
# Sleep Quality in the Context of Operational Fatigue Modeling

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# Presentation Overview

1. **What is Sleep Quality?**
   - Definitions
   - Methods of Measurement
   - Modeling Sleep Quality

2. **Impact of Sleep Quality on Performance**

3. **Influences on Sleep Quality**
   - Demographics
   - Transmeridian Travel
   - Sleep Environment
   - Shift Work

4. **Incorporating Sleep Quality into the Fatigue Model**
   - Inputs
   - Issues
   - Next Steps



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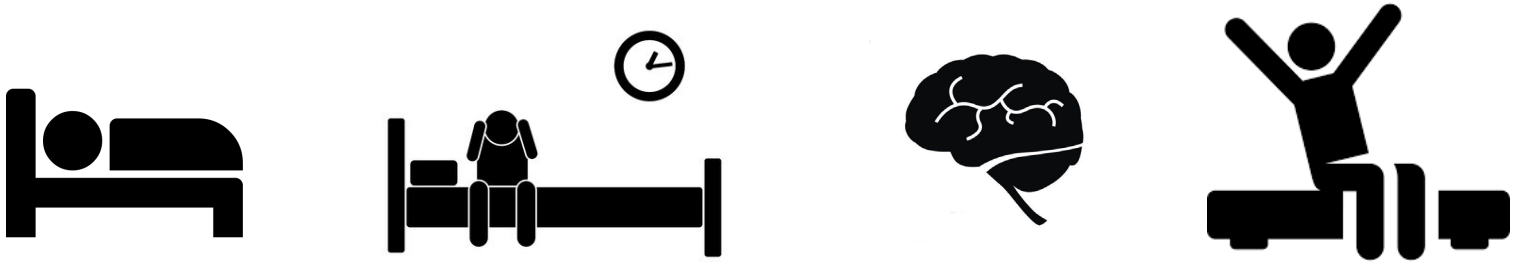
# What is Sleep Quality?

**General Definition:**

- A clinical construct representing a complex phenomenon which includes quantitative aspects of sleep such as latency or number of arousals as well as subjective aspects such as restfulness or satisfaction *(Buysse et al. 1989)*



**Model Definition:**

- Sleep features which are known to be predictably altered in response to situational factors (i.e., the operational environment) in a manner which decreases the effectiveness of sleep to protect against fatigue as measured by psychomotor vigilance task (PVT) reaction speed.

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# Measures of Sleep Quality


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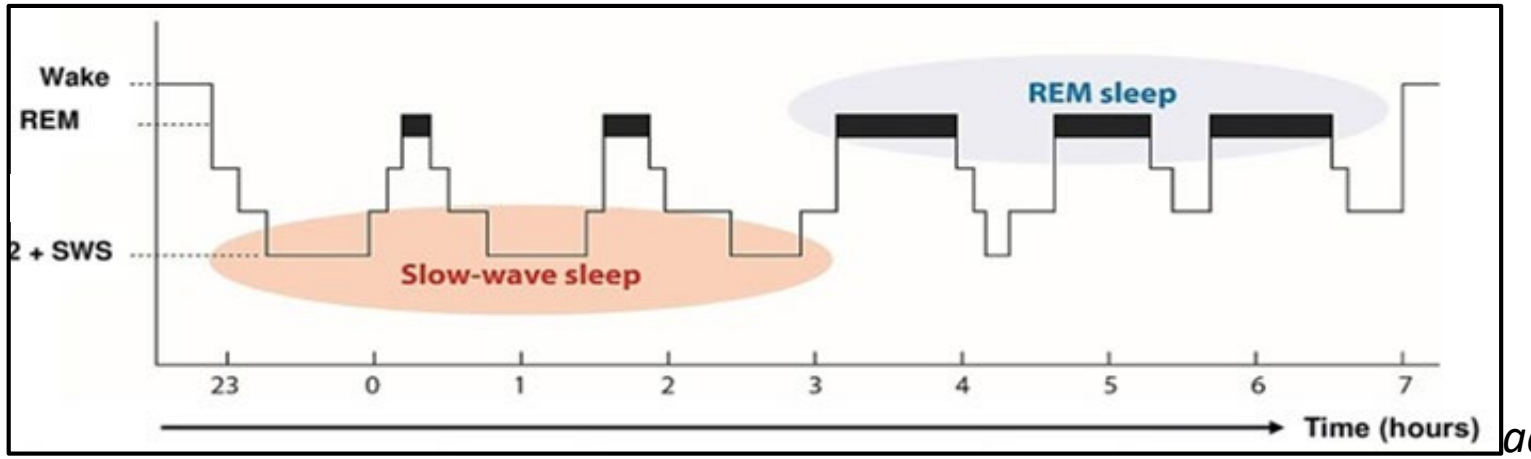
# Measuring Sleep Quality

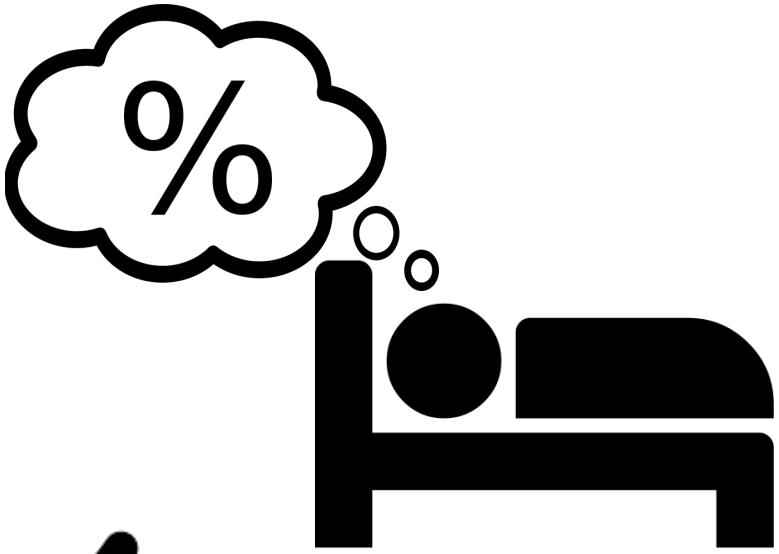
1. **Sleep Architecture**
   - Basic pattern of brain activity during sleep
     - Light Sleep: Stage 1 and 2
     - Deep Sleep: Slow Wave Sleep (SWS)
     - Rapid Eye Movement (REM)
   - ↑ sleep time ⟶ ↓ SWS & ↑ REM




