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Theoretical bases for a personal heat strain monitor

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THEORETICAL BASES FOR
A PERSONAL HEAT STRAIN MONITOR

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requirements for the award of the degree

Masters of Science (Hons)
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by

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I, Karen Anne Armstrong, declare that this thesis, is submitted in partial fulfilment of the requirements for the award of Master of Science (Hons), in the Department of Biomedical Science, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

________________________________ Date:_______________

Karen Anne Armstrong

ABSTRACT

Heat stress is a major consideration for a wide range of occupations including mining, construction and defence. Traditionally, heat stress equations have been used to identify scenarios likely to cause heat illness, based on the environmental conditions, and estimates of workload. However, as individuals respond differently to the same heat stress, it is often considered more appropriate to directly measure physiological responses (strain) so that behavioural changes may be used to reduce thermal strain. This project aimed to provide a theoretical basis for the development of a personal heat strain monitor, by evaluating a suitable surrogate index of core temperature for use in a working environment.

This index was an insulated skin temperature ($T_{skin\text{-}insul}$), located laterally to the T2-T4 spine. Using linear regression modelling, we have found this $T_{skin\text{-}insul}$ to closely approximate changes in oesophageal temperature (T_{es}). In this research, we applied these regression model to pre-existing data from our laboratory, resulting in 83% of the variance in T_{es} being explained on the basis of $T_{skin\text{-}insul}$, with a standard error of the estimate of 0.15°C on individual trials. With multiple-linear regression analyses using physiological and psychophysical measures as potential predictor variables, the standard error of the estimate fell to 0.10°C. Due to variation in the intercept and slope values, no single prediction equation was able to be derived for all situations, and this technique was considered impractical for use in a commercial monitor.

By combining data collected at the same air temperature, four sets of equations were developed for each of three ambient temperature ranges. The predictor variables in these equations were: (i) $T_{skin\text{-}insul}$ only (simple linear regression modelling); (ii) $T_{skin\text{-}insul}$ and heart rate; (iii) $T_{skin\text{-}insul}$, heart rate, mass and sum of six skinfolds; and (iv) perceived exertion, $T_{skin\text{-}insul}$, mass and sum of six skinfolds. It was possible to predict T_{es} to an acceptable accuracy (standard error of estimate <0.2°C) using $T_{skin\text{-}insul}$, heart rate, body mass and sum of skinfolds in a multiple linear regression analysis.

When these equations were trialed on independent datasets (air temperature ≥30°C), all the equations developed for use in air temperatures of 30-36°C resulted in the standard error of the estimate being >0.2°C. The equations developed on data collected at 40°C had a similarly high error, with the most accurate equation, which utilised only $T_{skin\text{-}insul}$ as a predictor variable, having a standard error of the estimate of 0.05°C above the maximum recommended level. The prediction equations utilising additional variables recorded standard error of the estimate values exceeding twice the recommended maximum level.

These prediction equations were examined in relation to their efficacy for use with industrial heat strain guidelines. The equations developed using $T_{skin\text{-}insul}$, heart rate, mass and sum of six skinfolds were the most accurate equations at measuring a 0.8°C and 1.0°C change in T_{es}, at air temperatures of 30°C and 40°C. The prediction of an T_{es} measurement of 38.0°C and 38.5°C revealed that equations using $T_{skin\text{-}insul}$ as the only predictor variable were most accurate. The equations for use at an air temperature of 36-40°C were considered sufficiently accurate for use in a personal monitoring system, with those developed for 30-36°C deemed to be unsuitable in the present form.

The prediction equations were trialed in two heat strain indices: the Physiological Strain Index and the Cumulative Heat Strain Index. The predicted T_{es} measurement was inserted into these indices. It was found that the prediction equations using $T_{skin\text{-}insul}$ as the only predictor variable in the Physiological Strain Index, created a result that could be considered desirable in the air temperature range of 30-40°C. It was determined that, due to the level of inaccuracy of the equations, it was not possible to use surrogate measures of T_{es} in the Cumulative Heat Strain Index. Future research should primarily focus on reducing $T_{skin\text{-}insul}$ measurement error, with the measurement then being trialed across a broad range of conditions to examine its efficacy for use in a personal monitoring system.

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LIST OF COMMON ABBREVIATIONS

CHSI	Cumulative Heat Strain Index
f_c	Cardiac Frequency / Heart Rate
f_{cmax}	Maximum cardiac frequency
IPE	Index of Physiological Effort
ISO	International Organisation for Standardisation
PSI	Physiological Strain Index
r	Correlation Coefficient
r^2	Proportion of explained variability
RPE	Rating of Perceived Exertion
$S.E.E._y$	Standard error of the estimate
T_a	Air Temperature
T_{es}	Oesophageal Temperature
T_c	Core Temperature
T_{re}	Rectal Temperature
$T_{skin\text{-}insul}$	Insulated Skin Temperature
T_{sk}	Skin Temperature
$\bar{T}_{sk}$	Mean Skin Temperature
$\dot{V}_{02}$	Oxygen Consumption
WBGT	Wet Bulb Globe Temperature