Accuracy of Tympanic Temperature Measurement in Firefighters Completing a Simulated Structural Firefighting Task

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Abbreviations:
EMS: Emergency Medical Services
PPC: personal protective clothing
SCBA: self-contained breathing apparatus
T_{GI}: gastrointestinal temperature measurement
T_{Tym}: tympanic membrane temperature measurement

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Abstract

Introduction: In the course of their duties, firefighters risk heat stroke and other medical conditions due to exertion in high-temperature environments. Infrared tympanic temperature measurement (T_{Tym}) is often used by Emergency Medical Services (EMS) to assess the core body temperature of firefighters. The accuracy of T_{Tym} in this setting has been called into question.

Hypothesis/Problem: This study aimed to examine the accuracy of T_{Tym} for core body temperature assessment at emergency firefighting events compared with gastrointestinal temperature measurement (T_{GI}) as measured by ingestible thermometers.

Methods: Forty-five (42 male, three female) professional urban firefighters from an Australian fire service completed two 20-minute work periods in a 100°C (± 5°C) heat chamber while wearing personal protective clothing (PPC) and breathing apparatus (weighing approximately 22 kg). Measurements were taken immediately before entering, and on exiting, the heat chamber. Tympanic temperature was assessed by an infrared tympanic thermometer and T_{GI} was measured by ingestible sensor and radio receiver.

Results: Complete data were available for 37 participants. Participant temperatures were higher on exiting the heat chamber than at baseline (T_{Tym}: 35.9°C (SD = 0.7) vs 37.5°C (SD = 0.8); T_{GI}: 37.2°C (SD = 0.4) vs 38.6°C (SD = 0.5)). Tympanic temperature underestimated T_{GI} on average by 1.3°C (SD = 0.5) before entering the chamber and by 1.0°C (SD = 0.8) following the exercise. Using pooled data, the average underestimation was 1.2°C (SD = 0.7).

Conclusion: Tympanic thermometers cause an unreliable measure of core body temperature for firefighters engaged in fire suppression activities. Accurate and practical measures of core body temperature are required urgently.

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Introduction

Firefighters regularly undertake emergency responses in hot environments wearing personal protective clothing (PPC) and self-contained breathing apparatus (SCBA) weighing in excess of 20 kg.[1,2] The physical nature of this work, when combined with high ambient temperatures, results in increased core body temperatures, potentially leading to life-threatening heat stroke.[3,4] High core body temperatures, resulting from work in the heat, can also lead to premature fatigue, cognitive decline, and changes to inflammatory and coagulation factors.[5-9]

Emergency Medical Services (EMS) may be tasked in a preventative and/or treatment capacity at fire scenes to mitigate the risk of firefighter heat stroke during, and directly following, fire suppression activities. Exertional heat stroke has been defined clinically as a core temperature above 40°C with central nervous system dysfunction.[10] To assist in appropriate identification and management of heat stroke and other heat conditions, a practical and valid measure of core body temperature should be available at the fire scene. Various measurement sites and methods have been used to estimate core body temperature in laboratory and clinical settings. However, measurement tools such as rectal probes are

Characteristic	Mean (SD)	Range
Age (years)	40.1 (SD = 8.6)	25-57
Height (cm)	178.8 (SD = 7.5)	155-199
Weight (kg)	83.3 (SD = 9.4)	57.0-102.7

Table 1. Participant Characteristics (n = 45)

particularly invasive in-dwelling devices, which have limited application to field settings. Ingestible thermometers provide valid and reliable measurement of gastrointestinal temperature (T_{GI}), and have been shown to be a reliable surrogate of core body temperature.[11,12] Ingestion of thermometers must occur more than six hours prior to use, thus limiting their practicality as a tool for emergency response.[8]

Infrared temperature measurement of the tympanic membrane (T_{Tym}) is used widely by EMS as a surrogate measure of core body temperature. The units are cost-effective, simple to use, and have been reported to measure core body temperature accurately in some clinical settings.[13,14] However, the accuracy of T_{Tym} as a measure of core body temperature has been questioned, particularly in field settings.[11,13,15,16]

This study aimed to examine the accuracy of T_{Tym} for core body temperature assessment, as used by EMS at emergency firefighting events, with reference to $T_{GI,}$ as measured by ingestible thermometers. By replicating the working conditions experienced by firefighters via a simulated structural firefighting event, this study further aimed to establish whether the current practice of using tympanic thermometry for firefighters working in a hot environment is appropriate.

