Prediction of Core Body Temperature, Sweat Rate, Cardiac Output, and Stroke Volume for Firefighters Using a 3D Whole Body Model

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Purpose: This study determines the core body temperature (T_c), sweat rate, cardiac output, and stroke volume for individual firefighters using a computational whole body model. The *hypothesis* of this research is that the heat-induced stress in the firefighters can be determined by the computational model. Inability of the firefighters to dissipate bodily heat during physical exertion caused by firefighting results in an increase of their heat stress levels. Elevated heat stress could lead to a number of health related adverse events, including unconsciousness and cardiac arrest. To prevent these adverse effects, early determination and mitigation of heat stress is critical for firefighters.

Design: The objectives for the project are defined by the following four aims: 1) revise the existing human body model to incorporate the firefighting suit, 2) adapt the existing model to recreate the results of the experimental data, which was collected during the live-burn studies, 3) determine the variations in T_c, sweat rate, cardiac output, and stroke volume during live-burn activities in real time, and 4) inform fire departments of the warning signs that may lead to adverse events when exposed to working in a hot environment.

Methods: The method utilizes two equations simultaneously: a) the Pennes bioheat equation in the whole body, and b) an energy balance equation to determine the change in the blood temperature in relation to the body temperature during a sequence of the firefighting activity. The inputs for the model are the heart rate time series, details of the firefighting suit, the geometry and the physiological details of the individual firefighters. The firefighting data assessed in this study included periodic work and rest periods. T_c obtained from the model (T_{c_comp}) was verified with the experimental variation of T_c ($T_{c\_experimental}$) over time. Various sweat rates were tested to evaluate the experimental data. These sweat rates were expressed as a percentage value of the maximum sweating rate (E_{max}). Additionally, the model also computed the predictive lower and upper T_c bounds ($T_{c\_comp\_lower}$ and $T_{c\_comp\_upper}$), which were obtained by varying each temporal value of the input heart rate time series by -10% and +10%.

Results: The results obtained are: 1) using available data and realistic assumptions, the error between $T_{c\_experimental}$ and T_{c_comp} was computed to be less than 1%, 2) cardiac output varied between 5.6 lit/min – 33.9 lit/min during the combination of firefighting and resting activities, and 3) stroke volume was computed to be between 0.05 lit/beat - 0.31 lit/beat. The reported range of stroke volume is moderately higher when compared with the literature reported values

and is currently under investigation. Additionally, the variation in $T_{c\_experimental}$ was within the predictive bounds of $T_{c\_comp\_lower}$ and $T_{c\_comp\_upper}$.

Conclusion: Utilizing the results of the whole body model, the heat stress and the physical exertion levels can be quantified for firefighters.

Acknowledgement: *This research study was supported by the National Institute for Occupational Safety and Health Targeted Research Training Program of the University of Cincinnati Education and Research Center Grant #T42-OH008432.*

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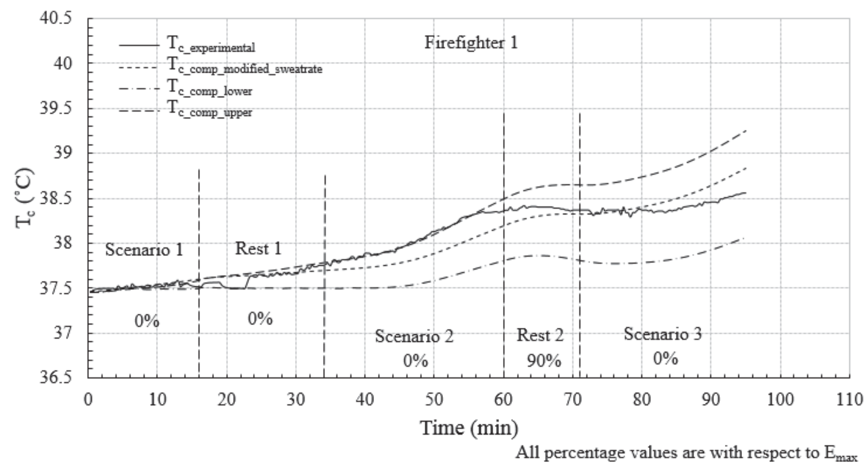

Figure 1: Comparison of $T_{c\_experimental}$ with T_{c_comp}, $T_{c\_comp\_lower}$, and $T_{c\_comp\_upper}$ during a firefighting training drill

University of Cincinnati
15th Annual
Pilot Research Project Symposium
October 9-10, 2014

Hosted by: The University of Cincinnati Education and Research Center
Supported by: The National Institute for Occupational Safety and Health. (NIOSH) Grant #: T42/OH008432

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Produced by Kurt Roberts Department of Environmental Health