*adapted from Cross et al. 2018*

   - **SWS-heavy sleep is more beneficial for PVT performance than REM-heavy sleep** ***(Wu et al. 2010)***

# Measuring Sleep Quality




**2. Sleep Efficiency (SE)**

- Ratio of total sleep time (TST) over total time spent in bed (TIB)
- Incorporates other measures of sleep quality
  - Sleep Onset Latency (SOL)
  - Sleep Fragmentation/Wake After Sleep Onset (WASO)/Arousals

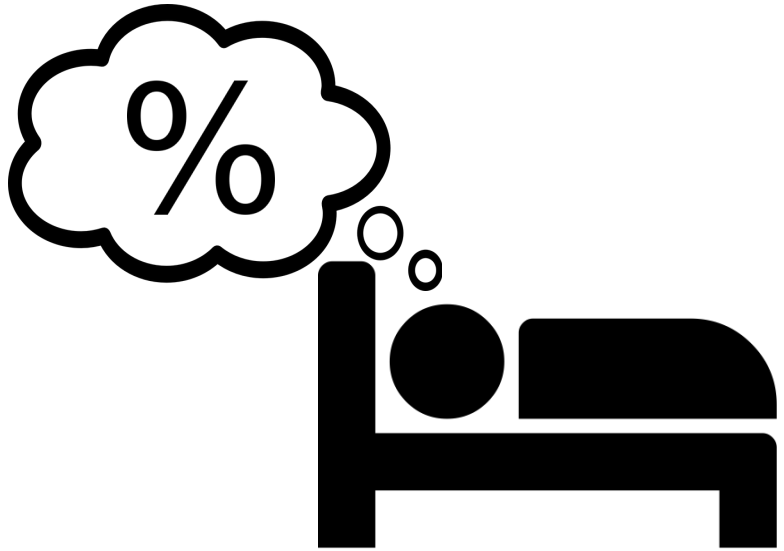
**3. Subjective Sleep Quality (SQ)**

- Satisfaction with the recuperative value of one's own sleep
- Often correlates closely to objective measures

# Modeling a Measure of Sleep Quality

**Requirements:**

- Robust proxy for sleep quality in general
- Can be conceptualized mathematically
- Predictably altered by situational factors
  - Can be estimated from work schedules
- Relationship to performance can be reliably estimated




**Best Option: Sleep Efficiency**

- **"Sleep efficiency is recommended for monitoring sleep quality due to its small level of instability and moderate effect size." (*Claudino et al. 2018).***

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# Impact of Sleep Quality on Performance


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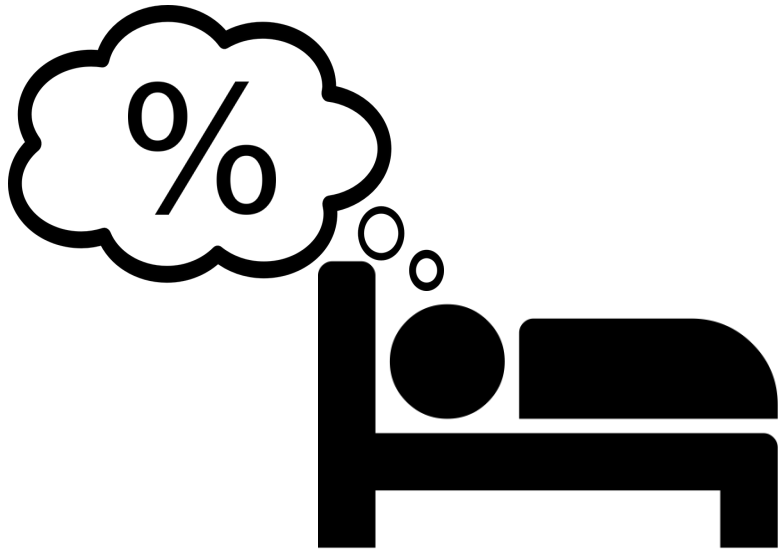
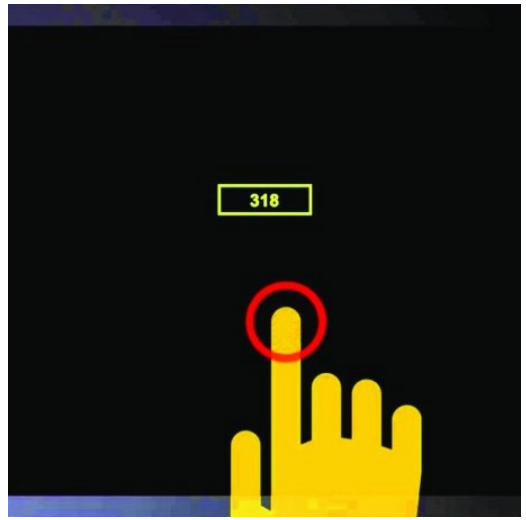
# Impact of Sleep Quality on Performance