Methods

Participants

Forty-five (42 male, three female) professional urban firefighters from an Australian fire service volunteered to participate in the current study (Table 1). All participants were active operationally at the time of testing and represented all ranks within the fire service. Informed written consent from participants was obtained before testing, based on protocols approved by the University of Canberra Human Research Ethics Committee (Canberra, Australia).

Procedure

Qualified operational paramedics, employed by an Australian government ambulance service, undertook T_{Tym} and T_{GI} measurement of participants. Baseline measurements (Time 1) were taken in an air-conditioned room (22°C-24°C) located adjacent to a purpose-built heat chamber with participants wearing boots, socks, pants, and a cotton t-shirt. To mitigate the possible confounding effects of dehydration, participants' hydration status was evaluated prior to heat testing by a portable refractometer (Atago 3464 UG-a; Atago; Tokyo, Japan) with urine specific gravity less than 1.020 considered to be euhydrated.[15] Participants exceeding this value consumed 600 ml of water, provided in sealed bottles, before testing.

Following baseline measurement, participants completed two 20 minute work periods in the heat chamber set at 100°C (±5°C), as described previously.[8] Participants completed one 14 meter circuit every 30 seconds carrying a plastic drum weighing approximately 20 kg. Participants wore structural PPC issued by the fire service and an open-circuit SCBA (Scott Safety Australia; Sydney, New South Wales, Australia). The protective equipment weighed approximately 22.0 kg. A 10 minute intermediate rest interval outside the heat chamber (13.5°C (SD = 2.4)) separated the work periods. During the intermediate rest period, participants removed their SCBA, jacket, gloves and helmet, changed their SCBA cylinders, and consumed 600 ml of water, provided in sealed bottles. The timing protocols used in the current study have been reported as reflecting standard operating procedures for urban fire services at structural fires.[17,18]

On completion of the second work period, participants removed their SCBA, jacket, gloves, and helmet, and walked to the air-conditioned room adjacent to the heat chamber where T_{Tym} and T_{GI} were assessed (Time 2). Approximately five minutes elapsed between completion of the second work period and temperature measurement. The procedures were designed to replicate the process undertaken by firefighters and paramedics at a structure fire, with the exception that baseline measurements would normally not be taken at a real incident.

Measures

Gastrointestinal Temperature—Gastrointestinal temperature was monitored via an ingestible thermometer and radio receiver (HQ Inc; Florida, USA) consumed at least six hours prior to testing.[19] To control for the possible effect of localized cooling from fluid ingestion, participants were excluded from analysis when baseline temperatures were ≤35.5°C or decreased by 2°C in any five minute period during testing.[8,20]

Tympanic Temperature Measurement—A single infrared thermometer (Braun ThermoScan IRT 4520; Kronberg, Germany) was used to measure participants' T_{Tym}. Testing was conducted by qualified paramedics who were familiar with the use of this thermometer. One measurement per participant was undertaken at Time 1, and taken again at Time 2. Paramedics used the participant's ear that was most convenient, and no attempt was made to control for which ear was used.

Statistical Analysis

Data were analyzed using R[21] and are reported as mean (SD). The level of agreement between T_{Tym} and T_{GI} was evaluated using procedures proposed by Bland and Altman.[22,23] This method compares the mean of the two different measures against the difference between the measurements. From this, a 95% confidence interval (CI) is derived to determine the limits of agreement between the two methods. If the CI is narrower than a pre-determined cut-off, then the two measurements are said to be interchangeable. The cut-off is determined clinically based on what is being measured; for this study, a difference of less than 0.5°C was considered a clinically acceptable level of agreement.

Results

Gastrointestinal temperature measurement was unable to be obtained in two participants at Time 1 and an additional six participants at Time 2, resulting in 37 participants with complete measurements at both time points (Table 2). Gastrointestinal temperature was significantly higher at Time 2 than Time 1 ($P < .001$), as was T_{Tym} ($P < .001$; Table 2).

