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

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Office of Research and Development

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# Acknowledgements

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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

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# 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:

$$d = (M_E - M_C)/SD$$

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# 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

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# 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

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# 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

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# 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

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# 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

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# 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

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# Variables Examined (1)

- Type of Temperature Exposure
  - Hot ($ 70 °F WBGT)
    - Hot1 (70 - 79.9 °F WBGT)
    - Hot2 (80 - 89.9 °F WBGT)
    - Hot3 ($ 90 °F WBGT)
  - Cold (< 65 °F)
    - Cold1 (50 - 64.9 °F)
    - Cold2 (< 50 °F)

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# Variables Examined (2)

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

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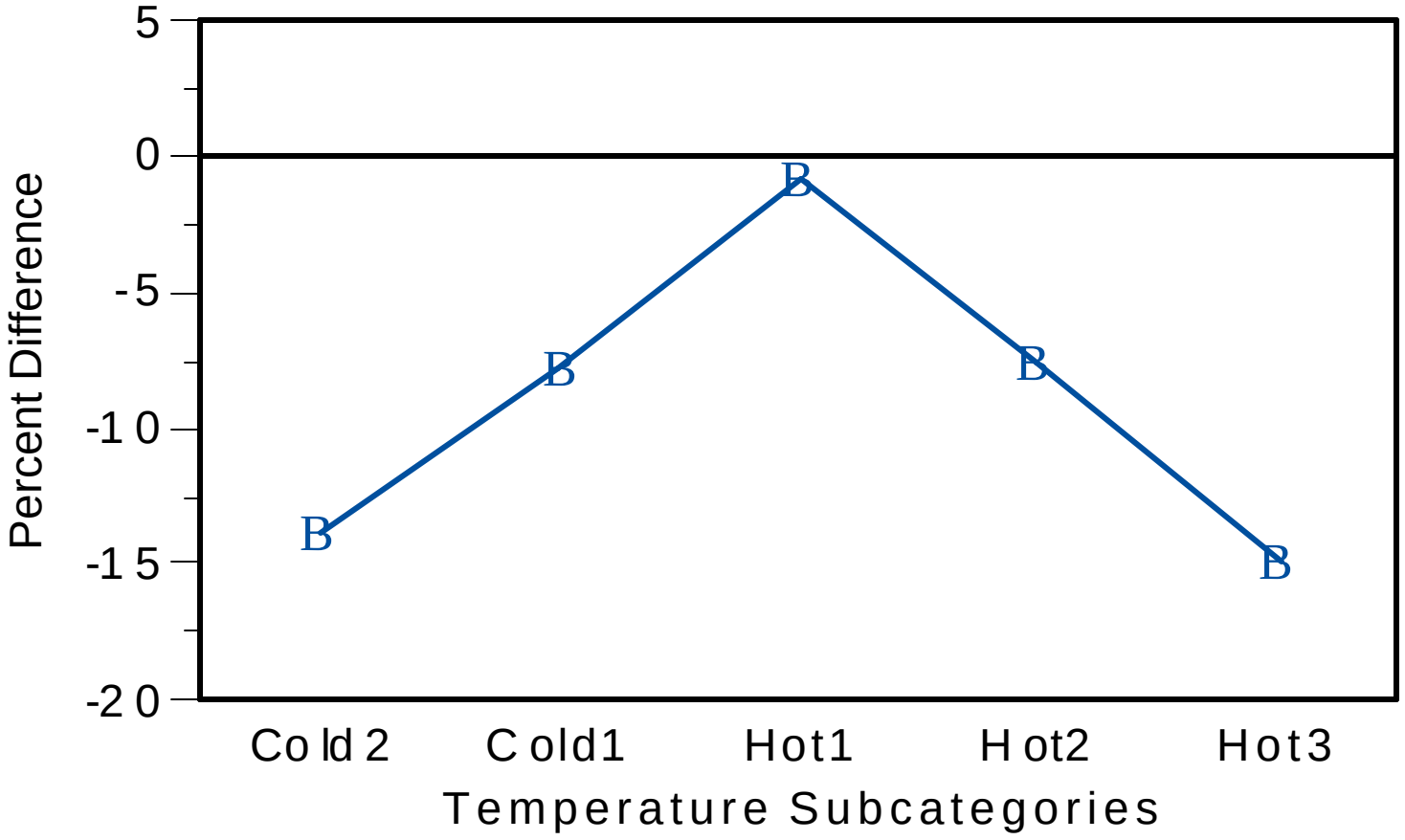
# Results (1)

