Effects of Hot and Cold Temperature Exposure on Performance: A Meta-Analytic Review

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What is Meta-Analysis?

• Quantitative Approach to Summarize Data Across Research Studies
  – Not the traditional narrative summary
  – Does not count number of statistically significant studies
  – Instead “averages” quantitative outcomes across studies
What Are Quantitative Outcomes? (1)

• Effect Size for each study
  – Difference between means of experimental groups and control group in units of the pooled standard deviation
  – Mathematically:

\[ d = \frac{M_E - M_C}{SD} \]
What Are Quantitative Outcomes? (2)

- Effect Sizes across studies can then be averaged
  - positive d score indicates better performance in experimental group relative to control group
  - Negative d score indicates worse performance relative to control group
What Are Quantitative Outcomes? (3)

- Effect Sizes were computed for three ranges of hot temperatures and two ranges of cold temperatures.
- Effect Sizes were also computed for several moderating variables, including performance measures that are relevant to the tasks performed by locomotive crews.

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Methods in this Meta-Analysis (1)

• Location of Data
  – APA’s PsychInfo literature database
    • Keywords: thermal, temperature, hot, cold, heat
  – *Ergonomics, Human Factors*
  – Identified 527 articles, reports and dissertations published between 1922 and 1997
  – 226 were primary studies of temperature effects on performance
Methods in this Meta-Analysis (2)

• Inclusion Criteria (1)
  – Hot or cold environmental exposure as experimental condition
  – Hot exposure could be quantified as Wet Bulb Globe Temperature (WBGT)
  – Cold exposure included air temperature
  – Studies with exposure by water, clothing, head gear excluded
Methods in this Meta-Analysis (3)

• Inclusion Criteria (2)
  – Neutral temperature ranges within defined limits
    • Hot: 60 – 69.6 EF WGBT
    • Cold: 65 – 75 EF
Methods in this Meta-Analysis (4)

• Inclusion Criteria (3)
  – Each included study reported at least one performance measure
    • Reaction time
    • Attention/Perceptual
    • Mathematical processing
    • Reasoning, learning, memory
Methods in this Meta-Analysis (5)

• Inclusion Criteria (4)
  – Studies using only motor tasks, self-reports and physiological measures were excluded
  – Effect Size capable of computation
    • Mean and Standard Deviation
  – 23 of 226 primary studies met all criteria and were used
Variables Examined (1)

• Type of Temperature Exposure
  – Hot ($70 \, ^{\circ}F \, WBG\text{T}$)
    • Hot1 (70 - 79.9 \, ^{\circ}F \, WBG\text{T})
    • Hot2 (80 - 89.9 \, ^{\circ}F \, WBG\text{T})
    • Hot3 ($90 \, ^{\circ}F \, WBG\text{T}$)
  – Cold (< $65 \, ^{\circ}F$)
    • Cold1 (50 - 64.9 \, ^{\circ}F)
    • Cold2 (< $50 \, ^{\circ}F$)
Variables Examined (2)

- Type of Performance Task
  - Reaction Time
  - Attention/Perceptual
  - Mathematical Processing
  - Reasoning, Learning, Memory
Results (2)

The graph illustrates the percent performance change across different temperatures for various tasks. The tasks include:

- Reaction Time
- Perception, Attention
- Math
- Learning, Memory, Reasoning

The performance change is measured on a scale from -30 to 5, with specific zones for temperature categories:

- < 50
- 70 - 79.9
- > 90

The graph shows how these performance changes vary across different temperature ranges for each task type.
Results (3)

• Hot and Cold Temperatures Cause Decrements in Performance
• The performances affected are all components of tasks performed by locomotive crews in their jobs
  – Attention (Vigilance) / Perceptual
  – Math Processing
  – Reasoning, Learning, Memory
• In the context of accidents, performance decrements are called human errors, unsafe or at-risk behaviors
• Accidents have multiple causes, including human errors (Reason’s “swiss cheese” model)
• Various factors, including temperature, contribute to human errors
Discussion (2)