	Time 1 (n = 37)		Time 2 (n = 37)	
	T_{Tym}	T_{GI}	T_{Tym}	T_{GI}
Mean (SD)	35.9 (SD = 0.7)	37.2 (SD = 0.4)	37.5 (SD = 0.8)	38.6 (SD = 0.5)

Table 2. Summary Statistics for T_{GI} and T_{Tym} at Time 1 and Time 2 (Complete Measurements at Both Time Points)
Abbreviations: T_{GI}, gastrointestinal temperature measurement; T_{Tym}, tympanic membrane temperature measurement.

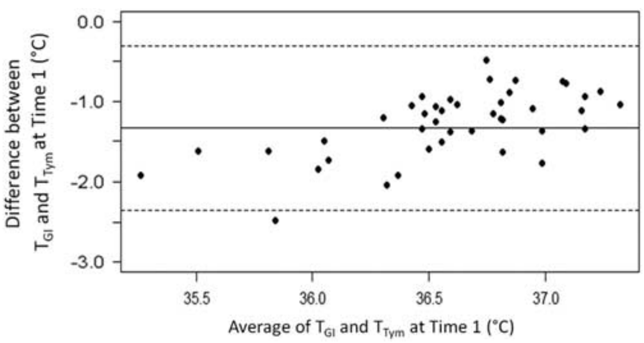

Figure 1. Levels of Agreement between T_{GI} and T_{Tym} at Time 1. Solid Line is the Mean Difference; Dashed Lines Show the 95% CI.
Abbreviations: T_{GI}, gastrointestinal temperature measurement; T_{Tym}, tympanic membrane temperature measurement.

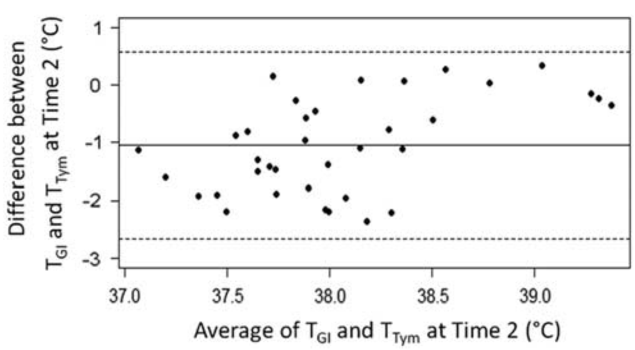

Figure 2. Levels of Agreement between T_{GI} and T_{Tym} at Time 2. Solid Line is the Mean Difference; Dashed Lines Show the 95% CI.
Abbreviations: T_{GI}, gastrointestinal temperature measurement; T_{Tym}, tympanic membrane temperature measurement.

Levels of agreement initially were calculated separately for Time 1 and Time 2. At Time 1, the mean difference between T_{Tym} and T_{GI} was -1.3°C (SD = 0.5). The 95% CI for the difference was -2.3°C to -0.3°C (Figure 1). For Time 2, the mean difference was -1.0°C (SD = 0.8); the 95% CI was -2.6°C to 0.6°C (Figure 2).

Levels of agreement were then calculated on the pooled data, regardless of time. Within subject variance was corrected for using the procedure outlined by Bland and Altman.[24] Using this method, the mean difference was -1.2°C (SD = 0.7); the 95% CI was -2.5°C to 0.1°C (Figure 3).

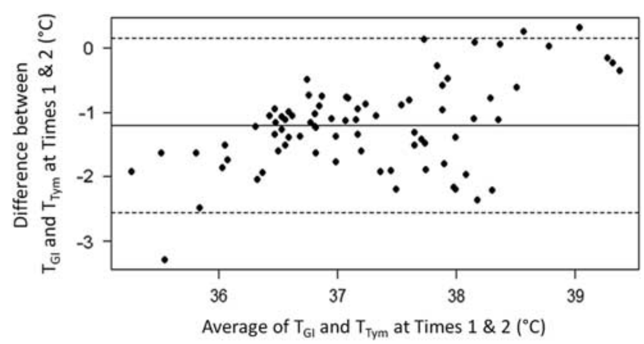

Figure 3. Levels of Agreement between T_{GI} and T_{Tym} Pooled Across Time 1 and Time 2. Solid Line is the Mean Difference; Dashed Lines Show the 95% CI.
Abbreviations: T_{GI}, gastrointestinal temperature measurement; T_{Tym}, tympanic membrane temperature measurement.

