



Managing Sleep to Sustain Performance

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Why is Sleep Important?

- **Productivity**

- **Personal**

- **Corporate**

- **Safety**

- **Personal**

- **Corporate**

- **Public**

- **Health**

- **Well-being**

“I do not care how much they sleep; I want to know how well they perform.”

General Max Thurman

Disasters spring from “not a major blunder, but reasoned calculations that slip just a little.”

***Brigadier General
S.L.A. Marshall***



The Operational Environment Defined

- ***Operational Environment***
 - ***Human performance critical to correct outcome of the system – the outcome itself is critical***
 - ***There a temporal envelope within which the correct decision must be made or the system fails***
 - ***John Boyd and the Observation, Orientation, Decision, Action (OODA) Loop***
- ***Most operational settings are complex and tightly-coupled***
- ***Many operational settings involve 24x7 operations, extended work hours and shift work***
- ***High reliability organizations maintain***
 - ***Mindfulness in day-to-day operations***
 - ***Presence of mind in emergencies***



Sleep, Fatigue, and Predicting Performance

- ***Fatigue operationally defined***
 - ***Subjectively by self-report***
 - ***Objectively by degraded performance***
- ***Fatigue is the final common pathway integrating***
 - ***Time awake, sleep/wake history, and sleep loss - Quantifiable***
 - ***Time on task, task intensity, and task complexity - Quantifiable***
 - ***Circadian rhythm - Quantifiable***
 - ***Individual differences - Quantifiable***
- ***Mathematical models integrate these quantities to predict individual performance in real-time***



Consequences of Sleep Restriction and Sleep Deprivation

- ***Short term***
 - ***Minutes, hours***
 - ***Error, accident, catastrophe***
- ***Mid-term***
 - ***Weeks, months, years***
 - ***Bad planning, inadequate strategizing, poor life decisions***
- ***Long-term***
 - ***Years***
 - ***Overweight/obesity, Type II Diabetes, Sleep Disorder Breathing, Metabolic Syndrome, etc.***
- ***Triad of factors supporting health, productivity, and well-being***
 - ***Diet***
 - ***Exercise***
 - ***Sleep***



Sleep:

A Fundamental Mystery in Neurobiology

- ***Sleep is found humans, mammals, birds, reptiles, fish, insects, and (perhaps) jellyfish – in any animal with one or more assemblies of nerve cells (neuronal assemblies)***
- ***After over 100 years of experimental work, we know:***
 - ***Adequate sleep sustains performance***
 - ***Inadequate sleep degrades performance***
 - ***Sleep creates risk and loss***
 - ***Risk of predation***
 - ***Loss of time to forage, reproduce***
 - ***Must convey large advantage to evolved***
- ***We do not know:***
 - ***Why extended waking degrades performance?***
 - ***How sleep restores performance?***



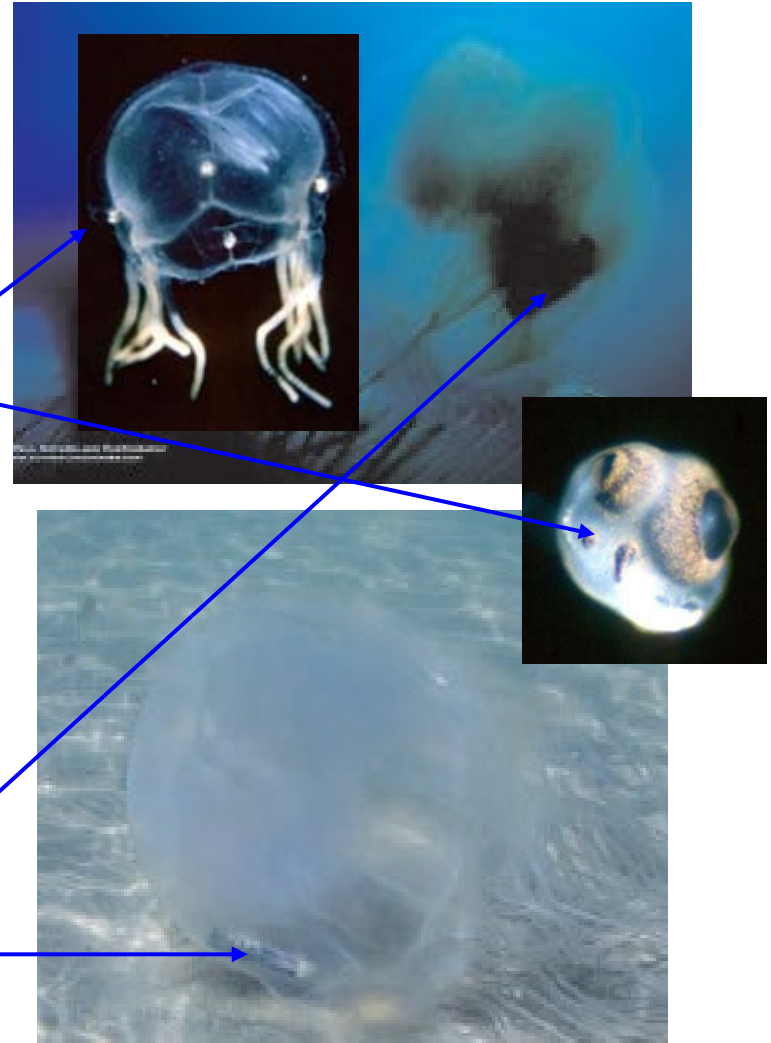
Objective Measures of Sleep

- ***In mammals and birds - electrophysiological criteria***
 - ***EEG, EOG, EMG, EKG***
 - ***Both Non-rapid-eye-movement (NREM) and rapid-eye-movement sleep (REM)***
- ***In lower animals - add behavioral criteria***
 - ***Prolonged quiescence***
 - ***Reduced responsiveness***
 - ***Rapid reversibility***
 - ***Rebound after deprivation***
- ***Reptiles and other show NREM (slow wave) sleep or sleep-like behavioral states***



Sleep in the Box Jellyfish (*Chironex fleckeri*)

