Sleep Measurement, Polysomnography, and Quantitative EEG

Michael Goldstein
PSY 501A - Psychophysiology
University of Arizona
Spring, 2013

Outline

• Defining sleep
• Subjective measures
• Objective measures
  o Polysomnography (PSG)
  o Quantitative EEG for research

What is sleep?

• How do we know someone is sleeping?

  • Behavioral characteristics
  • Physiological characteristics
  • Homeostatic features
  • Circadian features

Behavioral characteristics

• Eyes closed (usually)
• Minimal movement (except for twitches and position changes)
• Substantially decreased responsiveness and awareness of environment
• Changes to breathing patterns
• Reversible

Physiological characteristics

• Body temperature
• Endocrine changes
• Brain activity
  o Blood flow
  o Metabolism
  o Chemistry
  o Electrical output

Homeostatic features

• Extended wakefulness/sleep deprivation
• Sleep “rebound”

Extended wakefulness/sleep deprivation

Adapted from Saper & Achermann (1999)
Circadian features

- Early morning class
- Jet lag


Subjective measurement of sleep

- Retrospective ratings
- Sleep diary

Retrospective ratings

The Pittsburgh Sleep Quality Index (PSQI)

Instructions: The following questionnaire is to be completed each night before going to sleep, and each morning after waking. Each answer should indicate the most accurate level of sleep difficulty, and the next day's ratings should be based on the previous night's. Rate your sleep quality and difficulties using a scale of 0 to 3, where 0 = never and 3 = always.

1. How many times did you wake up during the night?
2. Did you feel depressed or hopeless during the past week?
3. How often did you feel self-conscious during the past week?
4. How many hours of actual sleep did you get at night? (This may be different than the number of hours you spent in bed.)

<table>
<thead>
<tr>
<th>Item</th>
<th>PSQI Score</th>
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http://elearning.restproject.org.uk

Objective measurement of sleep

- Wrist actigraphy
- Polysomnography (PSG)
  - Sleep staging and scoring
- Quantitative electroencephalography (EEG)

http://elearning.restproject.org.uk
Wrist actigraphy

Portable EEG systems

Zmachine

Sleep Polysomnography (PSG)

PSG – Types and uses

• Overnight
  o “Gold-standard” for sleep measurement
  o Assess and monitor treatment for a variety of sleep disorders (e.g. sleep apnea, periodic limb movements, narcolepsy)

• Daytime
  o Provide additional information to help assess specific sleep disorders (e.g. narcolepsy)
  o Multiple Sleep Latency Test (MSLT)
  o Maintenance of Wakefulness Test (MWT)

PSG - Components

• Electroencephalography (EEG)
• Electrooculography (EOG)
• Chin electromyography (EMG)
• Electrocardiography (ECG/EKG)
• Respiration
• Snore mic
• Pulse oximetry
• Leg EMG

• Subjective staging/scoring process based on 30-second windows
### Electroencephalography (EEG)

![EEG Diagram](http://www.ebme.co.uk/)

### EEG Frequency Bands

<table>
<thead>
<tr>
<th>Frequency Band</th>
<th>Range</th>
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<tbody>
<tr>
<td>Delta (δ)</td>
<td>0.5-4 Hz</td>
</tr>
<tr>
<td>Theta (θ)</td>
<td>4-8 Hz</td>
</tr>
<tr>
<td>Alpha (α)</td>
<td>8-13 Hz</td>
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<tr>
<td>Beta (β)</td>
<td>13-30 Hz</td>
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Source: American Academy of Sleep Medicine

PSG – Sleep stages

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Electrical and Magnetic Field Effects: An Introduction to Electromagnetics and Biomedical Engineering


PSG – Sleep stages

Awake
- Wake (Relaxed)
  - W: Alpha EEG (8-12 Hz)

Drowsy
- NREM Sleep
  - N1: Low voltage, mixed frequency (theta EEG 3-7 Hz), slow, rolling eye movements
  - N2: Presence of sleep spindles (burst of EEG activity of 12-14 Hz lasting at least 0.5 sec) and K-complexes (large well-defined negative deflection followed by a positive deflection — larger than 75 microvolts)

