Industrial Athlete Core Temperature Accuracy Analysis of Commercial Arm Worn Device vs Rectal Thermometry

FireHUD, Inc
Lee University

A practical review to accuracy of core body temperature retrieval taken by FireHUD's Biotrac Band and the Datatherm II during firefighting training

This study was completed in collaboration with Lee University and Dr. Racheal Lawler. Dr. Lawler, is an assistant professor and Clinical Education Coordinator for the Athletic Training Education Program.

Dr. Lawler is a certified Athletic trainer and has a clinical background within professional and college sports. Her passion to understand exertional heat illnesses has led to her influential involvement within the emergency service community.

FIREHUD BACKGROUND

FireHUD is a technology company that provides easy-to-use, group physiological monitoring to first responders, the military, and industrial workers. FireHUD aims to make jobs safer with new technology and improved situational awareness.

Through the collection of critical biometric markers such as heart rate and core body temperature, FireHUD uses machine learning to create personalized profiles that predict exertion levels for all group members and provides real-time alerts in order to prevent injuries and deaths. FireHUD has received funding from the National Science Foundation and the US Air Force to accelerate development of its IoT platform.

STUDY BACKGROUND AND PURPOSE

In early 2020, FireHUD participated in a University study to validate the core body temperature algorithm used by FireHUD's Biotrac Band to the 'gold standard' of core body temperature via rectal measurement from the Datatherm II.

This validation study would build upon previous studies with an ingestible pill made by HQinc. The FireHUD team as well as various emergency, military and safety community partners believe the ability to accurately measure and predict core body temperature in real-time in a noninvasive manner will be revolutionary for safety and situational awareness in industries where personnel protective equipment is worn.

This technology will be especially useful in the fire service where heat stress and overexertion are significant risk factors to cardiovascular strain. This is a known issue in the research field as Dr. Denise Smith from the First Responder Health and Safety Laboratory at Skidmore College attests in her landmark report on the "Effect of Heat Stress and Dehydration on Cardiovascular Function" "Effect of Heat Stress and Dehydration on Cardiovascular Function" which states:

> *"Firefighters are exposed to numerous life-threatening dangers, including high temperatures, flames, smoke, hazardous chemicals, and unstable structures. Despite these dangers, the physiological strain, specifically cardiovascular strain, associated with firefighting poses the greatest threat to the life and health of a firefighter."*

Therefore, the purpose of this study is to compare the noninvasive core body temperature measured by the arm worn FireHUD BioTrac Band to the invasive rectal measurement from the DataTherm II. The goal of this study was to find if the FireHUD core body temperature algorithm is, statistically speaking, in agreement with the DataTherm II probe.

Image 1. Firefighters performing the required drills during training exercise.

STUDY SCENARIO

The study consisted of 5 individual recruits at a local firefighting training facility. This study was an augment to an already planned local fire departments training exercise. Data was captured during the 2-day training event where subscribed activities are intended to test a firefighter recruit's ability to perform simulated implementation of tactical operations. Activities captured during this training consisted of live firefighting technique training and heavy calisthenics in full PPE load out as well as various hose training and firefighting approaches.

Data was captured by Test Facilitator (University PhD Professor) via two retrieval methods:

1. FireHUD BioTrac Band on each recruit
    a. Received via reusable arm device and viewed in real-time through web portal.
2. DataTherm® II* on each recruit
    a. Received via disposable probes inserted rectally. Downloaded once before lunch and once at the end of day. Viewed in Microsoft Excel post training exercise.

Image 2. Shows the FireHUD BioTrac Band worn on the arm of firefighters before training.

ANALYSIS

After the conclusion of the two-day training event, the test facilitator emailed the data to the FireHUD team for independent analysis and comparisons. The FireHUD team's analysis was first performed in Microsoft Excel and then migrated to Matlab.