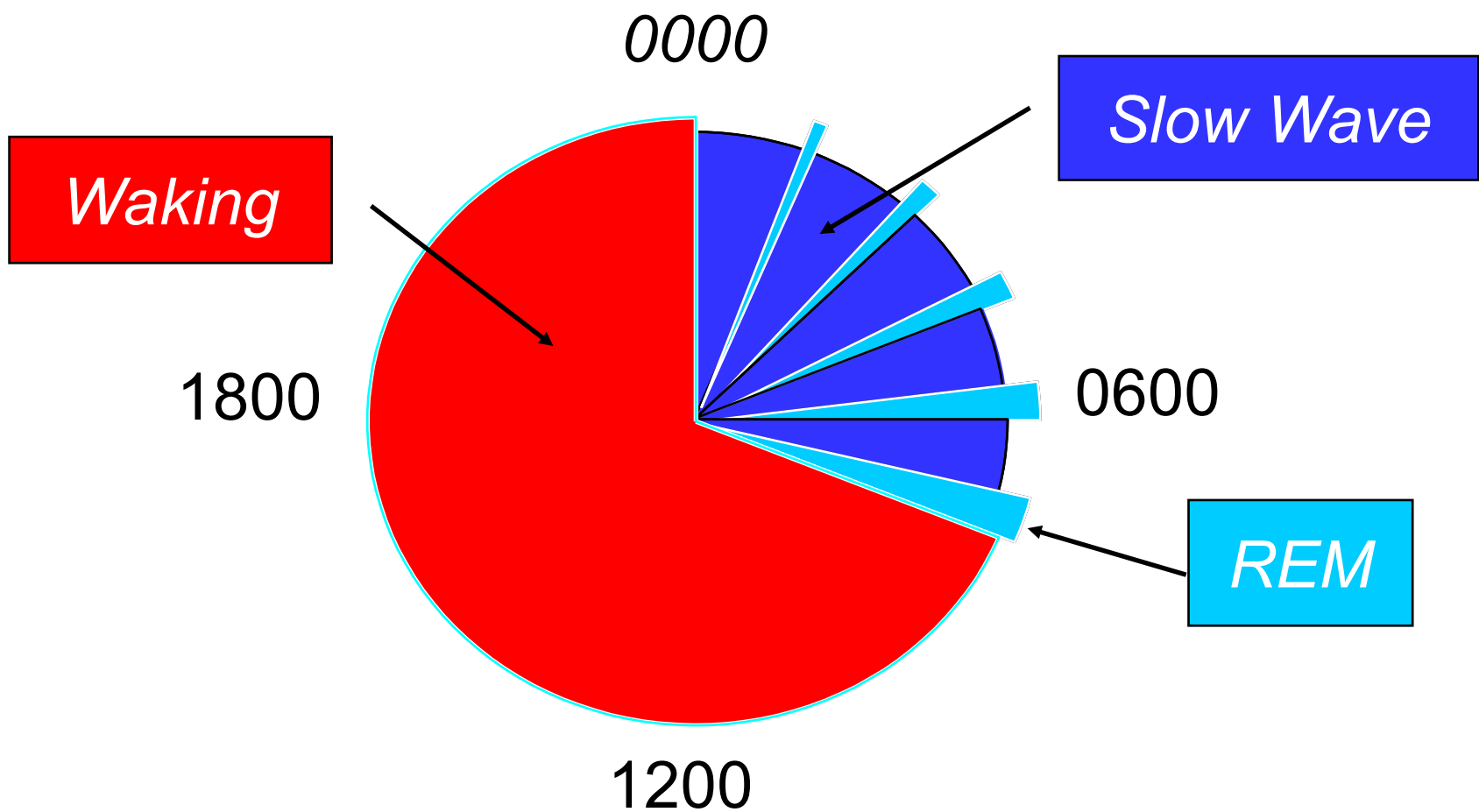
- **Box jellyfish are one of the simplest multi-cellular organisms**
 - **A nervous system consisting of a few neuronal assemblies**
 - **No brain per se, as symmetry is radial rather than bilateral**
 - **Their visual system is complex**
- **Box jellyfish are quiescent 15 hours/day**
 - **Diurnal pattern**
 - **Active during the day (0600-1500 hours)**
 - **Move 212 m/hour during day**
 - **Move 10 m/hour at night**
- **Note attached movement/location sensors**