Stage 1
- NREM Sleep

Stage 2
- SWS (formerly 3&4)

REM
- Alpha EEG (8-12 Hz)

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PSG – Sleep stages

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PSG – Sleep stages

**Awake**
- Wake (Relaxed)
  - W: Alpha EEG (8-12 hz)

**Drowsy**
- NREM Sleep
  - N1: Low voltage, mixed frequency (theta EEG 3-7 hz), slow, rolling eye movements
  - N2: Presence of sleep spindles (burst of EEG activity of 12-14 hz lasting at least .5 sec) and K-complexes (large well-defined negative deflection followed by a positive deflection—larger than 75 microvolts)

**Stage 2**
- SWS (formerly 3&4)
  - N3: Presence for more than 20% of an epoch of delta EEG waves (greater than 75 microvolts and .5-2 hz)

**REM**
- R: Like N1 (but also has saw-tooth waves), muscle atonia, rapid eye-movements

Sleep Polysomnography (PSG)
- Electroencephalography (EEG)
- Electrooculography (EOG)
- Chin electromyography (EMG)
- Electrocardiography (ECG/EKG)
- Respiration
- Snore mic
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Subjective staging/scoring process based on 30-second windows

Where is the change from Stage 2 to Slow Wave Sleep?

PSG recording example – NREM sleep

PSG recording example – REM sleep
PSG recording example – REM sleep

Hypnogram of healthy sleep

Quantitative EEG for sleep research

- Spectral analysis (frequency domain)
- Other qEEG techniques

Power Spectra

Topography

Timecourse
Time-frequency plots

Waveform detection

Source localization

Many more (creative) options

Review

- Defining sleep
  - Behavioral characteristics
  - Physiological characteristics
  - Homeostatic features
  - Circadian features
- Subjective measures
  - Retrospective ratings
  - Sleep diary
- Objective measures
  - Wrist actigraphy
  - Portable EEG
  - Polysomnography (PSG)
  - Quantitative EEG for research
Developmental Changes in Sleep

Hypnograms from polysomnography (all-night sleep studies)

Richard R. Bootzin
University of Arizona

Biological Rhythms

Circadian: About a day

Ultradian: Shorter than a day; e.g. 90 minute cycles

Infraadian: Longer than a day; e.g., menstrual and seasonal cycles

Zeigebers (time givers): cues that entrain circadian rhythms to 24 hours

Kleitman & Engelmann, 1953; from the Howard Hughes Museum exhibit, Time Matters

Nathaniel Kleitman and Bruce Richardson after 32 days in Mammoth Cave
Cues for Aligning Sleep-Wake Rhythms to a 24 hour light-dark cycle: Zeitgebers

- Bright light: the blue end of the spectrum is the most effective zeitgeber (time-giver). It increases alertness.
- “Dark” is a zeitgeber. It increases sleepiness.
- Daily activity rhythms may have their effect through exposure to light; for example, getting up at 6 am increases exposure to early morning sunlight.

Is consolidated sleep our natural sleep?

Adolescent Use of Mobile Phones for Calling and for Sending Text Messages After Lights Out
Jan Van den Bulck
Sleep, 2007

<table>
<thead>
<tr>
<th>Use of Text messages and Telephone calls</th>
<th>Overall level of tiredness (row %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Not tired</td>
</tr>
<tr>
<td>Never</td>
<td>645</td>
</tr>
<tr>
<td>Less than once a month</td>
<td>397</td>
</tr>
<tr>
<td>Less than once a week</td>
<td>311</td>
</tr>
<tr>
<td>About once a week</td>
<td>174</td>
</tr>
<tr>
<td>More than once a week</td>
<td>84</td>
</tr>
<tr>
<td>When do you use text messaging?</td>
<td></td>
</tr>
<tr>
<td>Never</td>
<td>645</td>
</tr>
<tr>
<td>Right after lights out</td>
<td>547</td>
</tr>
<tr>
<td>Between midnight and 3 am</td>
<td>121</td>
</tr>
<tr>
<td>Any time of the night</td>
<td>121</td>
</tr>
</tbody>
</table>

* P < 0.001, ** P < 0.0001

The Spread of Sleep Loss Influences Drug Use in Adolescent Social Networks
Sara C. Mednick, Nicholas A. Christakis, James H. Fowler
PLoS ONE, 2010

Being central in the network negatively influences future sleep outcomes, but not vice versa.

