Predicting Uncompensable Heat Stress Using Physiological State

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Heat Balance

Heat Gain
- Metabolic Demands
- Environment

Heat Loss
- Evaporative Cooling
- Clothing / Environment

Levels of Heat Stress

Compensable Heat Stress
- Physiological Stability
- Thermal Balance
- Upper Limit Basis for Exposure Limits

Uncompensable Heat Stress
- Metastable Physiological State
- Heat Storage
Laboratory Model

Find Critical Conditions
- Environment, Metabolic Rate, Clothing
- Upper Limit of Physiological Stability

Data Set
- Participants: 25
- Clothing: 10 Ensembles
- Metabolic Rate: 3 Levels
- Heat Stress: 3 Levels
- Observations: 1461

Comparison to TLV

Question
Can physiological state be used to predict heat stress level?

Measures
- Core Temperature (Tre)
- Heart Rate (HR)
- Average (4 pnt) Skin Temperature (Tsk)
- Physiological Strain Index (PSI)
Heat Stress Level

- Compensable
  - State at the Critical Condition
  - State at 15 min prior to Critical Condition
- Uncompensable
  - State at 15 min after Critical Condition

Brief Lesson in Statistics

Logistical Regression (logit-p)
- Predicted probability of a case

Sensitivity
- Probability that a predicted case is a case

Specificity
- Probability that a predicted non-case is a non-case

Case: Uncompensable Heat Stress

Core Temperature

Tre: Receiver Operating Characteristic (ROC)
Set Threshold(s)

Tre Results

ROC = 0.71
No Effects
- Clothing
- Gender
Thresholds
- Low Threshold: 37.5 °C
- High Threshold: 38.2 °C

HR Results

ROC = 0.77
- Gender: ROC = 0.78
No Effects
- Clothing
Thresholds
- Low Threshold: 100 bpm
- High Threshold: 143 bpm

Skin Temperature
**Tsk Results**

ROC = 0.88

- Gender: ROC = 0.88

**No Effects**

- Clothing

**Thresholds**

- Low Threshold: 35.9 °C
- High Threshold: 37.1 °C

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**Combination**

Combined Factors - logit-p

- Tsk
- HR
- Gender

ROC = 0.90

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**PSI**

Moran, Shitzer and Pandolf

*a priori Combination*

- Core Temperature Range: 36.5 to 39.5
- Heart Rate Range: 60 to 180 bpm
- Nominal Range of 0 to 10

\[
PSI = 5 \left( \frac{Tre - 36.5}{39.5 - 36.5} \right) + 5 \left( \frac{HR - 75}{180 - 75} \right)
\]

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**PSI Results**

ROC = 0.77

- Gender: ROC = 0.78

**No Effects**

- Clothing

**Thresholds**

- Low Threshold: 2.7
- High Threshold: 5.7
What do I think?

Simple Outcomes
- Single Factors
- Little or No Role for Clothing, Metabolic Rate and Gender

Tsk a surprise
HR strong predictor
Excellent Discrimination Elusive