Seymour et al., 2004

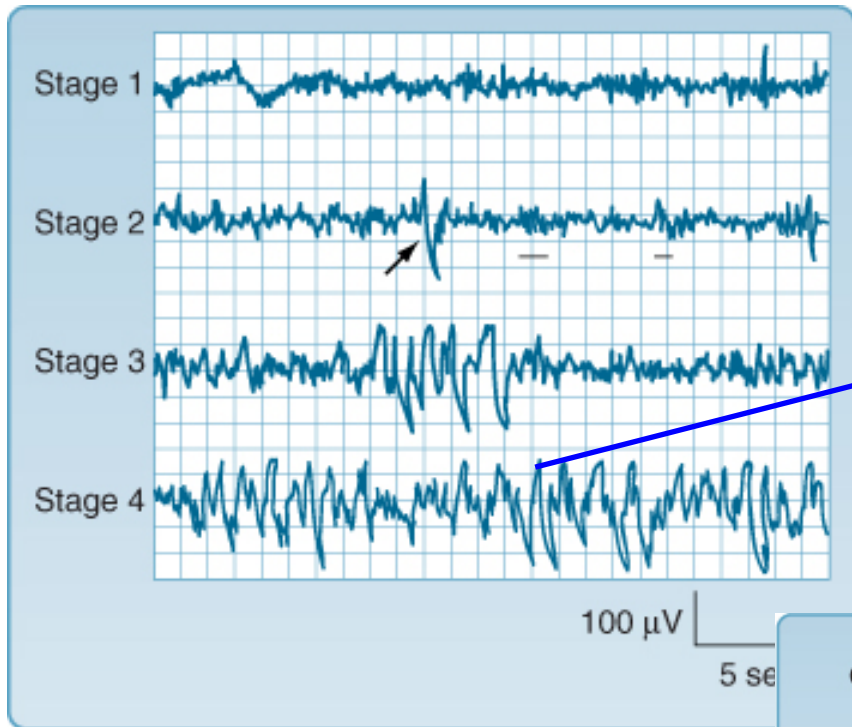


The 24-Hour Sleep/Wake Cycle





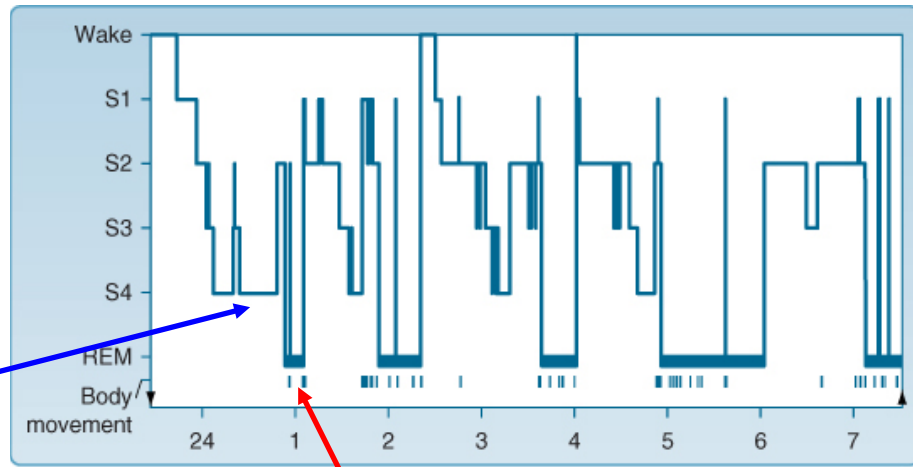
Physiology of Slow Wave and REM Sleep



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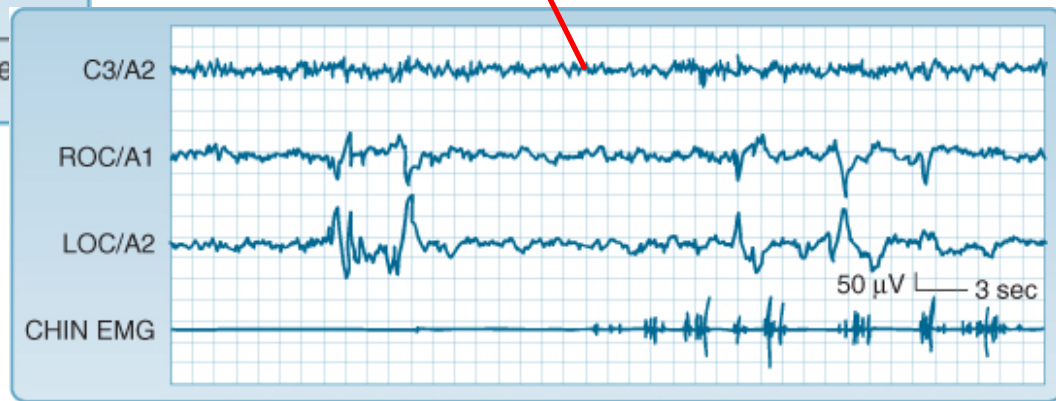
Slow Wave Sleep

**Kryger, Roth and Dement,
Principles and Practice of
Sleep Medicine, 2005**



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Sleep Cycle



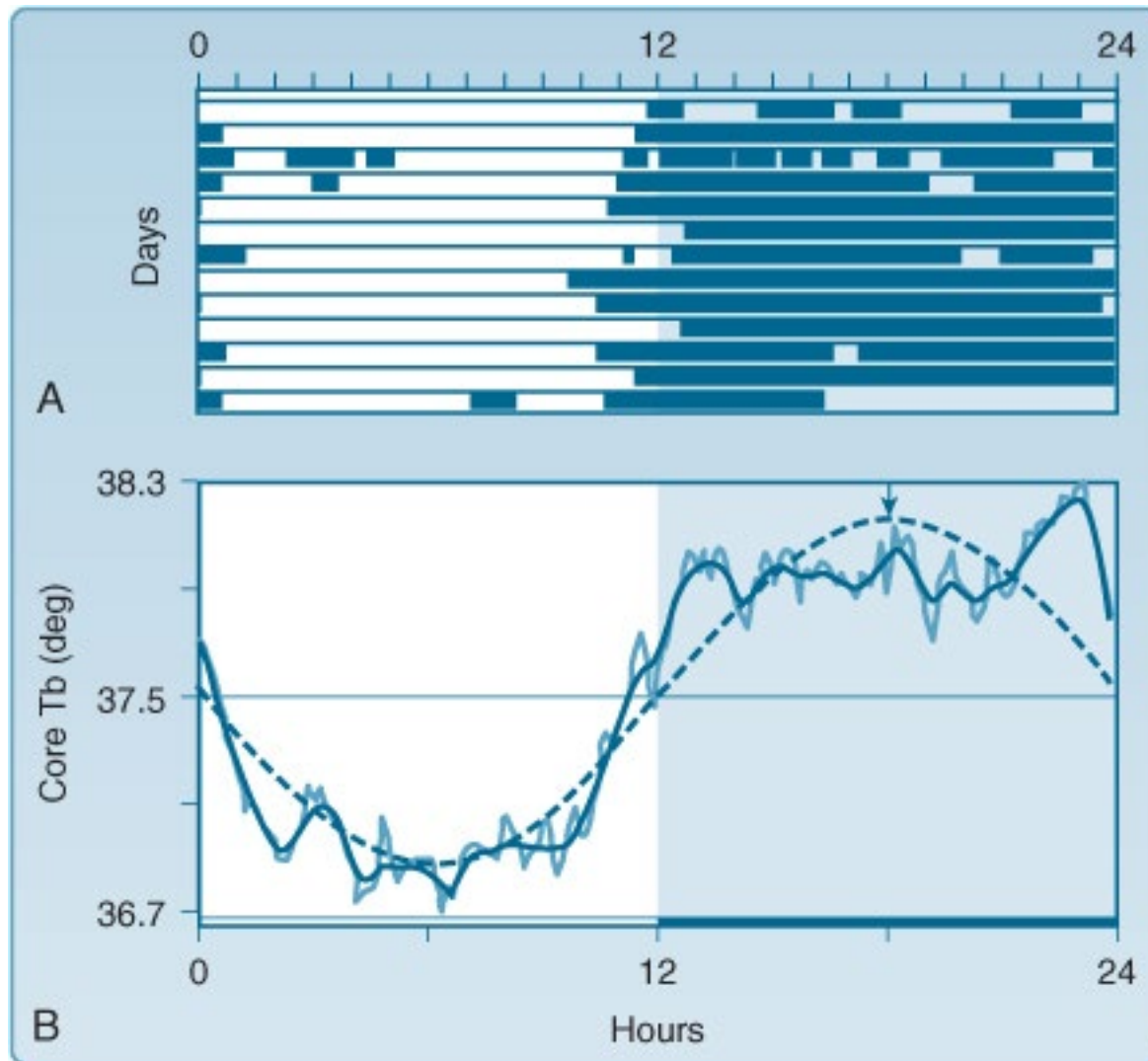
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REM Sleep

