EBME 380 Senior Capstone: Core Body Temperature (CBT) Wearable

Team 5:
Ben Alexander, Brenna Carbone, Madison Castellanos, Jonathan Chen, Jenna Wagner

CASE SCHOOL OF ENGINEERING
CASE WESTERN RESERVE UNIVERSITY

Need Statement

*There is an unmet clinical need for a **noninvasive** CBT wearable that helps the **prevention** of hyperthermia and other temperature related illnesses.*

The wearable will continuously relay reliable CBT to users during physical activities to give early warning and stop activity preventing long lasting physical effects/damage on the body.

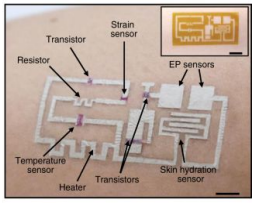
Clinical Need

- **Hyperthermia:** increase in core body temperature from 98.6 ℉ above 104℉
- **Hypothermia:** decrease to 95 ℉
- **Signs & Symptoms**: dehydration, fatigue, flushing, delirium, fainting, nausea, cramping, shallow breathing
- **Prevalence:**
  - 15% of the recreational runners developed exertional **hyperthermia**
  - 20% of runners develop **hypothermia**

The need for our Core Body Temperature wearable is as a preventative measure for hypo- and hyperthermia in athletes.

Market Background

- **Wearable Device Market:** 28 billion (2019)



- **Competitors:**

  General: Fitbit, Apple watch

  Sports Use: Oura Ring; Polar Belt, Core Belt, Drawn-on Sensors

  Gold Standard: Rectal Thermometer

- **Target market:** Athletes

- **Measurement types:** skin (external) temperature, heart rate, heat flux

- **Improvements:** noninvasive & continuous monitoring

Concept Selection

Chest Belt

- Most accurate
  - ±0.21°C accuracy
  - Continuous active recording
- Chest belts already on market
  - Material
  - Adjustable
  - Water resistant
- Improvements
  - Memory
  - Larger temperature range

Criteria	Importance	Rectal Probe (datum)	Head Band	Watch/Bracelet	Chest Belt
Comfort	8	0	7	10	8
Durability	8	5	5	9	9
Wearability	8	0	8	10	10
Life Span	5	10	7	8	7
Continous Monitoring	10	0	10	7	10
Accuracy	10	10	8	8	9
Weight	6	5	9	9	10
Cost	2	7	4	3	3
Size	3	3	4	9	9
Intuitive	5	0	8	10	8
Invasiveness	10	0	10	10	10
Score		243	589	659	674

Predictive Algorithms

HR Algorithm:

$$HR_t = 41 + \frac{152}{\left(1 + 0.06e^{-0.89(\widehat{CT}_t - 37.84)}\right)^{1/0.07}}$$

HR & Temp Algorithm:

$$T = 0.0100 \times \text{Heart rate} + 0.0837 \times T \text{ ins scapula} + 33.1735$$