• In Human Factor accidents, there is at least one identified human error

• There are many more errors or unsafe behaviors than accidents
  – Recognized by Heinrich in 1932
  – Heinrich’s accident triangle

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Discussion (3)

Heinrich’s Accident Triangle

1
Fatality, Serious Injury

29
Minor Injuries

300
Errors, Unsafe Acts, At-Risk Behaviors

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Discussion (4)

• Human Factors accidents (A) are proportional to errors (E)
  – Mathematically: $A \% E$

• Since temperature contributes to an increase in human error, controlling temperature in the cab working environment can reduce errors and accidents:
  
  \[ bA \% bE, \]

  where $b$ is percentage performance effect

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Discussion (5)

- Temperature does not cause all human error
- Only a proportion of E has temperature as a contributing cause, so

\[ cbA \% cbE \]
Potential For Accident Reduction (2)

- Total of 2509 HF accidents
- 1889 occurred in temperatures below 65 $^\circ$F and above 80 $^\circ$F
  - 39% below 50 $^\circ$F; 25% 50 to 65 $^\circ$F
  - 9% 80 to 90$^\circ$F; 3% above 90 $^\circ$F
- Suggests values of c

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Upward boundary: Prevented Accidents per 1000 Human Factors Accidents if Temperatures are maintained between 65 and 80°F.

<table>
<thead>
<tr>
<th>Temperature Range</th>
<th>Performance Decrement (b)</th>
<th>Estimated Proportion in Temperature Range (c)</th>
<th>Human Factors Accidents</th>
<th>Upward boundary; Prevented Accidents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 50°F</td>
<td>0.1391</td>
<td>0.39</td>
<td>1,000</td>
<td>54</td>
</tr>
<tr>
<td>50°F–64.9°F</td>
<td>0.0781</td>
<td>0.25</td>
<td>1,000</td>
<td>19</td>
</tr>
<tr>
<td>80°F–89.9°F WBGT</td>
<td>0.075</td>
<td>0.09</td>
<td>1,000</td>
<td>7</td>
</tr>
<tr>
<td>90°F WBGT and above</td>
<td>0.1488</td>
<td>0.03</td>
<td>1,000</td>
<td>4</td>
</tr>
<tr>
<td>Total Effect</td>
<td></td>
<td></td>
<td></td>
<td>84</td>
</tr>
</tbody>
</table>
Benefit Discount Factors

However, control of temperature extremes is not a relevant countermeasure with respect to many of these accidents, e.g.:

• Many of these train accidents occurred involving existing temperature controlled cabs (*despite* operative heating or air conditioning).

• FRA regulations require the heater maintain at least 50 degrees F.
Benefit Discount Factors

• Many of the accidents in question involved actions by ground crews and non-operating employees, e.g.,
  > Failure to protect the point or secure handbrakes;
  > Switch left reversed.

• Causes other than temperature-related stress can be inferred in some cases.
Review by Office of Safety

• The Office of Safety’s economic analysis was not able to determine a favorable benefit to cost ratio for a rule requiring temperature be controlled within the range 65 degrees F to 86 degrees wet bulb globe temperature.

• Cost involved in ensuring *operative* A/C during hot weather was principal driver.

• Research for the RSAC working group showed that low temperature extremes are readily avoided by maintaining existing heaters (which is generally being done).

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Review by Office of Safety

- Progress was also noted in the equipping of the locomotive fleets with A/C through purchase of new locomotives.

- New integral HVAC has higher reliability than earlier equipment.

- Conclusion: Based on available, quantifiable information, FRA is not able to support regulatory action as the appropriate strategy at this time.

- Note: An important factor here is the difficulty of putting numbers on non-safety benefits.
Application of Lessons from Research

• Temperature extremes do degrade performance (it’s not just a comfort issue).

• This is of particular concern for railroad operating employees, due to the duration of exposure, often irregular and unpredictable work cycles, and other sources of fatigue.

• Research should reinforce the railroads’ commitment to sound working conditions, which should also foster employee retention, morale, and productivity.

• Underscores the need for joint planning in connection with shared power agreements so that effective temperature control is provided where needed.
Questions

• Thanks for your attention.

• Questions?