Washington State University



The Internal Body Clock (Circadian Rhythm)



**Kryger,
Roth and
Dement,
*Principles
and
Practice of
Sleep
Medicine,*
2005**



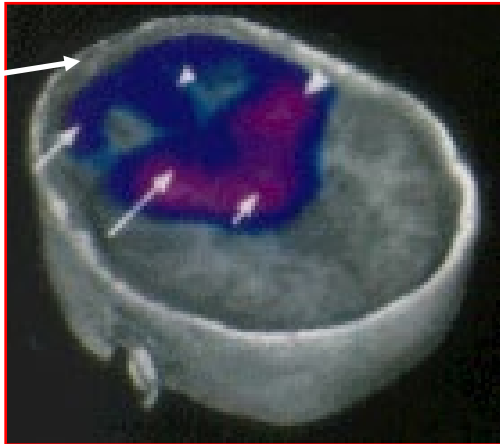
Brain Circulation and Metabolism

- ***Brain is the most metabolically active organ***
 - ***Brain is 2% of body weight, consumes 20% of resting total body oxygen consumption***
 - ***Overall brain metabolic rate for oxygen is similar unstressed heart or renal cortex***
 - ***Variability by region and by level of regional activation***
- ***Brain relies on just-in-time delivery of oxygen and glucose***
 - ***The brain has no meaningful reserves of either oxygen or glucose***
 - ***Brain blood flow is auto-regulated on the basis of local (regional) demand***
 - ***Brain uptake of glucose is not insulin dependent***
- ***Brain activity is temperature dependent***
 - ***Between 37 and 42°C, the brain metabolic rate increases 5% per degree***
- ***Brain uptake of oxygen and glucose is regional brain activation dependent***
 - ***Local use dependent***
 - ***Local autoregulation***



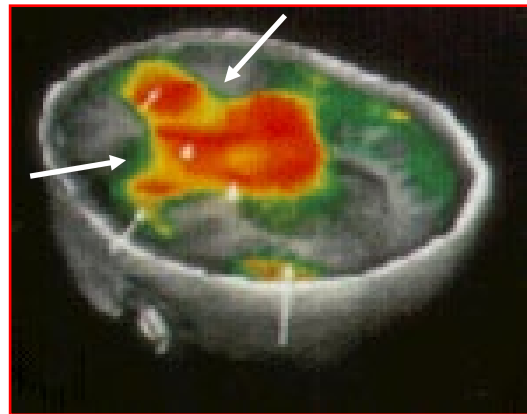
Brain Metabolism during Slow Wave and REM

Sleep

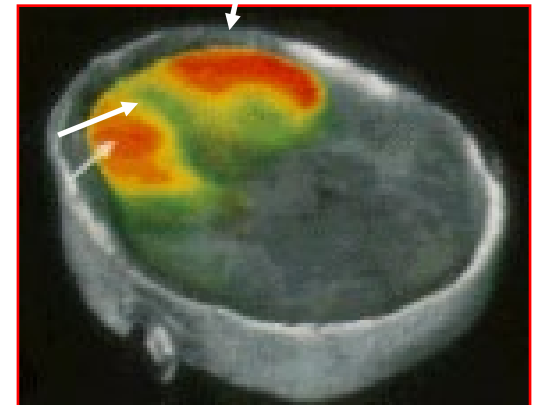
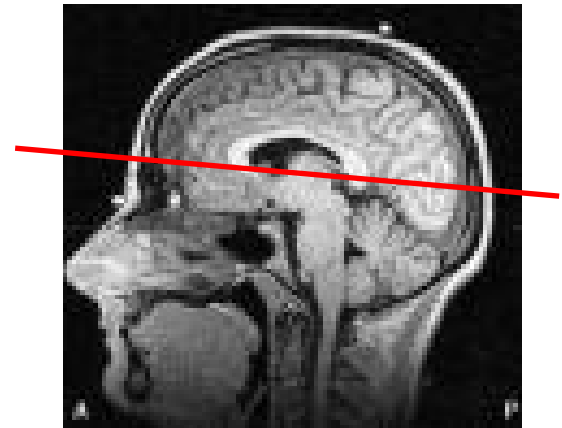


Frontal areas are deactivated during Slow Wave Sleep; decline in flow of ~30%

**Braun et al.,
Brain, 1997**



Frontal areas remain deactivated during REM; increase in flow to waking levels or above except in prefrontal cortex

