Fatigue and Circadian Rhythms

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Lecture 19
Outline

• Situations where fatigue is a factor
• Effects of fatigue
• Sleep
  – Components
  – Circadian rhythm
  – Stages
• Causes of fatigue
• Ways to measure fatigue
• Prevention methods
• My research!
Situations where fatigue is a factor

• Driving
• Shift work
• Aviation
• Astronauts
• School/tests
• Sports
• Jet lag
• Medical residents
• Commercial truck drivers
• Others?
Effects of fatigue – lower level

- Slower reaction times
- Reduced response accuracy
- Attentional lapses
- Take longer to perform tasks
- More errors
- More unnecessary movements
- Less systematic exploration
- Poor judgment
- Omission of details
- Indifference to essentials
- Generally inadequate performance
- Increased distractibility
- Worse driving performance
  - More inappropriate line crossings
  - Increased braking distance
  - Increased speed deviation around the speed limit

Have you observed any of this in your projects?
Effects of fatigue – higher level

• Decreased executive attention and executive control
  – Ability to regulate perceptual and motor processes for goal-directed behavior
• Decreased working memory
• Decreased flexibility
• Sub-optimal planning
• Impaired decision making involving unexpected situations or circumstances
• Impaired innovation, ability to revise plans, ability to handle competing distractions
• Less effective communication
• Distinction between low level, automatic, skill-based task components like steering and high-priority, rule- or knowledge-based tasks like hazard avoidance
  – Which would you guess are more affected? Why?
• Extent of the effect varies between individuals
Effects of fatigue – practical

• 1 in every 5 serious motor vehicle injuries is related to driver fatigue
• 80,000 drivers fall asleep behind the wheel every day
• 250,000 accidents every year related to sleep
• Accidents due to sleepiness are estimated to cost the US economy over $56 billion annually
• Sleep deprivation is attributed to over 24,000 deaths per year
• Sleep deprivation leads to the loss of 52 million work days each year
Effects of fatigue – practical

• Fatigue-related impairment often expressed as “blood-alcohol equivalent”

• Only 18-24 hours of continuous wakefulness can cause performance decline ~BAC of 0.1% (legal driving limit is 0.08%)

• Effect of one week of chronic sleep debt (6 hours of sleep per night) = effect of one night with no sleep
Effects of fatigue – aviation

• How many cases so far this semester have had fatigue as a contributing factor?
• FAA Work Limitations:
• **No certificate holder** conducting domestic operations **may schedule** any flight crewmember and **no flight crewmember may accept** an assignment for flight time in scheduled air transportation or in other commercial flying **if that crewmember's total flight time in all commercial flying will exceed**:  
  – 1000 hours in any calendar year  
  – 100 hours in any calendar month  
  – 30 hours in any 7 consecutive days  
  – 8 hours between required rest periods

*US Code Title 14, part 121.471*
Effects of fatigue – jet lag

- Shifting circadian rhythms
  - Phase advance shift
    - Shortened day
  - Phase delay shift
    - Lengthened day
- Jet-lag evidence suggests we can accommodate phase-delay changes more readily than phase-advance changes
  - (Nicholson et al., 1986)
Effects of fatigue – jet lag

- Phase response curve due to light exposure to the eyes
Effects of fatigue – space

- Astronauts average <6 hours of sleep per night
- Perform telerobotics tasks requiring vigilance, careful movements
- Mir-Progress 234 collision
- My research – more information later
Effects of fatigue – trucking

• Federal Trucking Work Limitations
  – 10-hour maximum without break
  – 15-hour maximum without 8-hour break
  – 60 hours in any 7 consecutive days
Now that we’re motivated...
Sleep cycle

- 2 processes – Sleep homeostat and circadian phase
Circadian rhythm

• *Circa dies* – approximately one day
• Many bodily functions of humans and other animals fluctuate over the course of a day:
  – Body temperature
  – Heart rate
  – Blood pressure
  – Adrenaline production
  – Melatonin production
  – Urine production
  – Flicker-fusion frequency
  – Mental ability
  – Release of hormones into the bloodstream
Circadian rhythm

Melatonin pg/ml

Core body temperature °C

Triacylglycerol mML

Subjective alertness VAS

Performance reaction time sec

Relative clock time h
Screenshot of Circadian Performance Simulation Software removed due to copyright restrictions.
Why do we need sleep?

• Specific function of sleep is still uncertain
• Sufficient sleep critical to health and performance
• Age dependent requirements
  – Newborns: 15-17 hours
  – Healthy Adults: 6-8 hours/night (with considerable individual variations)
  – Elderly: can decrease significantly – or does it?
• Quality is cyclical, with many stages and depths
# What happens when we’re asleep?

<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
<th>EEG Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Awake</strong></td>
<td>Low-voltage, high-frequency beta waves</td>
<td><img src="Image" alt="Waveform" /></td>
</tr>
<tr>
<td><strong>Drowsy</strong></td>
<td>Alpha waves prominent</td>
<td><img src="Image" alt="Waveform" /></td>
</tr>
<tr>
<td><strong>Stage 1 sleep</strong></td>
<td>Theta waves prominent</td>
<td><img src="Image" alt="Waveform" /></td>
</tr>
<tr>
<td><strong>Stage 2 sleep</strong></td>
<td>Sleep spindles and mixed EEG activity</td>
<td><img src="Image" alt="Waveform" /></td>
</tr>
<tr>
<td><strong>Slow-wave sleep</strong></td>
<td>Progressively more delta waves (Stage 4 shown)</td>
<td><img src="Image" alt="Waveform" /></td>
</tr>
<tr>
<td><strong>REM sleep</strong></td>
<td>Low-voltage, high-frequency waves</td>
<td><img src="Image" alt="Waveform" /></td>
</tr>
</tbody>
</table>

Image by MIT OpenCourseWare.
What happens when we’re asleep?