As can be seen in **Figure 1**, the FireHUD BioTrac Band was able to track the 'gold standard' of core body temperature measurement accurately. Due to comfortability the DataTherm II was not worn during a lunch break while the FireHUD BioTrac Band stayed on. This can be seen in the following graph by the gap in the orange line from around 11:30 AM to 1:20 PM. During this time period, the PPE was taken off and the workload was reduced causing core body temperature to decrease.

Additionally, some inaccurate spikes did appear in the DataTherm II measurements due to high levels of motion. These were cleaned away during the analysis portion. This data collection and cleaning was implemented for all five individuals over both days that testing was performed.

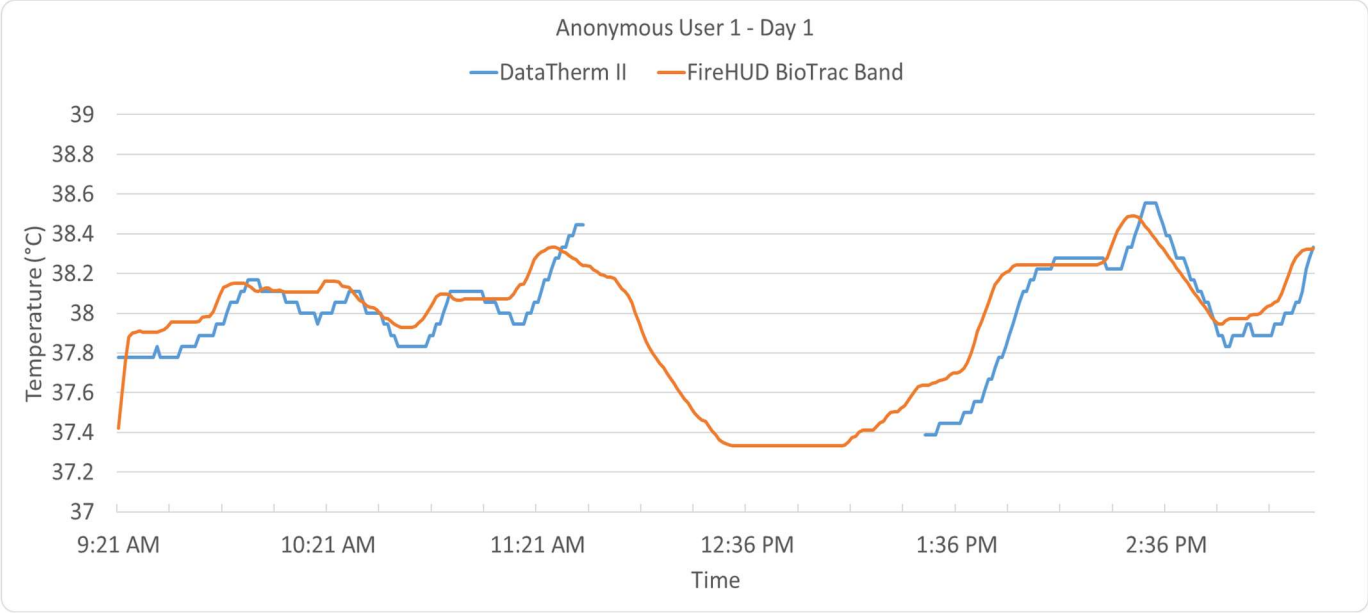


Figure 1. Example of the data collected from the DataTherm II (Orange) vs FireHUD BioTrac Band (Blue) from User 1.