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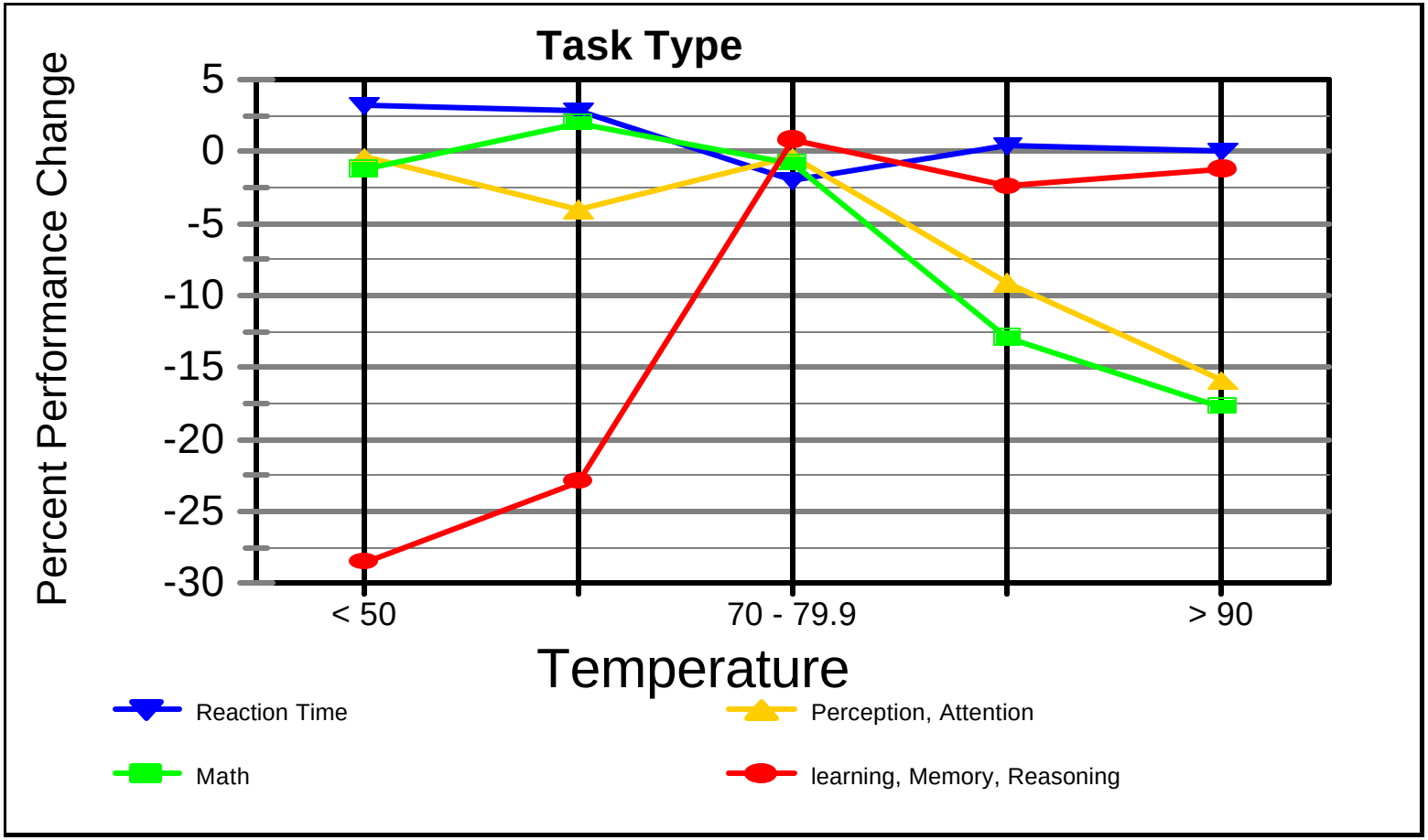
# Results (2)

