory conditions and may be difficult to achieve during exercise with elevated sweating and skin blood flow. Importantly, the observed mean absolute error of 0.27°C is significantly lower than that reported for commonly used wearable skin temperature sensors such as the iButton (±0.5°C), suggesting that the eTemp sensor shows a meaningful improvement in wireless contact skin thermometry.

Mean skin temperature increased from rest to exercise and remained slightly elevated during recovery for both devices, demonstrating the expected thermoregulatory response to sustained metabolic heat production during exercise. Although absolute temperature values were consistently recorded higher for the eTemp sensor, the change in skin temperature over time was able to be recorded reliably across all experimental stages. This suggests that the eTemp sensor is capable of tracking dynamic changes in skin temperature over time, which is an important requirement for its application in exercise and environmental physiology (Bach et al., 2015). Crucially, the observed measurement bias demonstrated a consistent overestimation rather than underestimation of skin temperature. From an applied perspective, this conservative error may be preferable in thermophysiological monitoring, as it reduces the risk of underestimating heat strain and may therefore support safer decision making in heat exposure or exercise settings.

The consistently higher skin temperature readings observed by the eTemp sensor across all stages throughout the protocol are likely attributable to differences in sensor design and the interface between the skin and sensor. The eTemp sensor utilises a plastic housing and a larger surface area, which may promote local insulation and reduce local convective and evaporative heat loss beneath the sensor. In contrast, the Physitemp SST-1 probe uses a smaller metal contact surface with low thermal mass, allowing for more rapid heat transfer and potentially greater evaporative cooling at the measurement site. These structural differences likely contributed to the systematic positive bias observed with the eTemp sensor.

Stage specific analyses revealed that the agreement between sensors varied across the three physiological stages, however the differences were minimal in magnitude and are unlikely to be practically meaningful. In the rest stage, the mean bias was 0.25°C, with relatively narrow limits of agreement (-0.06°C to 0.57°C), indicating good agreement under stable baseline conditions. For the exercise period, bias increased to 0.32°C and limits of agreement widened (-0.03°C to 0.67°C), demonstrating greater variability between sensors under dynamic thermal conditions. In recovery, bias decreased to 0.19°C with narrower limits of agreement (-0.12°C to 0.50°C), suggesting partial restoration of measurement stability as movement decreased and thermal conditions became more stable. Since the limits of agreement overlapped substantially between stages, it indicates that sensor agreement was largely consistent across different physiological states.

The increase in bias and variability observed during exercise is likely a result of a combined effects of elevated skin blood flow, increased sweat production and altered local heat flux beneath the sensors (Xu et al., 2013). Under high heat flux conditions, slight differences in sensor thermal conductivity, attachment stability and evaporative interference may become more pronounced. In addition, the larger surface area and plastic housing of the eTemp sensor may reduce evaporative cooling directly beneath the sensor, leading to a slight overestimation of local skin temperature, as observed in the Bland-Altman plots (Figure 5). Despite this, the magnitude of bias remained small and within acceptable physiological limits, indicating that agreement remained satisfactory during exercise.

Visual inspection of the overall Bland-Altman plot (Figure 5) demonstrated a very mild degree of proportional bias, with differences between sensors increasing slightly at higher mean skin temperatures. However, this trend was small in magnitude and confined to a narrow physiological range, only increasing by 0.1°C for every 3°C increase in skin temperature, suggesting limited practical significance. This effect may reflect initial sensor stabilisation, or differential thermal equilibration between the plastic eTemp housing and the metal Physitemp probe under low heat flux conditions.

No substantial proportional bias was evident during exercise or recovery, indicating that measurement error remained mostly independent of absolute skin temperature across the relevant temperature range during exercise. This supports the stability of the eTemp sensor across both moderate and elevated skin temperatures and reinforces its suitability for applications in monitoring skin temperature during dynamic physiological conditions.

Comparison With Other Studies

Building on the agreement thresholds outlined earlier, the magnitude of bias and limits of agreement observed in the present study are consistent with those reported in previous validation of wearable skin temperature sensors. Validation studies using wired thermistors and infrared thermometry have generally reported low measurement error under controlled conditions, but these systems are impractical for applied exercise monitoring (Burnham et al., 2006; MacRae et al., 2018). Thus, recent validation studies have focused on wireless and wearable sensors, as they typically exhibit greater measurement error due to differences in sensor design and attachment.

Smith et al. (2010) found that wireless iButton sensors recorded mean temperature differences ranging from 0.26°C to 0.99°C relative to wired thermistors across different ambient temperatures and exercise conditions, with wider limits of agreement observed during hotter and more dynamic conditions. Similarly, McFarlin et al. (2015) and Miozzi et al. (2017) demonstrated that wearable skin temperature devices commonly show systematic bias and increased variability during exercise, especially during sweating and elevated blood flow. The mean bias of 0.27°C and limits of agreement observed in the present study compares favourably with these previous studies, indicating improved agreement relative to other wireless sensors.

Methodological differences between studies should be taken into consideration when interpreting agreement metrics. Previous studies have performed short duration trials, isolated skin sites or static postures, whereas the present study assessed mean skin temperature derived from multiple anatomical locations across a prolonged period. This approach more closely reflects applied use cases in exercise physiology, as tracking dynamic thermal responses is crucial. Despite these variations in methodology, the eTemp sensor demonstrated agreement comparable to, or better than, that reported in existing literature.

Several limitations should be acknowledged. The sample size was modest (n = 14), which may limit the generalisability of the findings to broader populations. Measurements were obtained under controlled laboratory conditions with a fixed exercise intensity and environmental exposure, thus sensor performance under more variable ambient conditions needs to be investigated.

Future studies should extend this validation framework to outdoor environments, higher ambient temperatures and prolonged exercise durations. Investigation of site-specific performance may also provide further insight into optimal sensor placement for applied monitoring. Nevertheless, the present findings provide strong evidence supporting the validity of the eTemp Performance sensor for the assessment of mean skin temperature during exercise and recovery.

Conclusion

This study evaluated the agreement between the eTemp Performance sensor and the Physitemp SST-1 reference sensor for the measurement of mean skin temperature during rest, exercise and recovery. Overall, the eTemp sensor showed good agreement with the reference probe, demonstrating a small and consistent positive bias of 0.27°C and a low mean absolute error (0.27°C) across 794 paired observations. Over the whole testing protocol, there was a very slight positive proportional bias, however, it was limited to a narrow range, thus was not considered significant.

Stage-specific analyses indicated that agreement was slightly reduced during exercise, with higher bias and wide limits of agreement, likely reflecting increased skin blood flow, sweating and heat flux. However, measurement error remained small and largely independent of absolute skin temperature, with no meaningful proportional bias observed during this period. This indicates stable sensor performance during the physiological conditions most relevant to exercise heat stress monitoring.

Despite a modest sample size and the controlled laboratory setting, the results support the validity of the eTemp Performance sensor for assessing mean skin temperature during dynamic thermal conditions. Overall, the findings demonstrate that the eTemp sensor is suitable for use in exercise and environmental physiology applications where accurate tracking of skin temperature is required.

Future research should investigate the performance of the eTemp sensor in larger and more diverse populations, as well as in field-based settings with greater environmental variability. Further studies could also examine sensor performance during prolonged exercise, different environmental extremes, and comparisons with additional reference methods to strengthen external validity.

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