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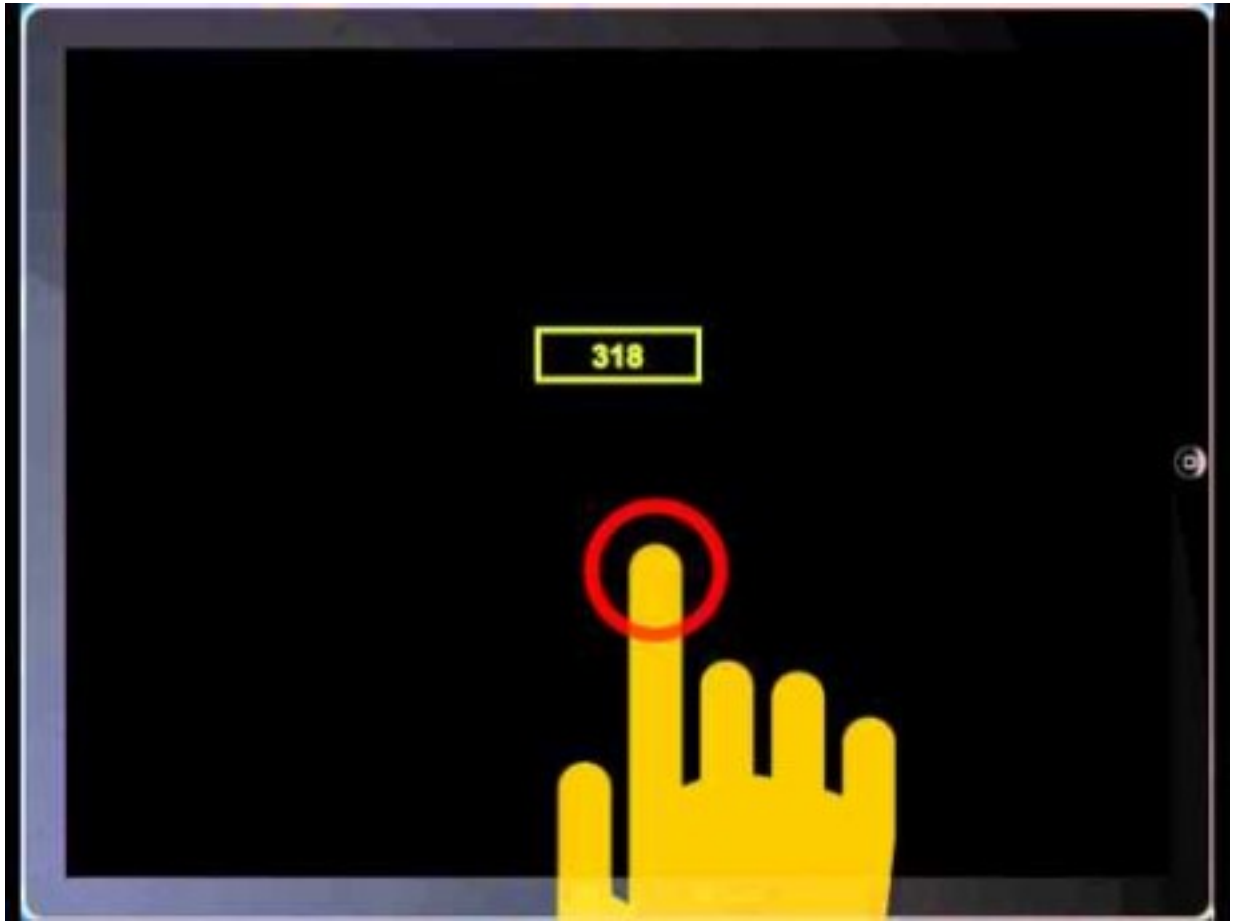
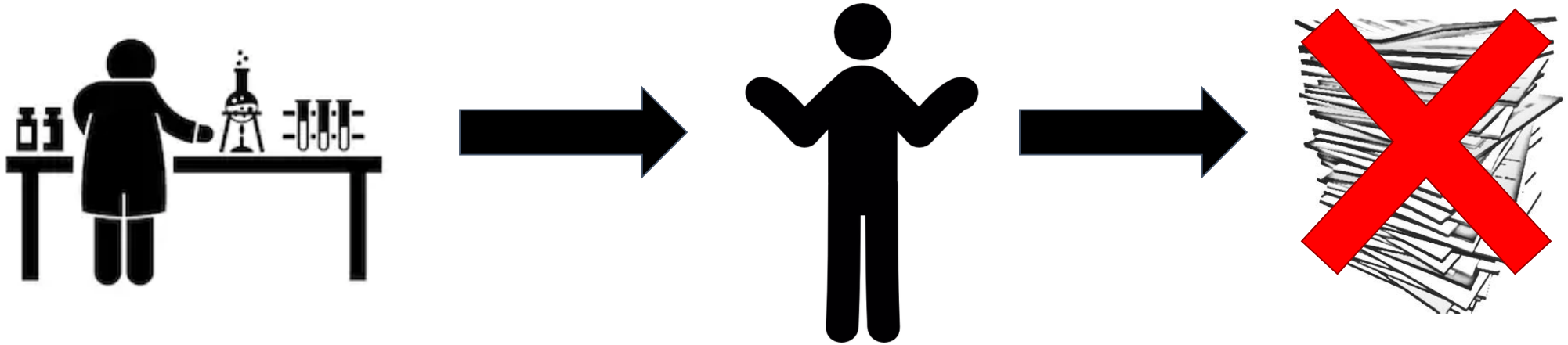
# Psychomotor Vigilance Task (PVT)