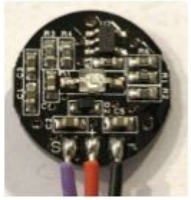
Device Configuration

1) HOUSING MODEL

Chest Belt

2) ELECTRICAL

Heart Rate

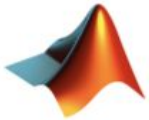


Temp

3) SOFTWARE

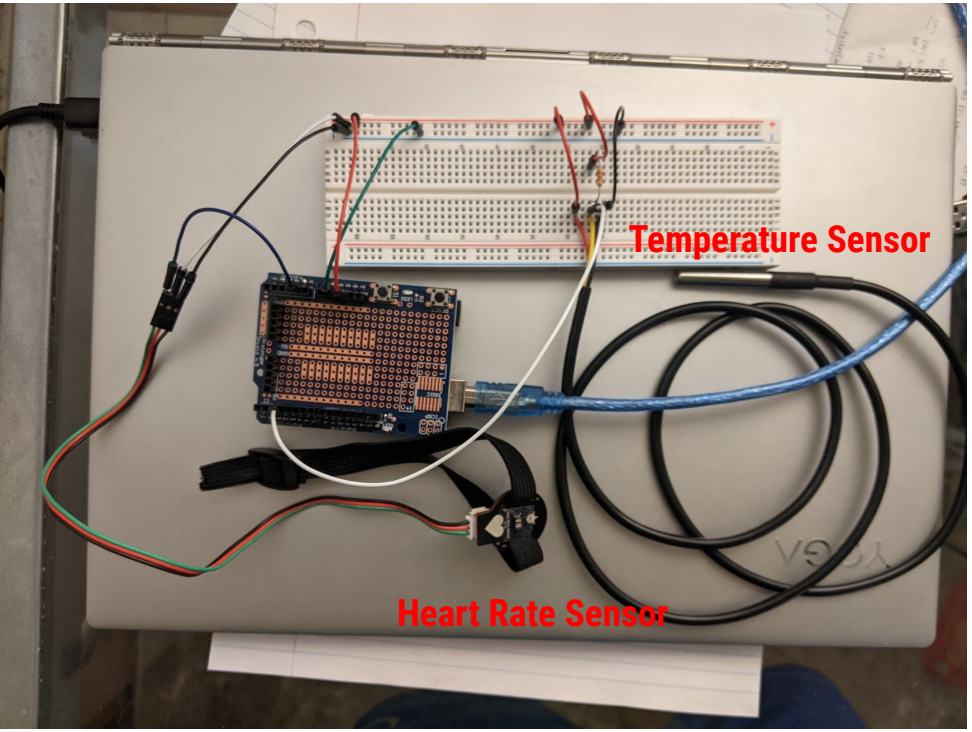
Arduino

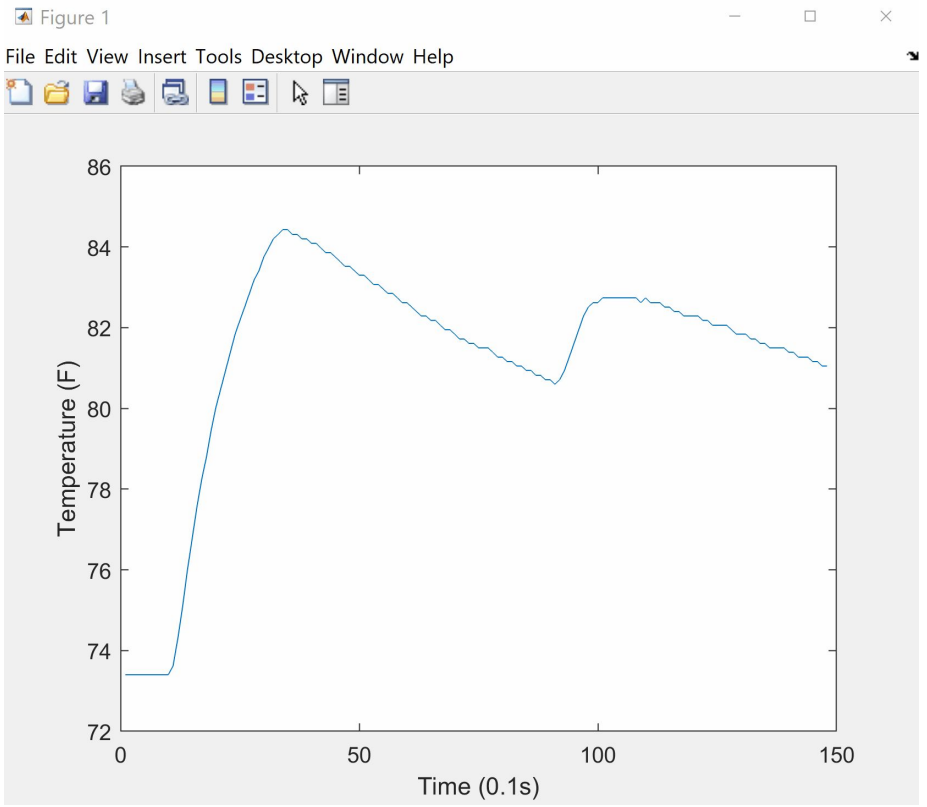
MATLAB



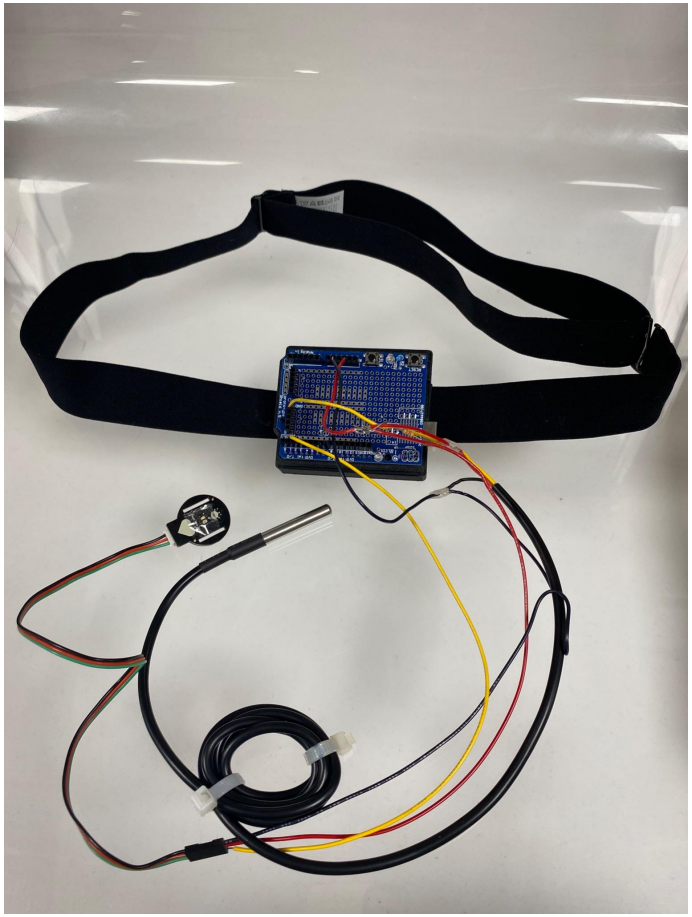
Android

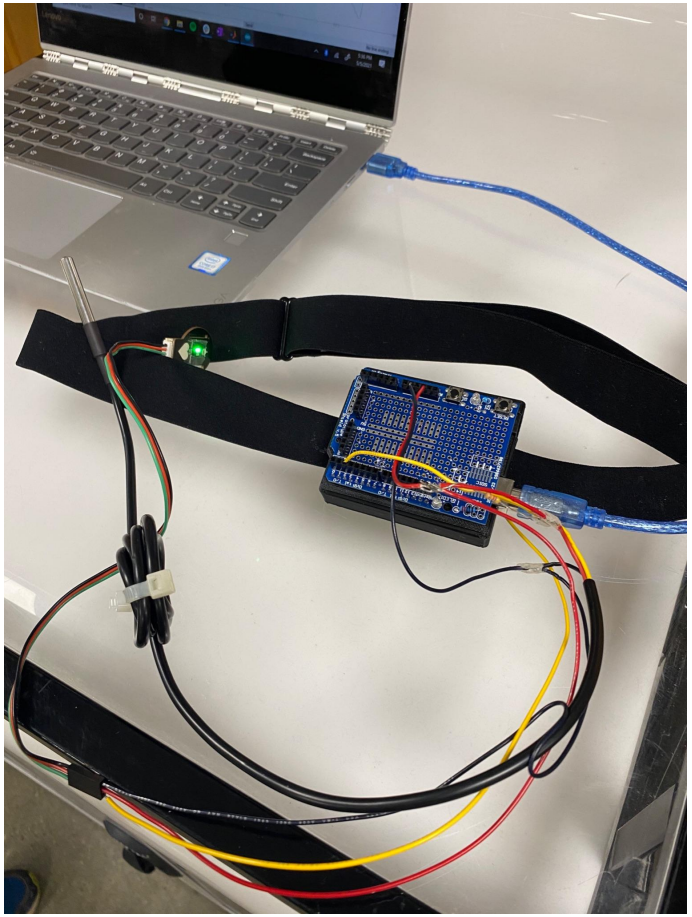
Initial Prototype - Electrical



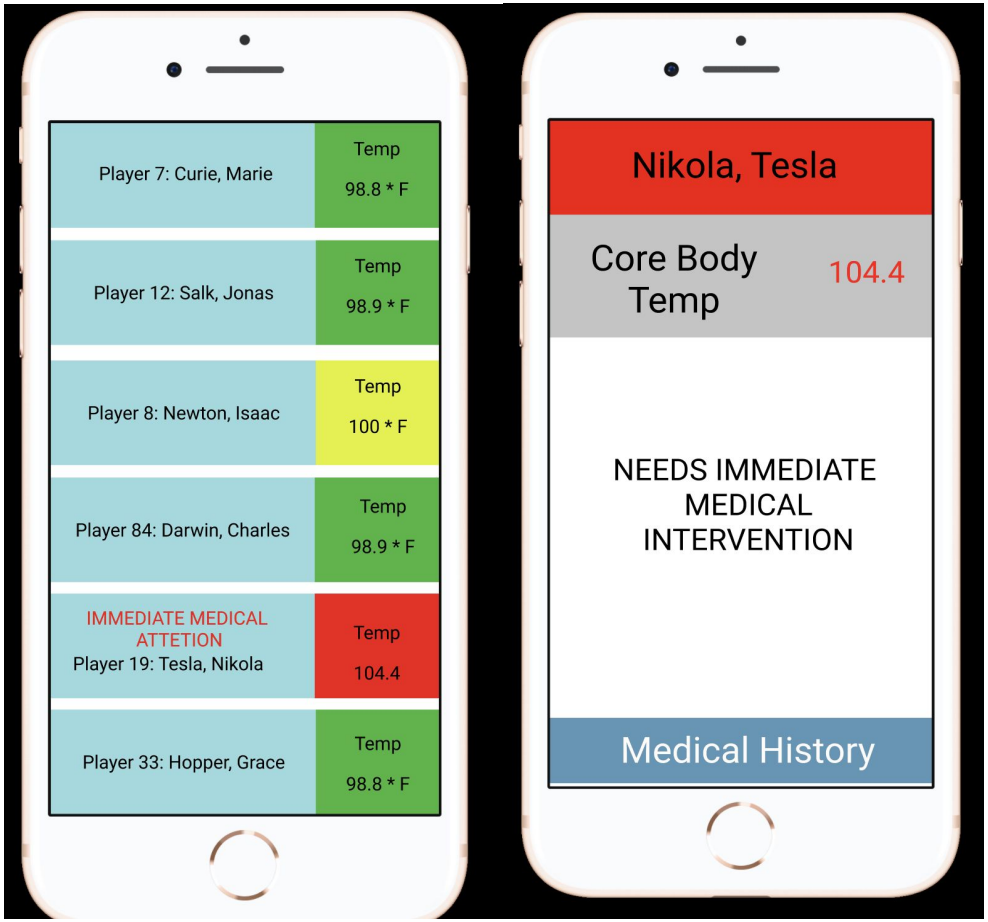


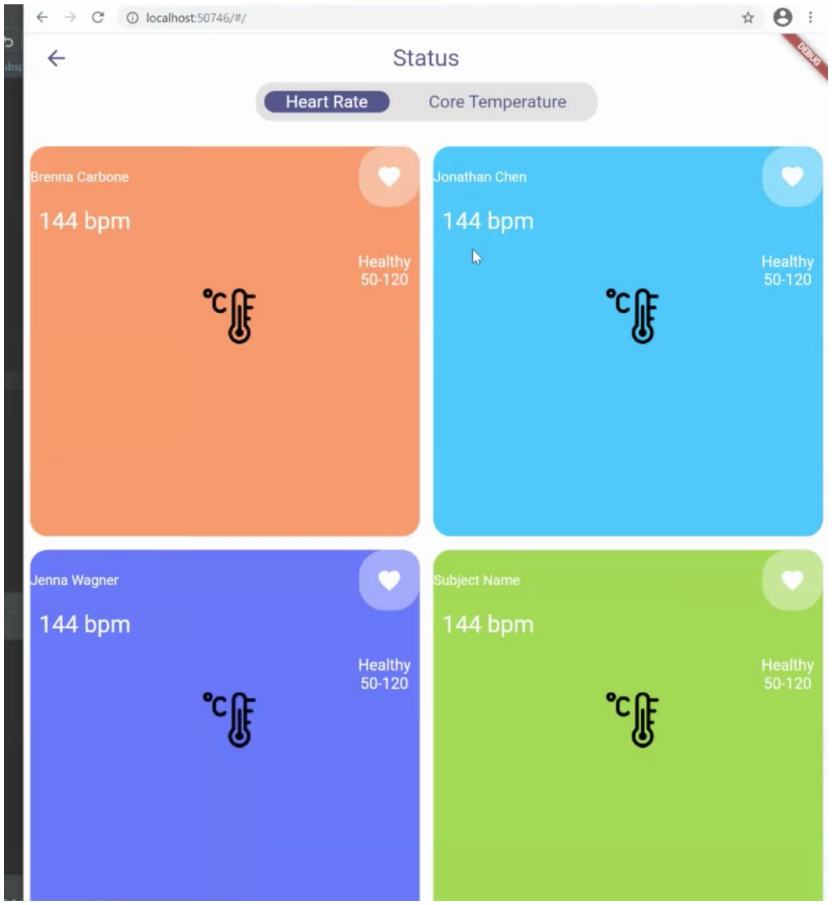
Final Prototype - Chest Belt





Initial Prototype - App UI





Validation

- Generalizability to a wider market from algorithm (SOURCE)
- Accuracy of temperature readings
  - Testing on subjects and preset conditions
- Movement/Impact