If a friend sleeps <8 hours, it increases the likelihood a person sleeps <8 hours by 11%. If a friend uses marijuana, it increases the likelihood of marijuana use by 110%.

Moreover, the likelihood that an individual uses drugs increases by 19% when a friend sleeps <8 hours, and a mediation analysis shows that 20% of this effect results from the spread of sleep behavior from one person to another.
Conclusions from recent sleep literature

Sleep disturbance is transdiagnostic. It predicts later development of depression, anxiety, substance abuse, and attention deficit disorder.

Sleep affects health, learning, cognition, emotion regulation, and social interaction.

There are rapid advances in neuroimaging and sleep genetics.

Air Traffic Control: A Case Study in the Failure to Apply Sleep Science to Public Policy

- “Two more cases of dozing controllers” One found sleeping in LA was suspended, one in Fort Worth seen with his eyes closed was reprimanded. USA TODAY, May 25, 2011

What is the 2-2-1 schedule and why do controllers want it?

- 2 evening shifts—2 PM to 10 PM
- 2 day shifts—6 AM to 2 PM—8 hrs
- 1 overnight shift—10 PM to 6 AM

This allows for 5 shifts in 4 days resulting in 3 days off. The NTSB tried and failed to eliminate the 2-2-1 schedule in 2007.

Sleep Extension in High School Students (Cousins, 2008)

19 students (14-18 years old) who extended their sleep > 60 min on 3 consecutive weekday nights showed the following results compared to controls (p < .05):

- Better sleep (increased total sleep time and sleep efficiency, decreased difficulty waking in the morning)
- Reduced daytime sleepiness
- Improved backward digit span
- Improved trailmaking B
### FAA Solutions (April, 2011)
- No solo overnight traffic controllers allowed at 27 airports—including DCA
- Rule that the controller must be off of work for at least 8 hours between shifts is expanded to 9 hours
- Scheduled naps will NOT BE ALLOWED
  “we’re not going to pay controllers to nap.” Transportation Secretary Ray LaHood.
  REUTERS, April 26, 2011

### Why no naps?
Charles Czeisler (a renowned sleep and circadian researcher, Harvard University) pointed out that we pay night shift workers, including air traffic controllers, to take bathroom breaks, to eat, to take breaks to smoke. But in the case of air traffic controllers, nap breaks, an effective tool to improve alertness and reduce risk to public safety, are not allowed. NPR, April 23, 2011

### Brief naps increase alertness
- “Ten to fifteen minutes of sleep seems to be the optimum period in terms of improving mental operations, performance, reaction times and subjective feelings of alertness.”
- “And that improvement in performance and alertness seems to be maintained for up to two and sometimes three hours after the nap.”
- “Interestingly, the five-minute nap just didn’t produce the same amount of improvement, while longer naps of 25 to 30 minutes led to subjects being somewhat drowsy and less alert for up to an hour after the nap.” Leon Lack
- Best time to nap is 6 to 8 hours after awakening.

### FAA Rest Rules for Pilots for Flights Longer than 12 Hours
- Flights longer than 9 hours must carry a 3rd pilot to allow for inflight rest
- “For international flights that require more than 12 hours of flight time, air carriers must establish rest periods and provide adequate sleeping facilities outside of the cockpit for in-flight rest.” FAA 1/27/10

### Air India Crash May 22, 2010
Capt. Zlatko Glusica was captured snoring loudly on a cockpit recorder, the accident investigation found, according to the Hindustan Times.
After waking, Glusica did not respond when his co-pilot H.S. Ahluwalia repeatedly urged him to abort the landing.
Sleep Inertia

- Continuation of the sleep state into wakefulness
  - Cognitive confusion
  - Automatic behavior
  - Amnesia for what was said and done
  - Worse after prior sleep deprivation
  - Worse after awakenings from slow-wave sleep