# Sleep Efficiency and PVT Performance

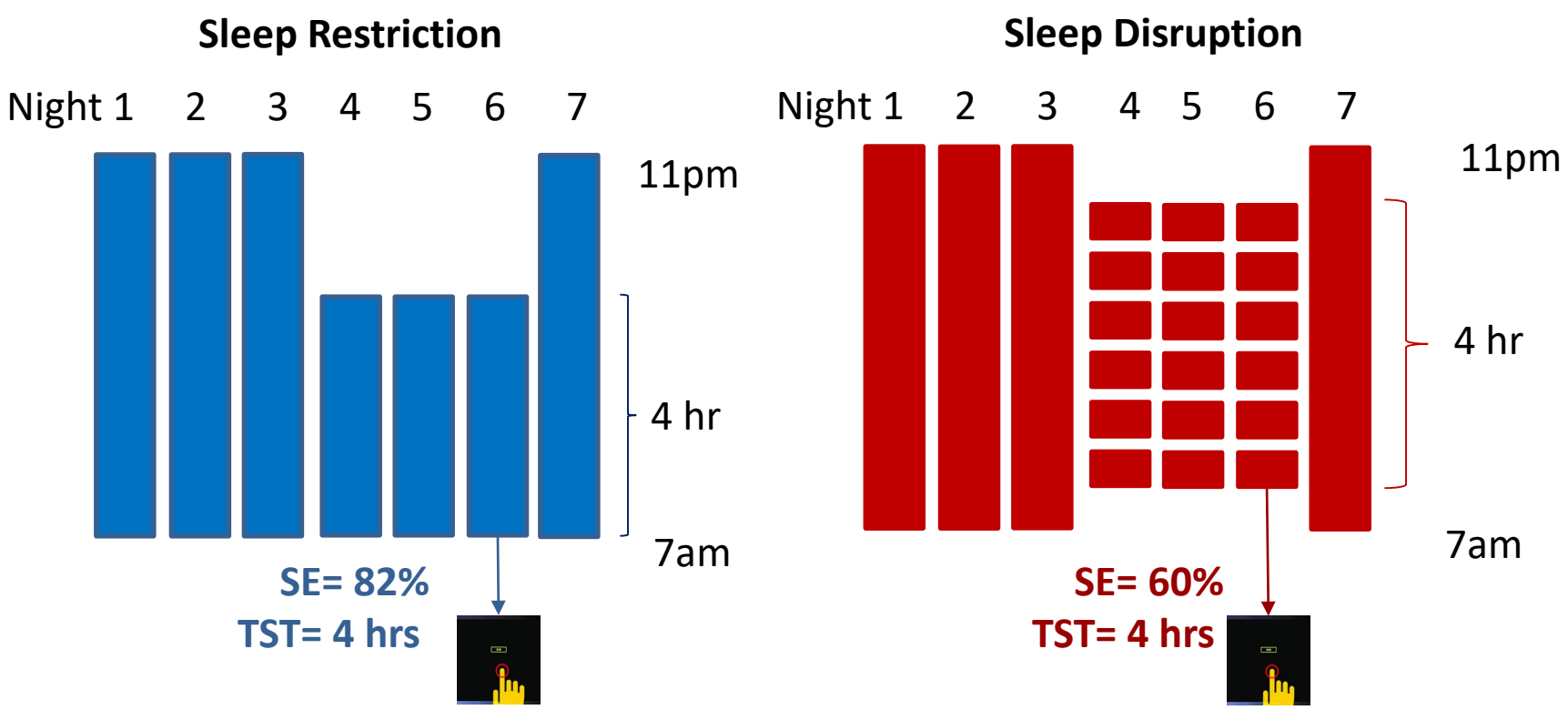
**Issue**

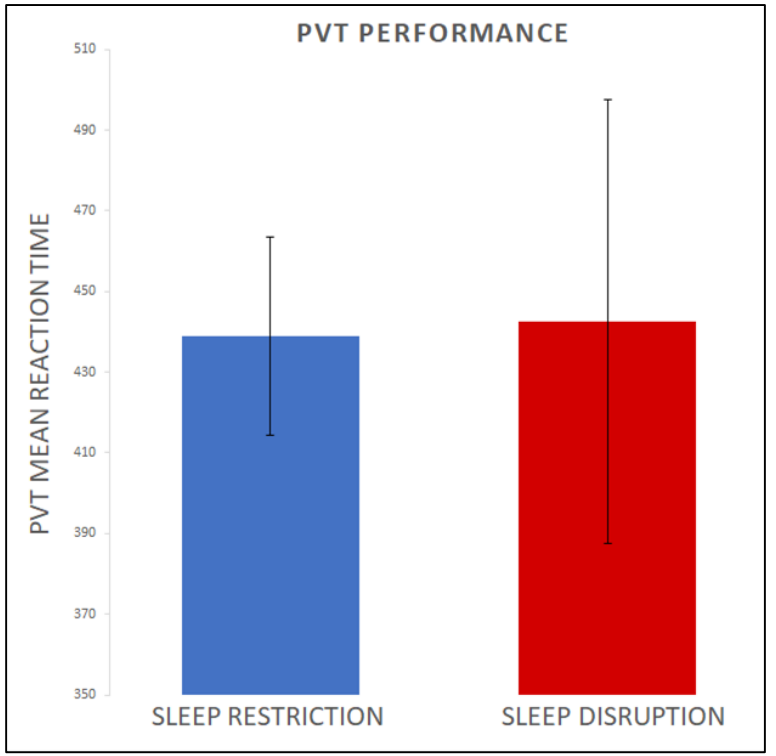
- Sparse literature
- No direct investigations of SE and PVT, controlling for duration (TST) and/or sleep architecture (SWS)



# Unpublished Data from BIDMC Sleep Lab

**Effects of Experimental Sleep Restriction versus Sleep Disruption**



# Sleep Efficiency and PVT Performance

**Issue**

- Sparse literature
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**Resolution**