  - Testing if movement changes accuracy or continuity
- User feedback/survey
  - Asking if device is restrictive or comfortable
- Plan for iterative mindset

Acknowledgement

Funding Source: Research reported in this publication was supported by the National Institute of Biomedical Imaging And Bioengineering of the National Institutes of Health under Award Number R25EB014774.

The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Clinical Sponsor: Tim Walker & Dhruv Seshadri

Provided Resources/Facilities: Colin Drummond & Matthew Williams

Provided Critical Advice: Aditi Shirke

Sources

"Accuracy and Precision of Noninvasive Temperature Monitoring Device Compared to PAC In Adults In ICU," *TempTraq*, 05-Jun-2019. [Online]. Available: https://temptraq.healthcare/accuracy-and-precision-of-noninvasive-temperature-monitoring-device-compared-to-pac-in-adults-in-icu/. [Accessed: 25-Sep-2020].

M. D. S. M. L; "Core temperature measurement: methods and current insights," *Sports medicine (Auckland, N.Z.)*. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/12427049/. [Accessed: 25-Sep-2020].

L. Critchey, "A Wireless and Wearable Polymer Temperature Sensor for Healthcare Monitoring", Electropages.com, 2020. [Online]. Available: https://www.electropages.com/blog/2020/03/wireless-and-wearable-polymer-temperature-sensor-healthcare-monitoring.[Accessed: 24- Sep- 2020].

P. Eggenberger, B. A. MacRae, S. Kemp, M. Bürgisser, R. M. Rossi, and S. Annaheim, "Prediction of Core Body Temperature Based on Skin Temperature, Heat Flux, and Heart Rate Under Different Exercise and Clothing Conditions in the Heat in Young Adult Males," *Frontiers*, 26-Nov-2018. [Online]. Available: https://www.frontiersin.org/articles/10.3389/fphys.2018.01780/full. [Accessed: 25-Sep-2020].

F. Ershad, A. Thukral, J. Yue, P. Comeaux, Y. Lu, H. Shim, K. Sim, N.-I. Kim, Z. Rao, R. Guevara, L. Contreras, F. Pan, Y. Zhang, Y.-S. Guan, P. Yang, X. Wang, P. Wang, X. Wu, and C. Yu, "Ultra-conformal drawn-on-skin electronics for multifunctional motion artifact-free sensing and point-of-care treatment," *Nature News*, 30-Jul-2020. [Online]. Available: https://www.nature.com/articles/s41467-020-17619-1. [Accessed: 25-Sep-2020].