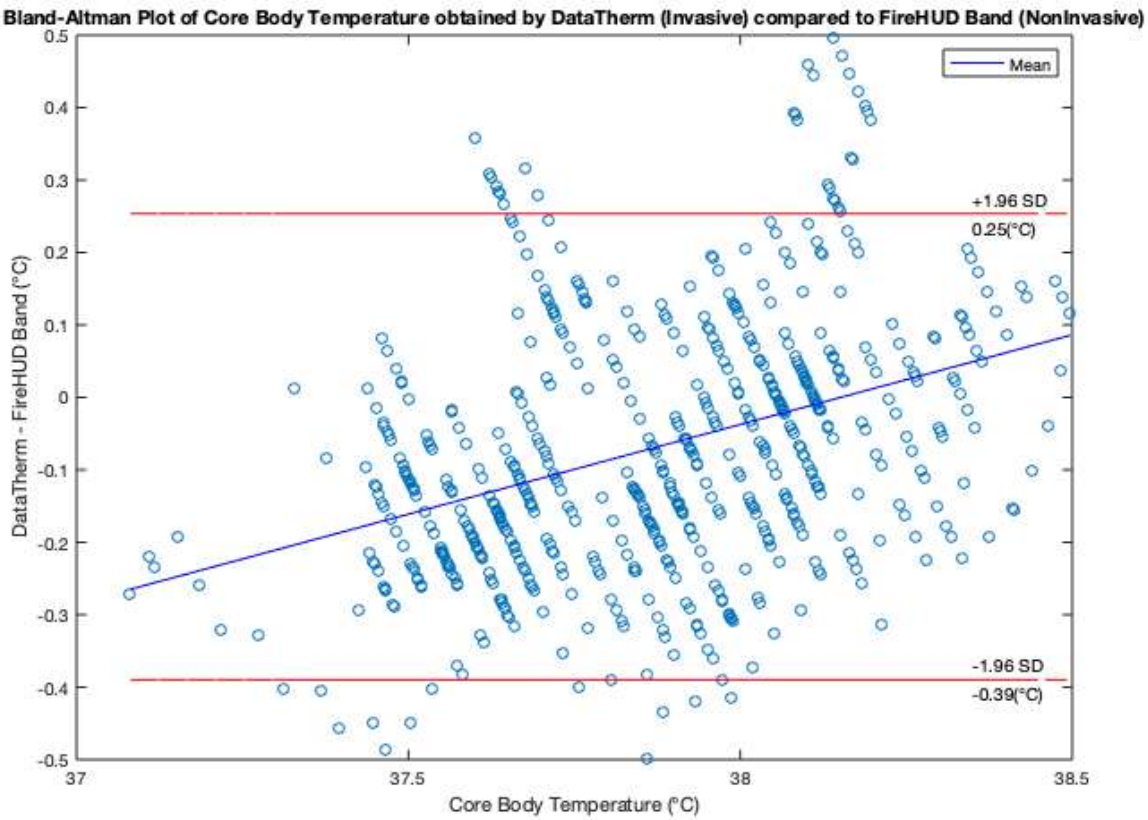


Figure 2. Bland-Altman plot of Core Body Temperature differences obtained by the DataTherm II using an invasive method and the FireHUD Band using a noninvasive method. The differences were calculated by Datatherm II minus FireHUD Band reading.

FINDINGS

By repeating this process to collect and clean all available data from all five individuals over the two days that testing was performed, notable trends were found. In general, the FireHUD core body temperature algorithm runs mostly in lockstep with that of the Datatherm II's measurement. When variation does occur, the FireHUD algorithm estimates a core body temperature slightly higher than Datatherm II's measurement. This tendency to offer a conservative estimate for core temperature is a desired behavior if trying to reduce false negatives. For FireHUD's use case, over estimating a person's core temperature is acceptable, underestimating is not.

For **Figure 1**, the average error across the day was 0.15 ℃ with a root mean squared error of 0.28 ℃. The use of root mean squared error was selected because of its tendency to assign a higher penalty weight to larger errors. In both the average error and root mean squared error the lower the value the better the algorithm performed. Attached in the Appendix, is **Table 1**, which displays the 5 individuals' average error and root mean squared error over the two day training scenario. The average aggregated error from the study is 0.23 ℃ and the aggregate root mean squared error is 0.25 ℃.

The average and root mean squared error are important measurements but only tell part of the story. The goal of this project was to see if the FireHUD

core body temperature algorithm is statistically in agreement with the DataTherm II probe. Therefore, the findings were additionally graphed using a Bland-Altman plot **(Figure 2)** which describes agreement between two quantitative measurements.

