Translating Fatigue Research into Technologic Countermeasures

David A. Lombardi, PhD
Principal Research Scientist
Center for Injury Epidemiology,
Liberty Mutual Research Institute for Safety

Co-Director, Occupational Injury Prevention Research Training Program (OIPRT)
Harvard Education and Research Center (ERC)

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Learning Objectives

1. Participants will be able to demonstrate an understanding of a conceptual model of fatigue and implications on safety.

2. Participants will be able to understand approaches to mitigate workplace fatigue, including basic attributes, challenges and opportunities of technical countermeasures.

3. Participants will understand the various measures of fatigue that include physiological, behavioral, subjective self-report and performance measures.

4. Participants will be able to explain Haddon’s Matrix and how it relates to technological countermeasures.
“Fatigue is a biological drive for recuperative rest”

- Time of day
- Time/seconds awake
- Task-related factors

Fatigue

Sleepiness

Rest

• Sleep homeostasis

Impaired Performance Capabilities

- Slowed reaction times
- Lapses of attention
- Errors of omission
- Compromised problem solving ability

Trends in Sleep Duration in the US

- Percentage of Adults Aged >18 Years Who Reported an Average of <6 Hours of Sleep per 24-Hour Period, by Sex and Age Group --- National Health Interview Survey, United States, 1985 and 2006

Source: MMWR, February 29, 2008 / 57(08);209.
Self-perception of Sleepiness

Measurement

Subjective-
Epworth
Sleepiness
Scale

Objective-
Multiple Sleep
Latency Test

Source: Drake CL, Roehrs TA, Richardson GS, Roth T. Epidemiology and morbidity of excessive daytime sleepiness. Sleep. 2002; A124.I.
Preventing and Managing Fatigue

• Can operator (e.g., driver, pilot, conductor etc.) fatigue be prevented or effectively managed to significantly reduce "accident" or performance error risk?
Approaches to Mitigate Workplace Fatigue

Low Tech

- Industry standards and best practices (e.g. ACGME)
- Regulatory (Gander et al., 2011)
  - Hours of service regulations
    - FAA: regulations for domestic flights generally limit pilots to eight hours of flight time during a 24-hour period
    - FMCSA: CMV 11-Hour Driving Limit, May drive a maximum of 11 hours after 10 consecutive hours off duty...
- Organizational (Folkard and Lombardi, 2006)
  - Designing safer work and “break” schedules (e.g. “risk index” models)
- Technological (Balkin et al., 2011)
  - Approaches in which “objectively detect or predict operator fatigue” used to complement or supplant organizational or regulatory approaches
The State of Fatigue Interventions

• “The scientific understanding of fatigue, sleep, shift work, and circadian physiology has advanced significantly over the past several decades, current regulations and industry practices have in large part failed to adequately incorporate the new knowledge.”

(Dinges, 1996, Caldwell et al., 2009)
Technological Countermeasures

- Frequently prescribed as countermeasures for fatigue in:
  - Road transport – Truck drivers
  - Aviation – Pilots, Air traffic controllers, security personnel
  - Maritime - Seafarers
  - Railway - Conductors
  - Aerospace- Astronauts
  - Plant operations – Nuclear plants
Technological Approaches (Balkin et al., 2011)

Ideally includes:

1. Ability to predict fatigue
   – based on the factors that produce it (i.e., take into consideration sleep patterns and circadian rhythm)
   – prior to any impact on operational performance (i.e., safety and productivity)

Technological Approaches (Balkin et al., 2011)

2. Can measure and monitor fatigue/performance online in the operational environment
   – as a backup and check of the performance prediction model

3. Can effectively intervene when potential deficits are identified or anticipated
   – with interventions calibrated to restore and sustain alertness/performance as long as needed
     » until operator can obtain adequate recuperative rest
Ideal fatigue-detection system (Dinges and Mallis, 2008)

Should be:

• Valid
• Reliable
• Sensitive (detect fatigue) and specific (minimize false negatives)
• Generalizable

• “Assessments of these criteria should be done in the actual operational environment”

  – Most fatigue-detection technologies unproven in real world situations (Brown, 1997, Balkin et al., 2011), with rare exceptions (Dinges et al., 2005)
“Measurement focuses on the crucial relationship between the empirically grounded indicator (i.e., the observable response) and the underlying unobservable concept” (Carmines & Zeller, 1979)

Ideal fatigue-detection systems

Hancock and Verwey (1997) propose that,:

- “Automated systems need to exhibit different types and levels of adaptation, so as to facilitate application to a wide sample of users”
  - should follow design guidelines, based on knowledge of human capabilities and limitations (e.g., static adaptation)
  - should take into account the effects of dynamic, external variables on the average operator (e.g. generalized dynamic adaptation)
  - should take into account the capabilities and limitations of the current operator (e.g. idiosyncratic dynamic adaptation)