- Rely on established pathways through which SE impacts PVT

↓ SE ⟶ ↓ TST ⟶ ↓ PVT performance *(Bonnet 1987, Gillberg and Åkerstedt 1994, Jewett et al. 1999, Stepanski 2002, Bonnet and Arand 2003, Insana et al. 2011, Basner and Dinges 2011)*

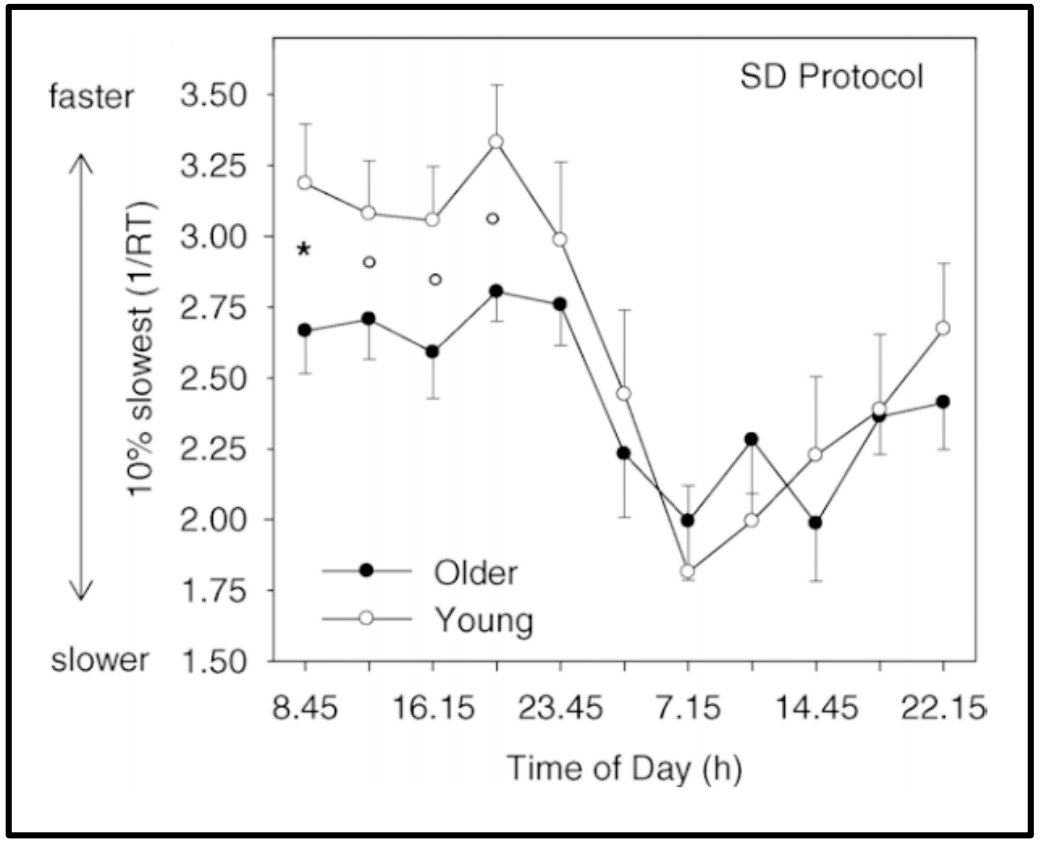
↓ SE ⟶ ↓ SWS ⟶ ↓ PVT performance *(Gillberg and Åkerstedt 1994, Jewett et al. 1999, Walsh et al. 2006, Wu et al. 2010)*



# Influences on Sleep Quality

# Influences on Sleep Quality

1. **Demographics**
   - Age
     - SE decreases steadily with age *(Ohayon et al 2004; Moraes et al. 2014)*
     - **No influence on SE and PVT performance** *(Blatter et al. 2006; Smulders et al. 1997; Adam et al. 2006)*
   - Gender
     - Women have better SE than men *(Mong et al. 2016; Mallampalli et al. 2014)*
       - But report worse SE *(Mallampalli et al 2014)*
     - **No influence on SE and PVT performance** *(Blatter et al. 2006; Beijamini et al. 2008)*
   - No general predictive rules from demographics



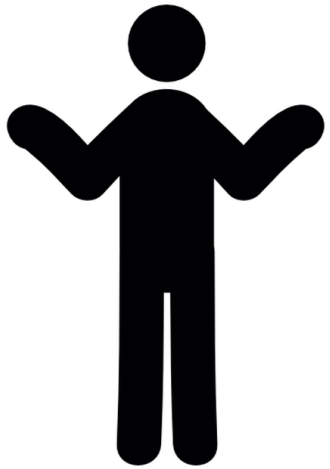

*Blatter et al. 2006*

# Influences on Sleep Quality

**2. Transmeridian Travel**

- Direction
  - Eastbound travel is related to worse sleep and jet lag *(Shon et al. 2016; Orth-Gomer 1983; Fowler et al. 2017)*
    - Delayed sleep onset
    - Disruption during the 1st half of sleep → **SWS-heavy sleep**

- Time Zone Changes
  - Δ Time zones ⟶ ↓ SQ *(Waterhouse et al. 2002; Rosekind et al. 1987; Fowler et al. 2014; Lowden and Akerstedt 1999; Roma et al. 2010)*
    - Δ SE is often not statistically significant
    - Non-significant results are often not reported
  - SE returns to baseline upon return home *(Gander et al. 2013)*