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# 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

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# Discussion (1)

- 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

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# 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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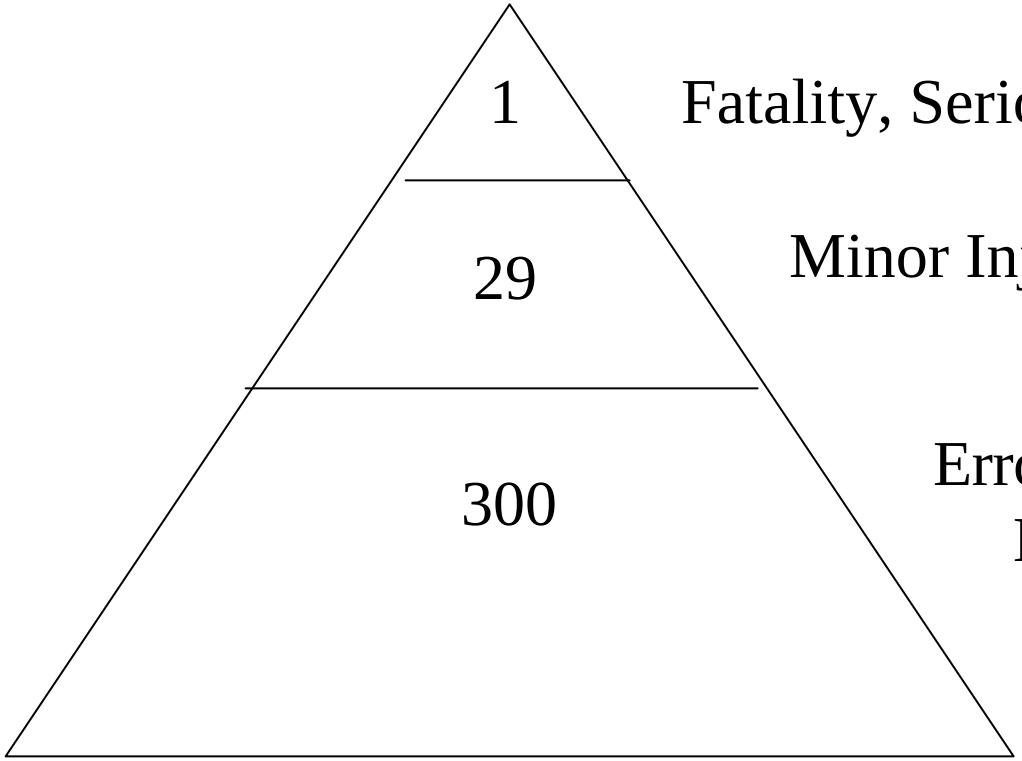
# Discussion (3)