Technological Countermeasures

Other challenges:

• Human–automation interaction requires user acceptance and compliance (Balkin et al., 2011)

• In real life?
  • “...nearly half of the surveyed truck drivers expressed a negative view towards developing a technological countermeasure against driver fatigue. The negative view was not related to personal experiences of fatigue-related problems while driving.” (Häkkinen et al., 2001)
Overview: Measurements of Fatigue

Types of fatigue measures:

1. Physiological Measures
2. Behavioral Measures
3. Self-Report Measures (subjective)
4. Performance Measures

“Primarily designed to be used in the laboratory and have varying levels of utility in the workplace.” (Sherry, 2000)

Overview of fatigue monitoring and detection approaches

Operator-centered approaches (Dinges et al., 1998, Balkin et al. 2001)

• Readiness-to-perform and fitness-for-duty technologies (e.g., PVT, OSPAT, Fit 2000, ART90, etc.)

Primary question: Does the operator have sufficient alertness prior to a work cycle?

– **Performance-based**: directly measures the cognitive processes and motor skills required for a specific safety-sensitive job

– **Physiological-based**: assess involuntary signs that stressors may produce due to their effect on the brain

  » “ability to process afferent impulses and generate appropriate involuntary efferent output”
Overview of fatigue monitoring and detection approaches

Operator-centered approaches (Dinges et al., 1998, Balkin et al. 2001)

- Online operator monitoring technologies
- Primary question: Does the operator have sufficient alertness during the work cycle?
  - EEG based algorithms (measuring brain wave activity, e.g., increases in alpha, beta, delta and theta waves)
  - Ocular (PERCLOS, MOMS, examines percent eye closure, measures of saccadic velocity, pupillometrics, see Dinges 1998 and 2005)
  - Actigraphy (reliable in estimating sleep/wake timing and duration for fatigue/prediction models, but not direct monitoring)
  - Video based (currently used to identify fatigue as a factor in triggering and event post-hoc with low real-time predictive ability)
Overview of fatigue monitoring and detection approaches

Operator-centered approaches (Dinges et al., 1998, Balkin et al. 2001)

- Performance-based monitoring technologies
  - a proxy for fatigue that identify behaviors and performance that may lead to unsafe conditions
    » lane tracking performance
    » reaction time changes
  - Limitations, subject to false alarms

- Biomathematical models of fatigue/alertness
  - Primary question: Is the structure of the operators work schedule maximized to be the safest possible, based upon known factors about the operator, environment, and tasks
Brief overview of biomathematical models of alertness and fatigue

• Useful in the prediction of performance or effectiveness levels when comparing different operational schedules (Mallis et al., 2004; Dinges et al., 2004)

• Used as support tools within Fatigue Risk Management Systems (FRMS)
  – Two process model, Three-process models
  – SAFE (System for Aircrew Fatigue Evaluation) model: developed for aviation operations
  – Sleep, Activity and Fatigue Task Effectiveness (SAFTE) model: developed for military and industrial settings
  – Fatigue Avoidance Scheduling Tool (FAST): designed to help optimize the operational management of aviation ground and flight crew
  – Interactive Neurobehavioral Models
  – Faid Model, CAS Model
  – “Risk Index” Model
Criteria in Evaluating Technical Countermeasures (Barr et al., 2009)

• Scientific and Engineering Guidelines
  – Environmental: does the technology operate accurately and reliably in real world conditions (lighting, temperature, humidity, vibration, etc.)?
  – Reliability and Validity: does the technology have positive and negative predictive value, sensitivity and specificity?
  – Anthropometric: can the technology be generalized across a broad range of users?
  – Engineering Design: how much maintenance does the technology require?
Criteria in Evaluating Technical Countermeasures
(Barr et al., 2009)

• User Acceptance Elements
  – Ease of Use: does the technology operate in real time, is it invasive, does it accommodate eyewear, provide a sufficient alert?
  – Ease of Learning: is training minimal allowing for adequate and reliable memory of proper use?
  – Perceived Value: does the user trust the feedback of the technology, providing a sense of efficacy with limited risk of usage?
  – Advocacy: will device be adopted, recommended and purchased by a sufficient number of users?
  – User Behavior: is the user distracted by the technology and do they adapt to using it effectively?
Haddon matrix implies that injury producing events occur over time and are modifiable.

Technological Countermeasures
Case Study

• TBD
References


References (continued)


Questions or Comments?

David A. Lombardi, Ph.D.
Principal Research Scientist
Center for Injury Epidemiology
e-mail: david.lombardi@LibertyMutual.com

Liberty Mutual Research Institute for Safety
Center for Injury Epidemiology
71 Frankland Road
Hopkinton, MA 01748
phone: (508) 497-0210
fax: (508) 435-3456