With this technique exact confidence intervals aren't produced; instead close approximations, called 'limits of agreements' are. In **Figure 2** the red lines on the plot represent +- 2 standard deviations or 95% limits of agreement (LoA). Using the Bland-Altman plot, based on the recorded 948 samples in our study, we can conclude with a close approximation that 95% of the FireHUD's core temperature readings will be equal to DataTherm II's -0.067 ± 0.32 C.

Furthermore, from the Bland Altman plot, the mean of Datatherm - FireHUD is 0.067 C(This is the average mean for the difference in each respective 948 data point pair for a DataTherm temperature and a FireHUD temperature at a given time interval). This means that FireHUD's estimate for core temperature is on average 0.067 C warmer than the sensor output of the Datatherm II. As shown in the plot, the mean of Datatherm - FireHUD appears to follow a linear curve(blue line) -- due to the conservative nature of our algorithm we tend to overestimate and gain accuracy as the subject's core temperature increases. This is a desired trait.

When looking at any particular given FireHUD temperature and evaluating whether it is a good approximation to what the Datatherm II would read, the interval grows slightly larger.

- With 95% confidence, any given FireHUD core temperature reading will be between +0.25 C and -0.39 C of the DataTherm II's reading
- With 99.9% confidence, any given FireHUD core temperature reading will be between +0.47 C and -0.60 C of the DataTherm II's reading

CONCLUSION

Measuring core body temperature is difficult for a number of reasons. Invasive sensors such as Datatherm II promise the most accurate readings, but are impractical to use for safety because they do not allow for real-time data dissemination and are uncomfortable for those equipped. FireHUD's core body temperature algorithm was designed to allow for similar measurements with a passive, real-time system. The leap in practicality will greatly assist industries such as firefighting that will significantly benefit from real-time heat stress monitoring. The findings from this study showed that the FireHUD Biotrac Band, based on the evaluation of 3 independent statistical measurements, can provide a reliable estimate core body temperature in a noninvasive manner.

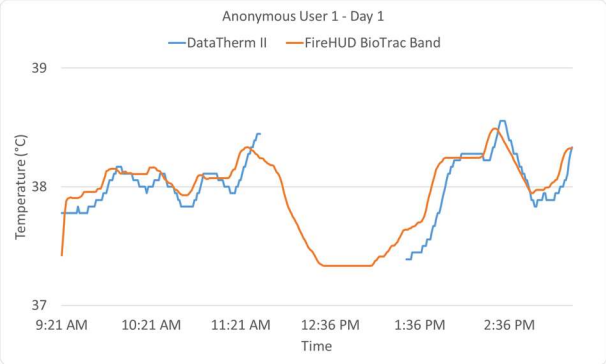
APPENDIX

Error Rates per User

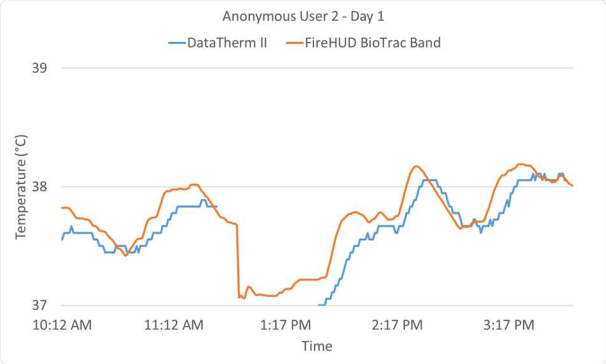
User	Avg. Error (°C)	RMSE* (°C)	Date
1	0.15	0.28	3/19
1	N/A	N/A	3/20
2	0.14	0.28	3/19
2	0.16	0.29	3/20
3	0.12	0.25	3/19
3	N/A	N/A	3/20
4	N/A	N/A	3/19
4	0.37	0.25	3/20
5	0.36	0.23	3/19
5	0.36	0.23	3/20

Table 1. Data collected during the study with error measurements. N/A signifies that there was a problem with the data collected from the DataTherm II probe.