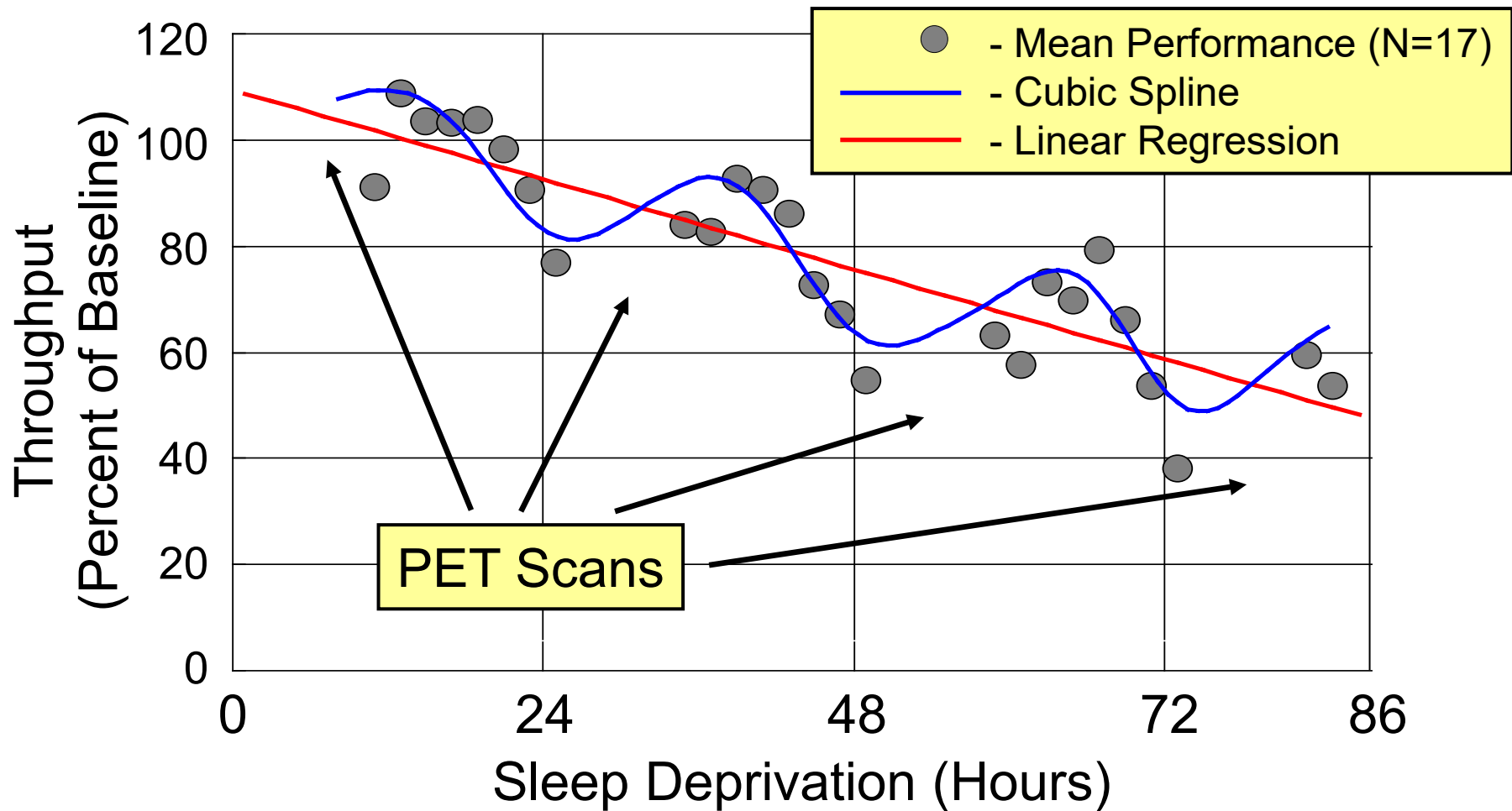


Frontal areas are re-activated only after awakening

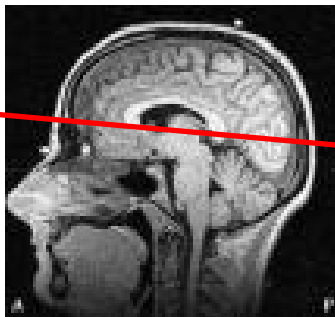
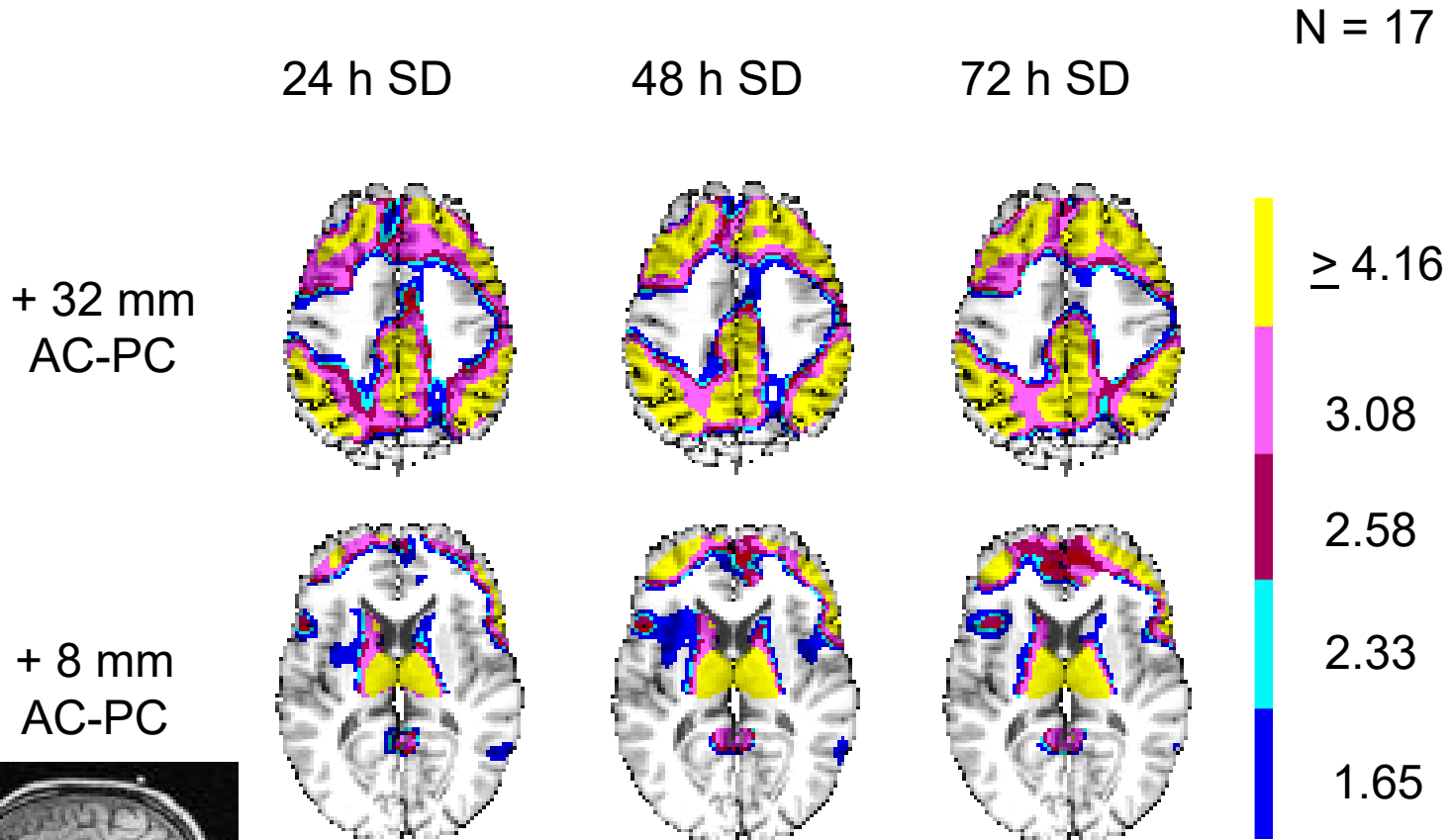