## Heinrich's Accident Triangle




Fatality, Serious Injury

Minor Injuries

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

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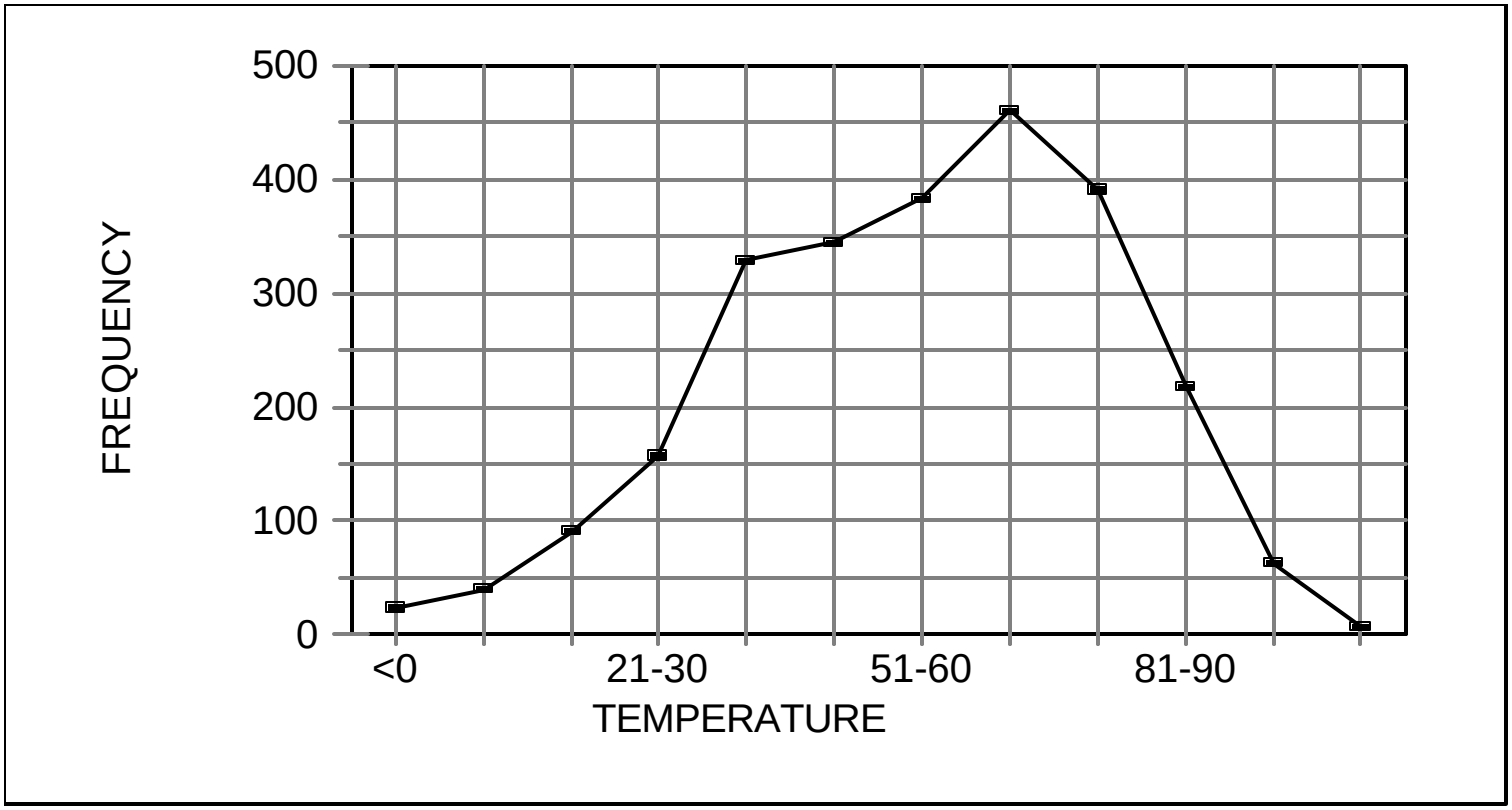
# Potential For Accident Reduction (1)

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# Potential For Accident Reduction (2)

- Human Factors accidents, 1992-1997
- Total of 2509 HF accidents
- 1889 occurred in temperatures below 65 EF and above 80 EF
  - 39% below 50 EF; 25% 50 to 65 EF
  - 9% 80 to 90EF; 3% above 90 EF
- Suggests values of c

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# Potential For Accident Reduction (3)

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

| Temperature Range | Performance Decrement (b) | Estimated Proportion in Temperature Range (c) | Human Factors Accidents | Upward boundary; Prevented Accidents |
|---|---|---|---|---|
| Below 50°F | .1391 | .39 | 1,000 | 54 |
| 50°F - 64.9°F | .0781 | .25 | 1,000 | 19 |
| 80°F – 89.9°F WBGT | .075 | .09 | 1,000 | 7 |
| 90°F WBGT and above | .1488 | .03 | 1,000 | 4 |
| Total Effect | | | | 84 |

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# 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.

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# 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.

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# 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 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.

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# 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.

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# Questions

- Thanks for your attention.
- Questions?