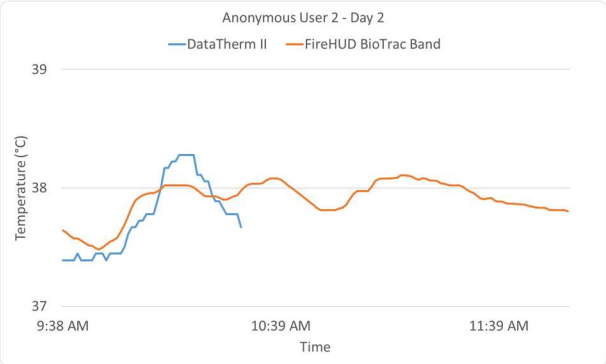
Data By User



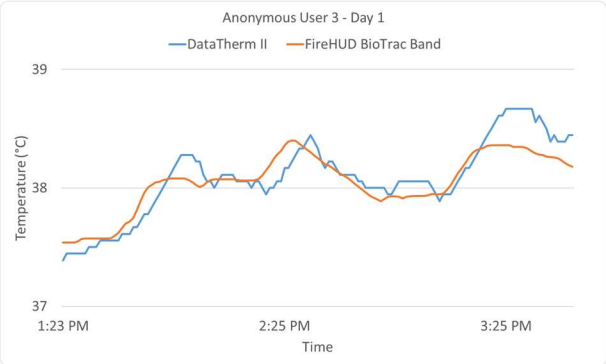
Graph 1



Graph 2



Graph 3



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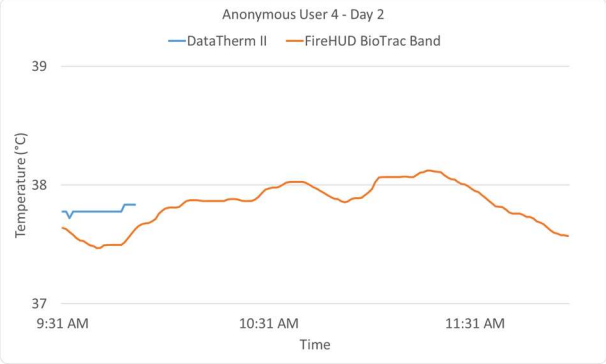
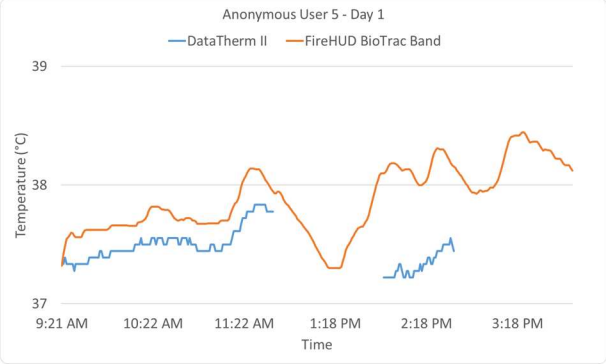
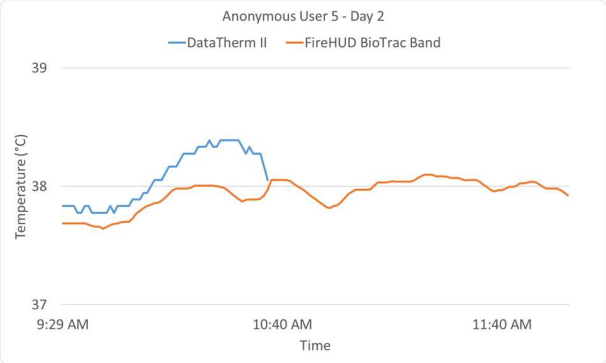


Graph 5



Graph 6



Graph 7