Total Sleep Deprivation

Imaging Studies



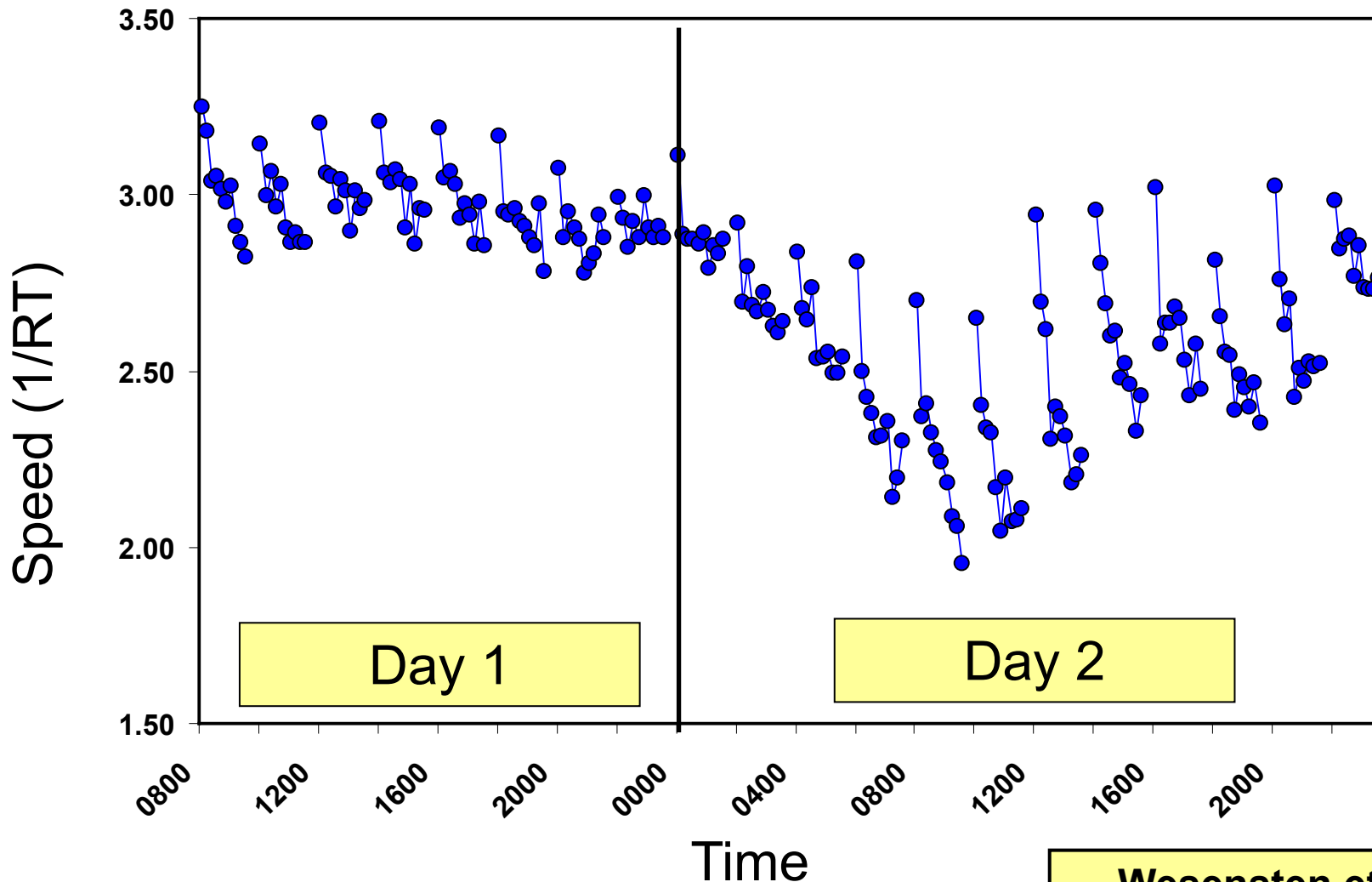
Brain Metabolism at 24, 48, & 72 Hours of Sleep Deprivation