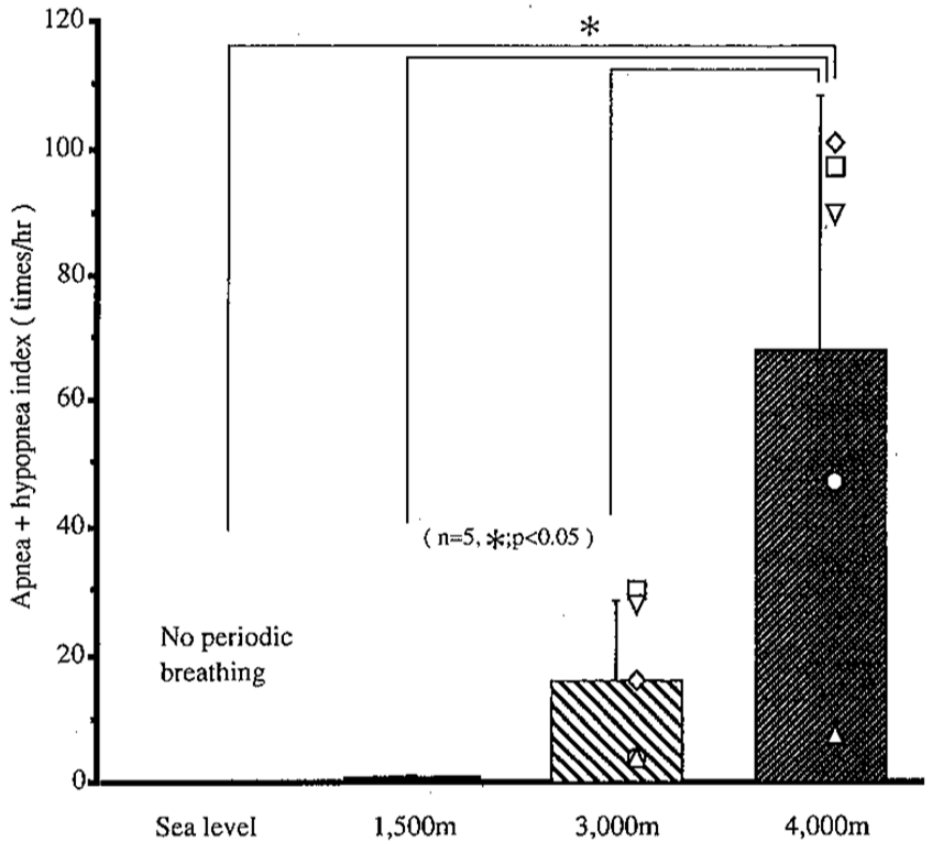
# Influences on Sleep Quality

**3. Sleep Environment**

- First Night Effect *(Coates et al. 1981, Curcio 2004, Kader 1983, Sharpley 1988, Toussaint 1995)*
  - ↓ SE
  - Resolves by the second night

- High Altitude (HA: >4000 m above sea level)
  - ↓ SE due to ↑ Apnea/Hypoxia Index (AHI)
    - AHI≥5 is criteria for sleep apnea
    - AHI≥30 is criteria for severe sleep apnea
  - Can adapt to HA *(Pun et al. 2018)*

  - Moderate HA (~2500m) effects on SE and PVT may be non-significant (*Muhm et al. 2009; Mizuno et al. 1993)*

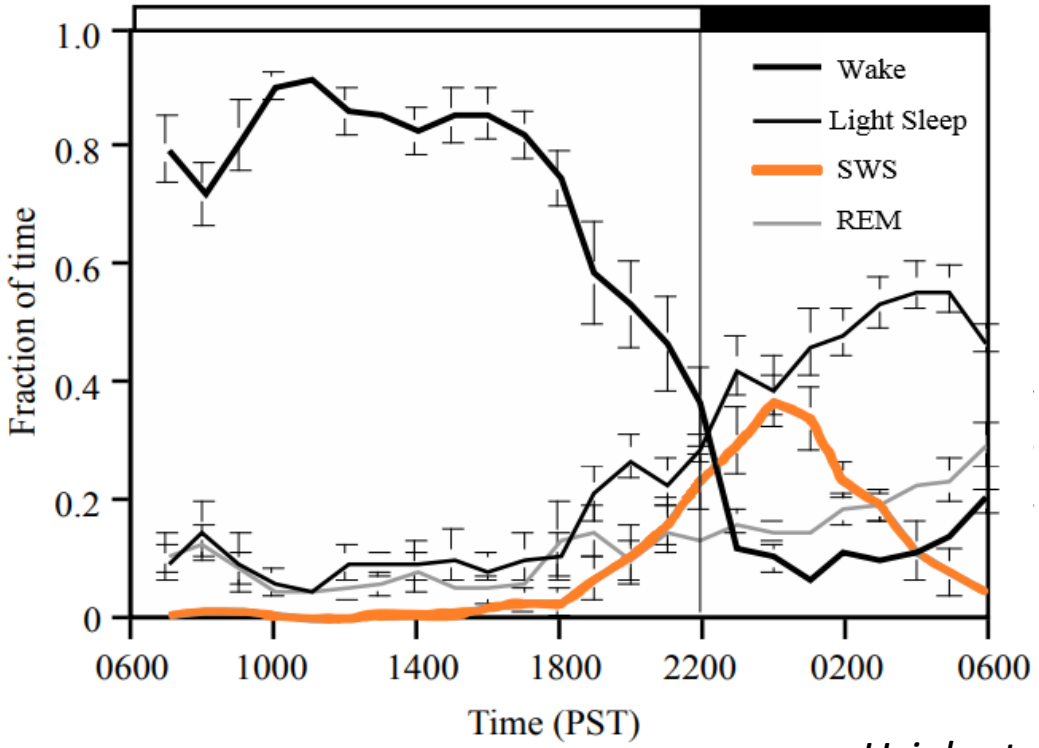



*Mizuno et al. 1993*

# Influences on Sleep Quality

**4. Shift Work**

- SE does not seem to be greatly affected by shift work *(Lamond et al. 2001, Bjorvatn et al. 2006, Vijaykumar et al. 2018)*
- PVT is affected by shift work *(Bjorvatn et al. 2006)*
- Circadian Misalignment
  - Accounted for in the SAFTE model
  - Can realign
    *(Lamond et al. 2001, Postnova et al. 2014)*
  - Sleep architecture fluctuates by time of day
    - ↓ SWS during daytime hours