- **Stage 1**
  - If awakened, people say they weren’t asleep
  - Automatic behavior may occur in Stage 1 sleep
- **Stage 2**
  - Up to 50% of sleep time
  - Comes between periods of deep sleep and REM
- **Stages 3-4**
  - “Slow-Wave Sleep” (SWS)
  - Most vital for recuperation
  - Increases after intellectually challenging tasks
  - Most occurs during first half of sleep period
- **REM**
  - “Brain on, body off”; wakeful EEG pattern
  - Increased cerebral blood flow
What happens when we’re asleep?

- Often ~4 descents into deep sleep, linked by intervening shallow periods
- 75% of SWS during first half of cycle
- 75% of REM during second half of cycle
What happens without sleep?

- Slow Wave Sleep (Stage 3, 4) deprivation
  - Feeling unrested
  - Reduction in cognitive performance

- REM deprivation
  - Moodiness
  - Hypersensitivity
  - Inability to consolidate complex learning
  - REM appears to be important for psychological well-being

- Sleep debt
  - Cumulative increase over consecutive poor-sleep nights
  - Very poor relationship between self-reported sleepiness over the long term and objective measures of fatigue
Causes of fatigue

- How much sleep did you get last night?
- How much do you get on average?
- Lack of sleep
- Circadian phase
- Physical or mental exertion
- Time on task
- Workload
- Diet
- Stress
Ways to measure fatigue

• Objective
  – Electroencephalography (EEG)
  – Multiple Sleep Latency Test (MSLT)
  – Karolinska Drowsiness Test (KDT)
  – OptAlert

• Subjective
  – Karolinska Sleepiness Scale (KSS)
  – Epworth Sleepiness Scale (ESS)
  – Stanford Sleepiness Scale
  – Secondary tasks
Karolinska Sleepiness Scale

Please indicate your sleepiness during the 5 minutes before this rating by checking the box next to the appropriate number. Use also the intermediate steps!

- [ ] 1 – very alert
- [ ] 2 –
- [ ] 3 – alert – normal level
- [ ] 4 –
- [ ] 5 – neither alert nor sleepy
- [ ] 6 –
- [ ] 7 – sleepy – but no effort to keep awake
- [ ] 8 –
- [ ] 9 – very sleepy, great effort to keep awake, fighting sleep
So you don’t want to be sleepy...
Prevention methods - Individual

• Set a schedule – go to bed and wake up at the same time every day
• Exercise about 5-6 hours before going to bed
• Avoid caffeine, nicotine, and alcohol
• Relax before bed
• Sleep until sunlight
• Don't lie in bed awake
• Control your room temperature
Intervention methods - Individual

- Intervention: caffeine
  - "World’s most popular drug"
  - Mild central nervous system stimulant
  - 3.5 – 6 hr half-life
  - 250 mg: improves psychomotor function if sleep deprived
  - 500 mg: side effects without further functional improvement
  - Shakiness
  - Diuretic
  - Tachyphylaxis (desensitization)
  - Withdrawal headaches
  - Affects sleep latency (time to get to sleep) and sleep quality
Intervention methods - Individual

• Intervention: blue-enriched white light
  – Used on the ISS
  – Helps users feel more alert
  – Much shorter half-life than caffeine
  – Looks the same as regular white light
  – Doesn’t affect sleep latency (time to get to sleep) or sleep quality
  – Requires special (expensive) equipment
Intervention methods - Individual

• Get more sleep!
• The only way to completely reverse physiological need for sleep is by sleeping
• Some sleep is better than no sleep
• Napping even 15 minutes can improve cognitive performance
  – “Stay Awake: Take a Break for Safety’s Sake!”
• Poor sleep over time can lead to accumulated sleep debt
Prevention methods - Institutional

• Regulations on rest time
• Maximum hours permitted to work
  – Medical residents can work shifts up to 36 hours!
• Readiness-to-perform tests
• What else?
Research question:

How does sleepiness affect workload and performance on complex space robotics tasks?
My research - Procedure

• 1 training session
• 2 test sessions
  – One midday (noon), one night (10pm, wake at 4am)
• 2 types of robotics tasks
  – Autosequence
  – Track and capture
• 2 types of secondary tasks
  – Simple and complex
• Subjects screened for morningness

• What were the secondary tasks measuring?
My research – Experimental design

• Within-subjects test
• Randomly grouped into midday-first or night-first
• Side task type fully crossed with primary task type for all subjects
• Workload ratings
• Sleepiness ratings

• What could I have done differently?
My research – Results

Log Grapple Time

<table>
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<tr>
<th>Group</th>
<th>Midday First</th>
<th>Night First</th>
</tr>
</thead>
<tbody>
<tr>
<td>Session</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Midday</td>
<td>3.60</td>
<td>3.55</td>
</tr>
<tr>
<td>Night</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First</td>
<td>3.50</td>
<td>3.65</td>
</tr>
</tbody>
</table>
Simple side task is more sensitive to sleepiness on autosequence. Complex side task is more sensitive to sleepiness on track and capture.
My research – Conclusions

• Subjects were significantly sleepier at the night session
• No significant effect on autosequence primary task performance
• Combination of learning and time-of-day effects
• Different embedded secondary tasks are appropriate depending on the type of primary task

• What do you think?
Review

- Situations where fatigue is a factor
- Effects of fatigue
- Sleep
  - Components
  - Circadian rhythm
  - Stages
- Drivers of fatigue
- Ways to measure fatigue
- Prevention methods
- My research! – not on the test 😊
Questions?