Thomas, et al., *J. Sleep Res.* 2000



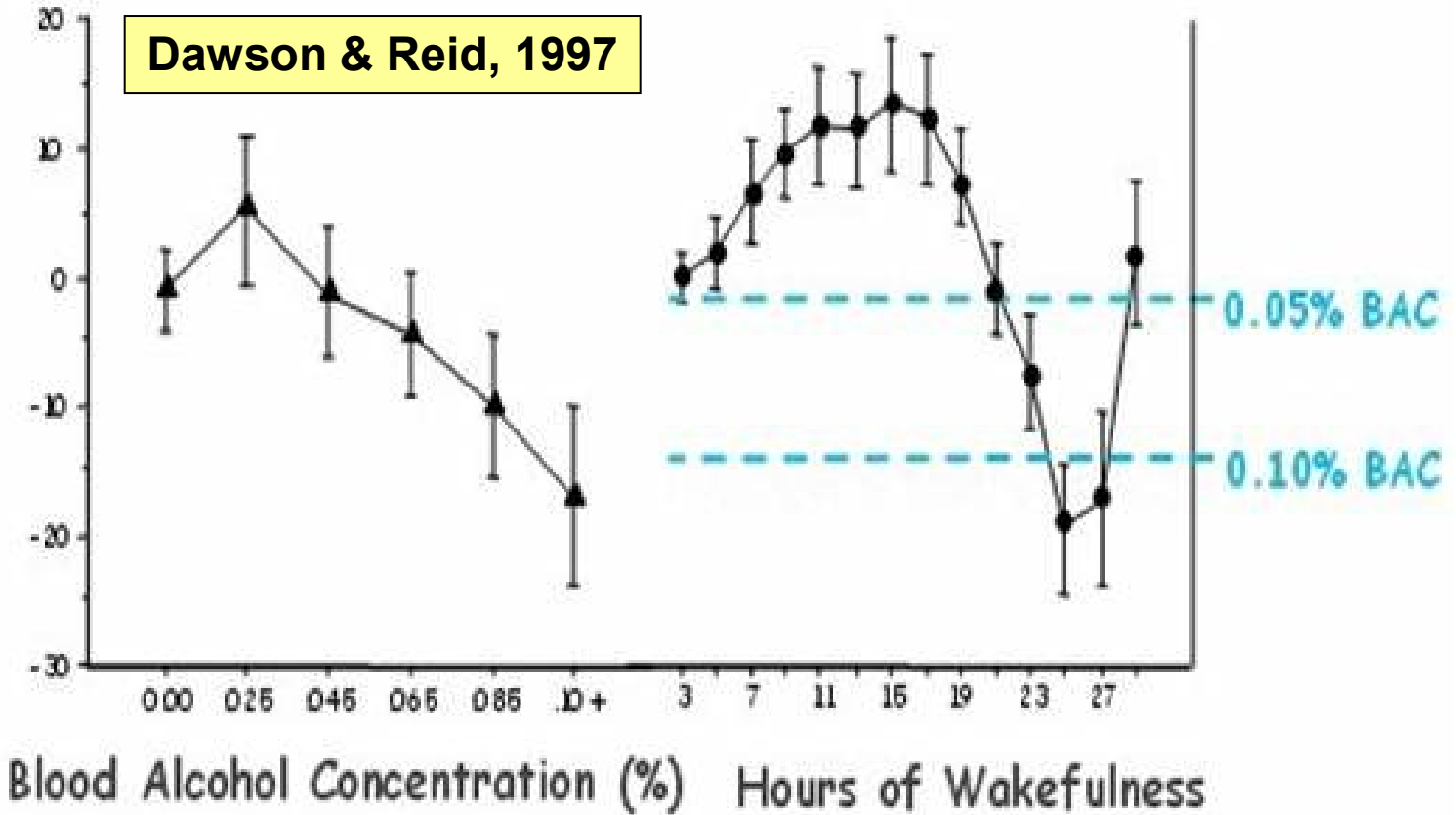
Sleep Deprivation, Circadian Rhythm, Time on Task, and Performance





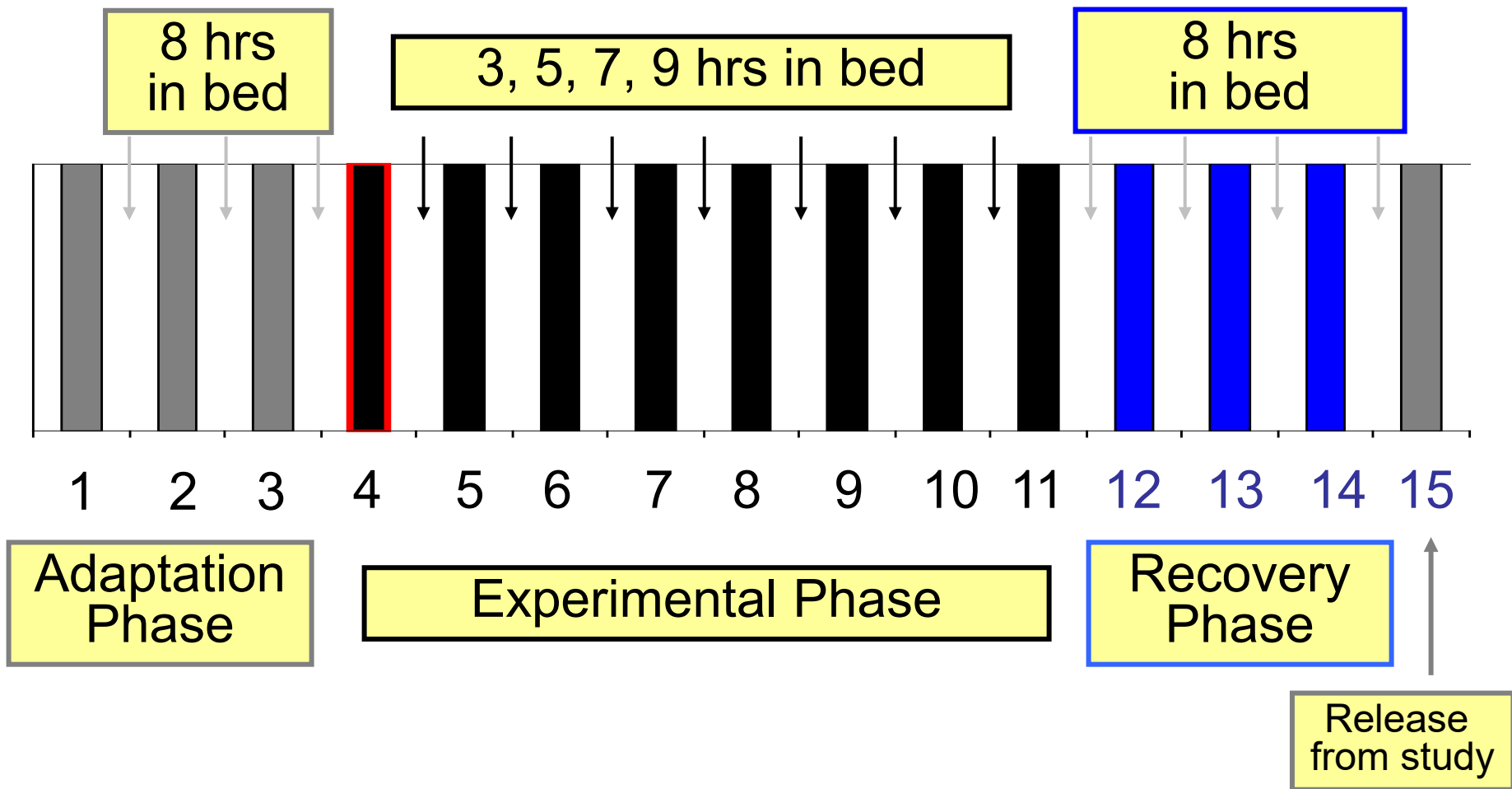
Sleep Deprivation and Alcohol Intoxication