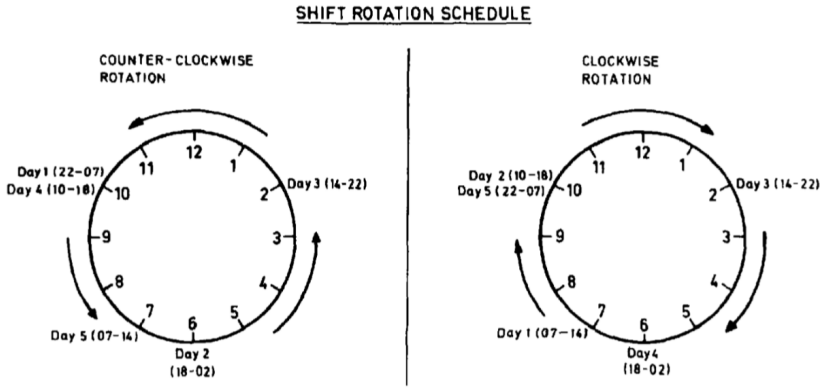



*Hsieh et al. 2008*

# Influences on Sleep Quality

**4. Shift Work**

- Rotating Shifts
  - Shorter rotation intervals ⟶ ↓ SQ *(Postnova et al. 2014, Kim et al. 2015, Harma et al. 2007)*
  - Counter-clockwise/Backward rotation (night to evening to morning) ⟶ ↓ SQ *(Orth-Gomer 1983, Shon et al 2016, Amelsvoort et al 2004)*
  - Lack of studies investigating objective SE and PVT performance in relation to shift rotation speed or direction




# Influences on Sleep Quality Summary

**1. Demographics**

- No general predictive rules

**2. Transmeridian Travel**

- Eastbound travel: ↓ SWS ⟶ ↓PVT performance
- Δ Time zones: ↓ SQ but… ? SE

**3. Sleep Environment**

- First night: ↓ SE ⟶ ↓PVT performance
- High Altitude (>4000m): ↓ SE ⟶ ↓PVT performance

**4. Shift Work**

- Circadian Misalignment/Sleep Timing: ↓ SWS ⟶ ↓PVT performance
- Rotation speed: ↓ SQ but… ? SE
- Backwards rotation: ↓ SQ but… ? SE

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# Incorporating Sleep Quality into the Fatigue Model


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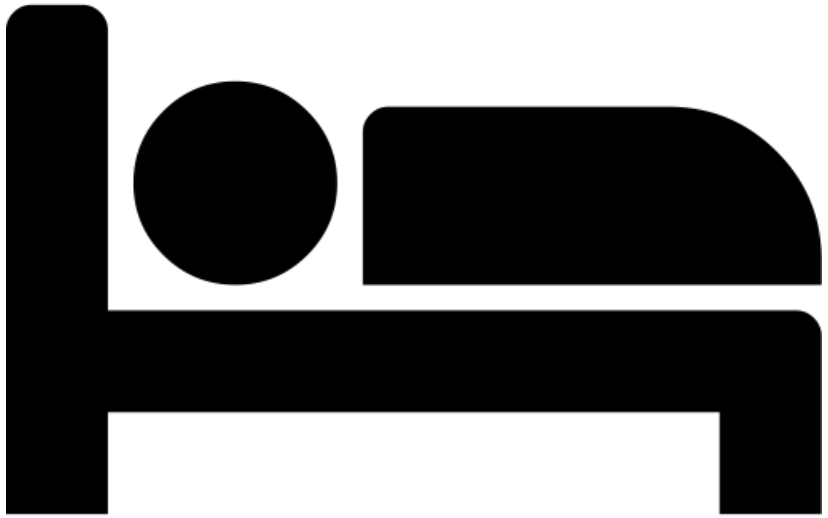
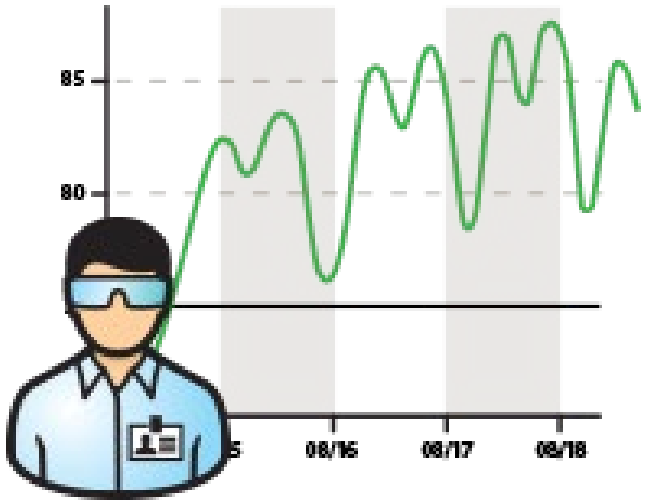
# Sleep Inputs to Fatigue Model

↑ Sleep Duration → ↑ Reservoir → ↑ Effectiveness



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# Sleep Quality Inputs to Fatigue Model

