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Sleepiness impairs performance

- **Mental performance**
  - Reduced logical reasoning
  - Impaired mental processing
  - Short-term memory problems
  - Reduced concentration
  - Frustration and irritability
  - Impaired decision making

- **Physical performance**
  - Impaired hand-eye coordination
  - Slower reaction time
  - Lowered visual discrimination
  - Reduced alertness
  - Increased error rates
Sleep deprivation and cognitive performance

Tower of Hanoi task: When subjects are retested a week after training, a significant 40% improvement in performance is seen. But if REM is experimentally reduced the night after training, no such improvement is seen.

Mathematical insight: Subjects taught a complex algorithm for solving mathematical problems. Unknown to the subjects, a simpler solution also exists, which none discovered during training. But at retest (+12 hours), a subset of subjects discovered simpler method. The probability of discovering it was more than doubled after a night of sleep.

Stickgold et al., Nature, 2005
Physiological determinants of sleepiness

- Biological time of day (circadian rhythms)
- Consecutive waking hours
- Nightly sleep duration
- Sleep inertia
- Sleep disorders
Plasma melatonin

Core body temperature

Triacylglycerol

Time of day (h)

Alertness

Mental performance

Plasma melatonin

Rajaratnam & Arendt, Lancet (2001)
Biological time of day: Human circadian pacemaker in suprachiasmatic nucleus (SCN) of hypothalamus


Courtesy Prof Russell G. Foster   http://www1.imperial.ac.uk
Two Process Model of Sleep Regulation
(Borbély & Daan)
1 – Biological time of day

![Psychomotor performance reaction time (ms) vs. Approximate time of day graph]

_Cajochn et al., Am J Physiol, 1999_
1 – Biological time of day

Time course of single vehicle truck accidents
After being awake for 19 hours, impairment on a simple reaction time test was comparable with impairment observed at a blood alcohol concentration of 0.05%.

After being awake for 24 hours, impairment on a simple reaction time test was comparable with impairment observed at a blood alcohol concentration of roughly 0.10%.

Effects of sleep deprivation on psychomotor performance: comparison with alcohol

Blood alcohol concentration (%)

0.00 0.02 0.04 0.06 0.08 0.10

Performance

Lamond & Dawson (1999)
Physiological Consequences of Healthcare Provider Schedules

<table>
<thead>
<tr>
<th></th>
<th>Misalignment of circadian phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological Time of Day</td>
<td></td>
</tr>
<tr>
<td>(circadian phase)</td>
<td></td>
</tr>
<tr>
<td>Number of Hours Awake</td>
<td>Acute total sleep deprivation</td>
</tr>
<tr>
<td></td>
<td>scheduled frequently</td>
</tr>
<tr>
<td>Nightly Sleep Duration</td>
<td>Chronic partial sleep deprivation</td>
</tr>
<tr>
<td></td>
<td>resulting in cumulative sleep</td>
</tr>
<tr>
<td></td>
<td>debt</td>
</tr>
<tr>
<td>Sleep Inertia</td>
<td>Performance often required</td>
</tr>
<tr>
<td></td>
<td>within minutes of awakening</td>
</tr>
</tbody>
</table>
Doctors working 24 h straight:

- make 36% more serious medical errors
- make 6 times more serious diagnostic errors
- get ‘needlestick’ injuries twice as often overnight
- report nearly 4 times more fatigue-related errors when working 1-4 24-h shifts/month
- report 300% more fatal adverse events
- had 2.3 times more actual crashes and 6 times more ‘near-crashes’ when driving home after work
Risk of car crash on drive home from work

Physician work hours, sleep and patient safety

- Physicians driving home after 24 h shift have 2.3x the odds of a crash than after <24 h shift
- Each extended shift adds 16% increased risk

<table>
<thead>
<tr>
<th>Variable</th>
<th>Extended Work Shifts (≥24 hr)</th>
<th>Nonextended Work Shifts (&lt;24 hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crashes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. reported</td>
<td>58</td>
<td>73</td>
</tr>
<tr>
<td>No. of commutes</td>
<td>54,121</td>
<td>180,289</td>
</tr>
<tr>
<td>Rate (per 1000 commutes)</td>
<td>1.07</td>
<td>0.40</td>
</tr>
<tr>
<td>Odds ratio (95% CI)</td>
<td><strong>2.3 (1.6–3.3)</strong></td>
<td>1.0</td>
</tr>
<tr>
<td>Near-miss incidents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. reported</td>
<td>1,971</td>
<td>1,156</td>
</tr>
<tr>
<td>No. of commutes</td>
<td>54,121</td>
<td>180,289</td>
</tr>
<tr>
<td>Rate (per 1000 commutes)</td>
<td>36.42</td>
<td>6.41</td>
</tr>
<tr>
<td>Odds ratio (95% CI)</td>
<td><strong>5.9 (5.4–6.3)</strong></td>
<td>1.0</td>
</tr>
</tbody>
</table>