Sleepiness and Fatigue Affect Many Critical Activities

- Transportation accidents
- Education
  - School start times
  - Morning classes in college
- Medical resident work hours
- Shift work
- Military operations
- Jet lag

Sleep Risk

Risk of Performance Errors Due to Fatigue Resulting from Sleep Loss, Circadian Desynchronization, Extended Wakefulness and Work Overload

Rookie of the Year:

‘Rookie of the Year’ award goes to Chris MacDonald, 32, (DEN) marking the third consecutive year a rookie has placed 2nd in RAAM. With a strategy of sleeping during the hottest parts of the day, obtaining more sleep than his nearest rival, Fabio Biasiolo (ITA)…

Hallucinations/Delusions

- Reports from previous RAAM races—usually from first-time racers
  - Loss of memory for a period of time and rider persuaded that his crew consists of aliens
  - Mailboxes on the side of the road “seen” as spectators encouraging the rider to get off the bike
  - Crowds “seen” applauding the rider as if he is at finish line

Richard R. Bootzin1,2, Ph.D., Patricia Dalby3, Ph.D., Patricia Haynes2, Ph.D., and Keith Fridel1, M.A. Departments of Psychology1, Psychiatry2, Orthopaedic Surgery3
Chris’s Dream

While cycling almost immediately after a short rest stop, Chris believed that he was still asleep and dreaming that he was cycling. He concluded that the only way he could stop the dream was to stop cycling. He then rode his bike into a ditch.

– Dream confusion due to sleep inertia?
– Crew insisted that Chris take a longer sleep break

Countermeasures for Sleepiness and Fatigue (Veasey, et al., JAMA, 2002)
Most vulnerable time: 2 – 9 am

Sleep:
- 2-8 hr nap prior to 24 hrs of sleep loss
- 15 min nap every 2 to 3 hrs maintains performance during 24 hrs of sleep deprivation
- 2 hr naps every 12 hrs maintains performance during 88 hrs of sleep deprivation
- Naps need to be < 2 hrs to avoid sleep inertia

Countermeasures for Sleepiness and Fatigue (Veasey, et al., JAMA, 2002)
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Stimulants
- High-dose caffeine, modafinil, and D-amphetamine are effective for short-term sleep loss (< than 48 hrs) but not for long term sleep loss.

Other Countermeasures that Reduce Sleepiness

- A consistent sleep-wake schedule reduces sleepiness compared to having an irregular schedule with the same amount of sleep (Manber, Bootzin, et al. 1996)
- Interesting activities increase alertness; boring activities increase sleepiness.
- Social interaction increases alertness.

Sensory Stimulation

- Sensory stimulation (sight, hearing, taste, smell, touch—also sensitivity to heat, balance, internal sensations) increases arousal

Irregular schedules lead to the development of sleep disturbance and problems with sleepiness
Causes of Sleep Disturbance

- Physical disorders (sleep apnea, chronic pain, restless legs, PLMS, GERD)
- Substances (legal and illegal substances)
- Circadian rhythm problems (shift work, jet lag, advanced or delayed sleep phases)
- Psychological factors (stress, psychopathology, nightmares)
- Poor sleep environment (noise, ambient temperature, bed partner)
- Poor sleep habits (irregular sleep schedule, naps, bed as a cue for arousal, extended time in bed)

Consequences of Insomnia

- Feel less physically well; more often visit physicians
- Have more absences from work due to illness
- Have more trouble with memory, concentration, and performance
- Have more work-related accidents and injuries
- Increases risk for major depression and alcohol and substance abuse

Prevalence of Insomnia

- 1-month insomnia—lifetime prevalence
  - Women: 31.1%
  - Men: 17.5%
- 2-3 week insomnia—lifetime prevalence
  - Women: 14.4%
  - Men: 12.0%
- No insomnia—lifetime prevalence
  - Women: 19.1%
  - Men: 25.7%

Recommended Reading


Email: bootzin@u.arizona.edu

Neuroimaging of Arousal in Insomnia

- Areas with less decrease in metabolic rate while asleep in insomniacs
- Areas with more decrease in metabolic rate while awake in insomniacs

Some brain areas “stay awake” during sleep

Some brain areas are less available during wake

Nofzinger et al., 2004, Am J Psychiatry

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