

This item was submitted to [Loughborough's Research Repository](#) by the author.  
Items in Figshare are protected by copyright, with all rights reserved, unless otherwise indicated.

## The use of non-invasive measures to predict thermal strain: How accurate are universal models?

PLEASE CITE THE PUBLISHED VERSION

PUBLISHER

International Society for Environmental Ergonomics © the authors

VERSION

VoR (Version of Record)

LICENCE

CC BY-NC-ND 4.0

REPOSITORY RECORD

Davey, Sarah, Victoria Richmond, Katharine E. Griggs, Nicola Gerrett, and George Havenith. 2019. "The Use of Non-invasive Measures to Predict Thermal Strain: How Accurate Are Universal Models?". figshare. <https://hdl.handle.net/2134/11964>.

This item was submitted to Loughborough's Institutional Repository (<https://dspace.lboro.ac.uk/>) by the author and is made available under the following Creative Commons Licence conditions.



**CC creative commons**  
COMMONS DEED

**Attribution-NonCommercial-NoDerivs 2.5**

**You are free:**

- to copy, distribute, display, and perform the work

**Under the following conditions:**

**BY:** **Attribution.** You must attribute the work in the manner specified by the author or licensor.

**Noncommercial.** You may not use this work for commercial purposes.

**No Derivative Works.** You may not alter, transform, or build upon this work.

- For any reuse or distribution, you must make clear to others the license terms of this work.
- Any of these conditions can be waived if you get permission from the copyright holder.

**Your fair use and other rights are in no way affected by the above.**

This is a human-readable summary of the [Legal Code \(the full license\)](#).

[Disclaimer](#) 

For the full text of this licence, please go to:  
<http://creativecommons.org/licenses/by-nc-nd/2.5/>

## The use of non-invasive measures to predict thermal strain: How accurate are universal models?

Sarah Davey\*, Victoria Richmond, Katy Griggs, Nicola Gerrett, George Havenith

Environmental Ergonomics Research Centre, Loughborough University, Loughborough, UK

\*corresponding author: G.Havenith@lboro.ac.uk

### Introduction

Over the past few decades there has been an upsurge in the development of monitoring devices that estimate levels of thermal strain non-invasively. However, developing a non-invasive monitoring device that estimates body core temperature ( $T_c$ ) with a certain level of accuracy that is satisfactory over multiple heat stress scenarios and a wide range of body core temperatures has been shown to be a difficult task [1]. The aim of this study was to investigate the potential of using a combination of simple non-invasive measures to estimate rectal temperature ( $T_{re}$ ) (used as a reference for  $T_c$ ) over multiple types of heat stress scenarios within a varied population.

### Method

A model that estimated  $T_{re}$  was developed and validated using a dataset that includes 35 participants (male = 19 and female = 16) and nine different environmental conditions. Each condition involved two continuous or intermittent 40-60 minute periods of treadmill walking in the heat (25°C-40°C, 20%-85% relative humidity [RH]), separated by a 20 minute seated rest in 22°C, 50% RH. Local skin temperature (11 sites),  $T_{re}$ , insulated skin temperature of the lower neck ( $T_{is}$ ), clothing microclimate temperature and RH, heart rate (HR), HR variability and breathing frequency were measured. The accuracy and practical implication of any prediction error was assessed using multiple linear regression, Bland and Altman charts and limits of agreement (LOA). The model was validated using an adapted version of the leave-out-one cross validation method. A root mean square deviation (rmsd) of 0.2°C was defined as an acceptable level of error. The study was approved by the Loughborough University Ethics Committee.

### Results and Discussion

The rmsd and LOA of the model over the nine conditions was 0.25°C and  $\pm 0.51^\circ\text{C}$ , respectively. Between the nine conditions the rmsd ranged between 0.16°C to 0.31°C. A higher proportion of negative errors occurred as  $T_{re}$  increased and several estimates had an error of  $\pm 1.0^\circ\text{C}$ . Thirty percent of  $T_{re}$ 's above 38.5°C were estimated less than 38.5°C.

### Conclusion

These results illustrate that using a universal model to accurately estimate  $T_c$  over multiple conditions at high  $T_{re}$ 's (i.e.  $>38.5^\circ\text{C}$ ) is not suitable, despite having a large number of predictors. Future models may require equations designed specifically for certain types of environmental conditions and/or high  $T_{re}$ 's.

### References

1. Yokota, M., Berglund, L., Cheuvront, S., Santee, W., Latzka, W., Mountain, S., Kolka, M., Moran. (2008) **Thermoregulatory model to predict physiological status from ambient environment and heart rate.** *Comput Biol Med* 38: 1187-93.