Barger et al., N Eng J Med, 2005
Traditional and intervention schedule of US medical interns

**Effects of extended duration shifts on incidence of medical errors**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Traditional Schedule</th>
<th>Intervention Schedule</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serious medical errors made by interns</td>
<td>no. of errors (rate/1000 patient-days)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serious medical errors</td>
<td>176 (136.0)</td>
<td>91 (100.1)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Preventable adverse events</td>
<td>27 (20.9)</td>
<td>15 (16.5)</td>
<td>0.21</td>
</tr>
<tr>
<td>Intercepted serious errors</td>
<td>91 (70.3)</td>
<td>50 (55.0)</td>
<td>0.02</td>
</tr>
<tr>
<td>Nonintercepted serious errors</td>
<td>58 (44.8)</td>
<td>26 (28.6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Types of serious medical errors made by interns</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medication</td>
<td>129 (99.7)</td>
<td>75 (82.5)</td>
<td>0.03</td>
</tr>
<tr>
<td>Procedural</td>
<td>11 (8.5)</td>
<td>6 (6.6)</td>
<td>0.34</td>
</tr>
<tr>
<td>Diagnostic</td>
<td>24 (18.6)</td>
<td>3 (3.3)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Other</td>
<td>12 (9.3)</td>
<td>7 (7.7)</td>
<td>0.47</td>
</tr>
<tr>
<td>All serious medical errors, unit-wide</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Serious medical errors</td>
<td>250 (193.2)</td>
<td>144 (158.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Preventable adverse events</td>
<td>50 (38.6)</td>
<td>35 (38.5)</td>
<td>0.91</td>
</tr>
<tr>
<td>Intercepted serious errors</td>
<td>123 (95.1)</td>
<td>63 (69.3)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Nonintercepted serious errors</td>
<td>77 (59.5)</td>
<td>46 (50.6)</td>
<td>0.14</td>
</tr>
<tr>
<td>Types of serious medical errors, unit-wide</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medication</td>
<td>175 (133.2)</td>
<td>103 (115.5)</td>
<td>0.03</td>
</tr>
<tr>
<td>Procedural</td>
<td>18 (13.9)</td>
<td>11 (12.1)</td>
<td>0.48</td>
</tr>
<tr>
<td>Diagnostic</td>
<td>28 (21.6)</td>
<td>10 (11.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Other</td>
<td>29 (22.4)</td>
<td>18 (19.8)</td>
<td>0.45</td>
</tr>
</tbody>
</table>

*Table 3. Incidence of Serious Medical Errors.*

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Effects of extended duration shifts on incidence of attentional failures

Thank you.

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Circadian misalignment in shift workers

Rajaratnam & Arendt  Lancet 2001

Clock time (h)

Study day

rest
work

Rajaratnam & Arendt  Lancet 2001
Shift-work patterns and accident risk

Risk depends on shift timing

Night shift has greatest risk

![Bar chart showing relative risk for different shift types. Morning has the lowest risk, afternoon has a moderate risk, and night shift has the highest risk.]

Folkard & Lombardi, Am J Indus Health 2006
Shift-work patterns and accident risk

Risk depends on consecutive shift number

Successive day/evening shifts

Successive night shifts

Folkard & Lombardi, Am J Indus Health 2006
Shift-work patterns and accident risk

Risk increases with increased hours on duty

As compared to the first 8 h,

- After 10 h on duty, the relative risk increases by ~90%
- After 12 h on duty, the relative risk increases by ~110%

Mean risk for duty hours 1 - 8 = 1.0
Shift-work patterns and accident risk

Comparison of different shift patterns

5 x 8 h days = risk of 1.0

Folkard & Lombardi, Am J Indus Health 2006
“The cumulative effects of sleep loss and sleep disorders … have been associated with a wide range of health consequences including an increased risk of hypertension, diabetes, obesity, depression, heart attack, and stroke.”

Institute of Medicine of the National Academies (USA), Sleep Disorders and Sleep Deprivation: An Unmet Public Health Problem (2006).
Circadian response to light

Subjective night

CBT min

Clock time

18.00 21.00 0.00 3.00 6.00 9.00 12.00 15.00 18.00

Increasing advance shift

Increasing delay shift

Mod. Rajaratnam & Arendt (2001)