Discussion

The current study assessed the accuracy of an infrared tympanic thermometer commonly used by EMS as a surrogate measure of core body temperature in firefighters compared with T_{GI}. The key finding of this study was that T_{Tym} showed poor agreement with T_{GI} as the 95% confidence intervals were well outside the pre-determined cut-off of 0.5°C difference. In this setting, T_{Tym} can be expected to underestimate T_{GI} by up to 2.6°C. Accurate assessment of temperatures in firefighters is critical in ensuring appropriate monitoring and treatment of heat-affected individuals in the field to minimize the risk of exertional heat stroke. As such, this discrepancy is too large to recommend T_{Tym} as a monitoring tool for use by EMS. If the error was reasonably constant, then a simple correction factor could be applied to T_{Tym} to improve validity. However, while T_{Tym} usually underestimated T_{GI}, a small amount of overestimation was also possible.

In the current study, T_{Tym} was measured in a temperate environment (22°C-24°C) prior to, and following, the work task. Given the auditory canal's exposure to the environment, it is intuitive to expect that the relatively mild, ambient conditions in the current study likely would impact upon temperature of the tympanum. Although the findings of this study may have been confounded by the temperate ambient conditions, when a similar exercise was undertaken in tropical conditions (mean ambient temperature 29.5°C), the mean discrepancy of -1.3°C between T_{Tym} and T_{GI} during a simulated work task matched the findings of the current investigation.[25] Further, Prior and colleagues reported that tympanic thermometers failed to measure core body temperature accurately of firefighters wearing PPC while exercising in a hot (38°C) laboratory.[26] In that study, a mean bias of -1.3°C was reported for an infrared thermometer, approximating the results of both the current investigation and Brearley et al.,[25] despite the large discrepancy in ambient conditions between investigations.

Interestingly, the T_{Tym} error reported by Pryor was relatively constant throughout their 20 minute rest phase, despite decreasing body temperatures.[26] In contrast, Langridge et al.[27] reported increasing error during serial measurements at five minute intervals during a cooling protocol. It is currently unclear whether the active cooling strategies employed by that study contributed to the difference in temperature measurements.

Given the ubiquitous nature of tympanic thermometers in EMS, it is worth considering the origin of the measurement inaccuracy. Daanen[28] made three dimensional models of the ear canal of healthy volunteers and compared these to tympanic thermometer accuracy, and it was found that visibility of the tympanic membrane was the most important factor in measurement accuracy. Further, it was reported that an inability to straighten the auditory canal to permit access to the tympanic membrane likely would measure auditory canal temperature, rather than that of the target tympanum, and result in an underestimation. The risk of measuring auditory canal temperature could be mitigated by combining the capabilities of an otoscope and a tympanic thermometer so that the operator could confirm visually accessibility of the tympanic membrane. However, this would lead to increased complexity and training requirements in using such a device.

Alternatively, insulating the auditory canal from the environment is likely to limit the temperature gradient drastically within the auditory canal,[29] permitting improved measurement accuracy through use of a tympanic probe.[30] While Pryor et al.[26] reported that tympanic probes were more erroneous than infrared tympanic monitors, the precise location of the probe was not detailed and the auditory canal was not insulated in that study. The primary limitation of "plugging the ear" for T_{Tym} monitoring is the inhibition of aural communication, a significant problem for firefighters working in hazardous environments. A potential solution combines a radio earpiece with an infrared tympanic thermometer.[31] The radio earpiece could achieve auditory canal insulation and T_{Tym} measurement, while also permitting firefighter radio communication.

Limitations

A significant limitation of this study is that no participant achieved T_{GI} greater than 39.5°C. The diagnosis of heat stroke requires a core body temperature greater than 40°C. While deliberately inducing body temperatures greater than 40°C is ethically dubious, this study cannot draw conclusions from the accuracy of T_{Tym} in a firefighter potentially suffering heat stroke. It is likely that the measurement error will remain as reported, or even larger, but this would be supposition at this time. An understanding of how body temperatures over 40°C affect measurement accuracy would be useful.

Conclusion

In this study of firefighters completing a simulated structural firefighting task, T_{Tym} showed poor agreement with T_{GI} as the 95% confidence intervals were well outside the pre-determined cut-off of 0.5°C difference. In this setting, T_{Tym} is not a reliable measure of T_{GI}.

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