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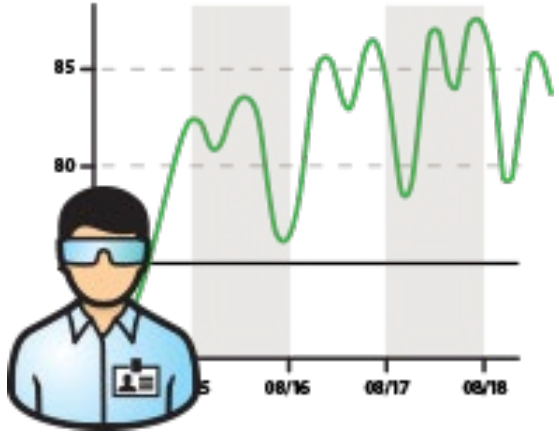



↕ Rate of Repletion

# Issues with Modeling Sleep Quality

1. **Lack of robust interaction data, i.e., concrete numbers**
   - SE across time zone changes
   - SE in relation to shift rotation speed and direction

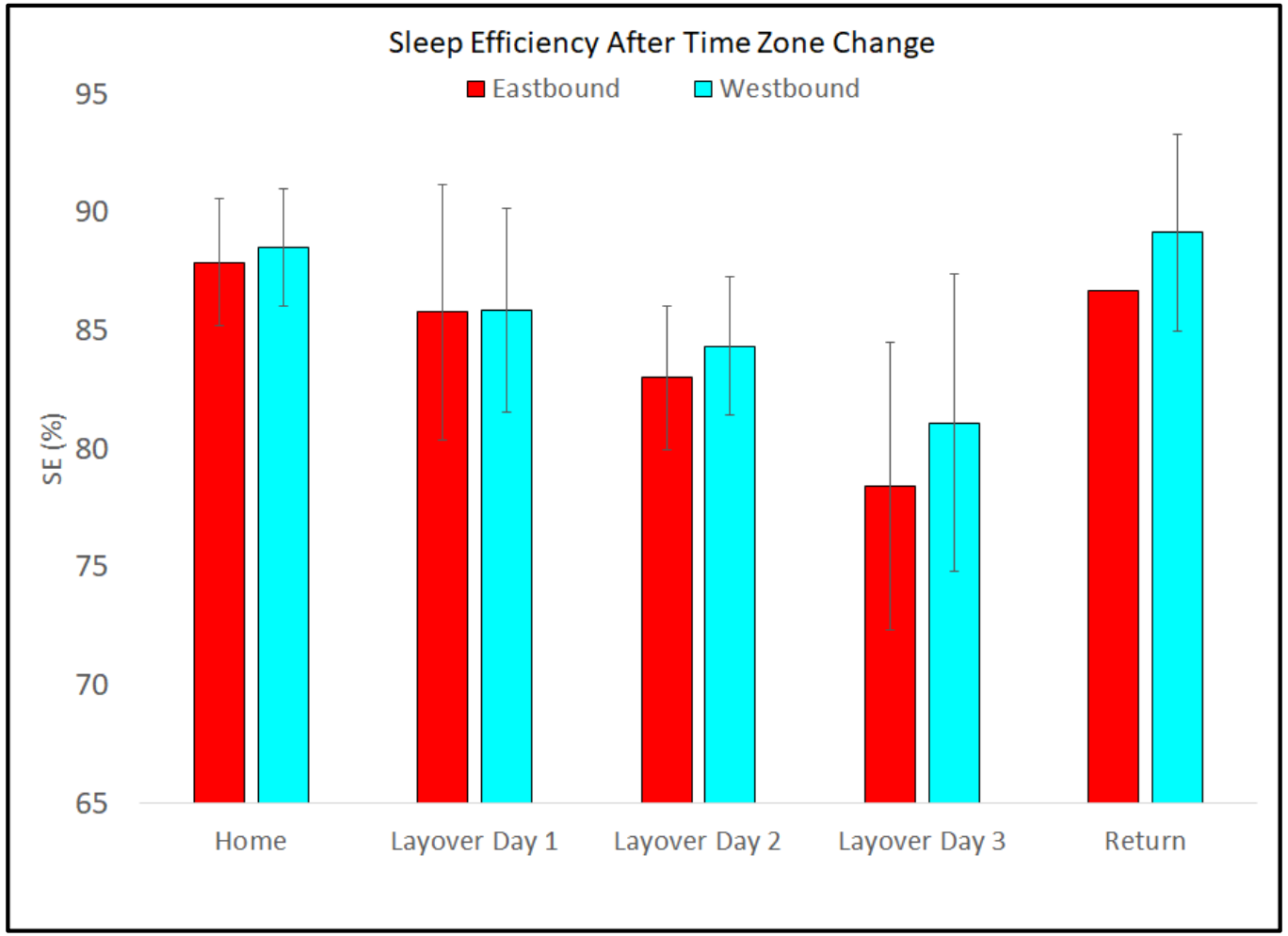
2. **Inter-individual variability**
   - Cannot predict resilience to sleep loss or compensatory behaviors

3. **Potential impact of stress and workload**
   - SQ is related to work-related stress
   - Cannot predict who will feel stress

4. **Mood**
   - SQ is related to mood, which can influence performance
   - Cannot predict crankiness



# Quantifying the Effects of Transmeridian Travel on SE




*Preliminary compiled data: Gander et al. 2013; Rosekind et al. 1987; Lowden 1999; Fowler 2017*

# Next Steps

**Data Requirements**

- Objective measure of sleep: Actigraphy or PSG
- Objective measure of performance: PVT

**Sources**

- Existing literature: meta-analysis
- Open source data mining
- Existing datasets from industry
- New studies and collaborations

**End Goal**

- More accurate model of sleep and performance
- Harmonization of model to actual data



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# Questions?

## Conclusion of Presentation