Feng J;Zhou C;He C;Li Y;Ye X; "Development of an improved wearable device for core body temperature monitoring based on the dual heat flux principle," *Physiological measurement*. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/28177299/. [Accessed: 25-Sep-2020].

H.-C. Gunga, M. Sandsund, R. E. Reinertsen, F. Sattler, and J. Koch, "A non-invasive device to continuously determine heat strain in humans," *Journal of Thermal Biology*, 01-Apr-2008. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0306456508000387. [Accessed: 25-Sep-2020].

H. Publishing, "Heat Stroke (Hyperthermia) - Harvard Health", *Harvard Health*, 2019. [Online]. Available: https://www.health.harvard.edu/a_to_z/heat-stroke-hyperthermia-a-to-z. [Accessed: 22- Sep- 2020]

How to Take Temperature | American Diagnostic Corporation", *Adctoday.com*, 2020. [Online]. Available: https://www.adctoday.com/learning-center/about-thermometers/how-take-temperature. [Accessed: 23- Sep- 2020].

J. Fang, C. Zhou and X. Ye, "Optimization of a Wearable Device for Core Body Temperature Monitoring Based on the Dual-Heat-Flux Model", *IOP Conference Series: Materials Science and Engineering*, vol. 677, p. 032006, 2019. Available: 10.1088/1757-899x/677/3/032006 [Accessed 24 September 2020].

S. Mazgaoker, I. Ketko, R. Yanovich, Y. Heled, and Y. Epstein, "Measuring core body temperature with a non-invasive sensor," *Journal of Thermal Biology*, 18-Mar-2017. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0306456516303199. [Accessed: 25-Sep-2020].

"MONITORING INTERNAL BODY TEMPERATURE." [Online]. Available: https://www.gssiweb.org/en/sports-science-exchange/Article/monitoring-internal-body-temperature. [Accessed: 25-Sep-2020].

Niedermann R;Wyss E;Annaheim S;Psikuta A;Davey S;Rossi RM; "Prediction of human core body temperature using non-invasive measurement methods," *International journal of biometeorology*. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/23760405/.

[Accessed: 25-Sep-2020].

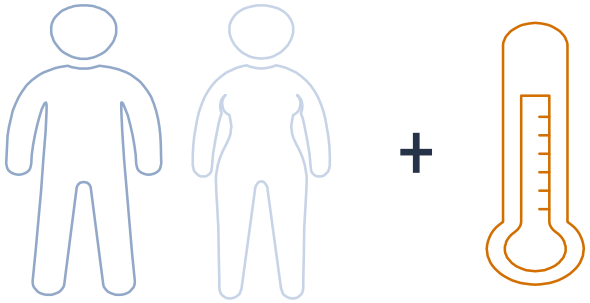
TempTraq - Continuous Temperature Monitoring. (n.d.). Retrieved September 25, 2020, from https://hs.nisshamedical.com/MedicalDevices/TempTraq.aspx

Teunissen LP;Klewer J;de Haan A;de Koning JJ;Daanen HA; "Non-invasive continuous core temperature measurement by zero heat flux," *Physiological measurement*. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/21444968/. [Accessed: 25-Sep-2020].

"The Oura Difference - The Pulse Blog", *The Pulse Blog*, 2020. [Online]. Available: https://blog.ouraring.com/the-oura-difference/. [Accessed: 24- Sep- 2020].

M.-F. Uth, J. Koch, and F. Sattler, "Body Core Temperature Sensing: Challenges and New Sensor Technologies," *Procedia Engineering*, vol. 168, pp. 89–92, 2016.

Eggenberger, Patrick, et al. "Prediction of Core Body Temperature Based on Skin Temperature, Heat Flux, and Heart Rate Under Different Exercise and Clothing Conditions in the Heat in Young Adult Males." *Frontiers in Physiology*, vol. 9, 2018, doi:10.3389/fphys.2018.01780.



THANK YOU

Any questions?