Mean Relative Performance





Effects of Sleep Restriction in Performance: A Sleep Dose/Response Study





Volunteers in the Laboratory

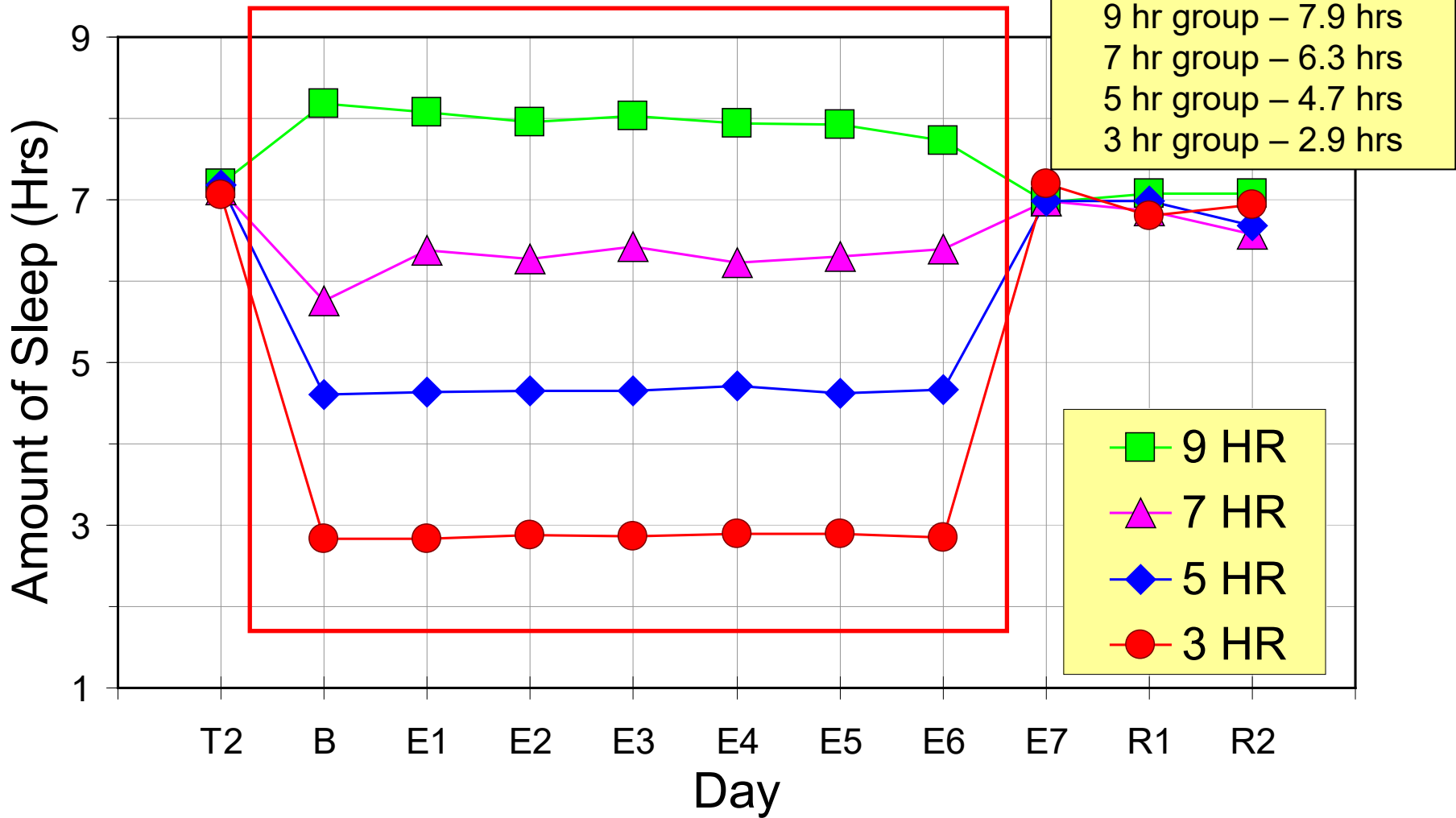


- *Sleep measured with poly-somnography (electrodes, wires, recorders)*
- *Performance measured with computer-based tests.*



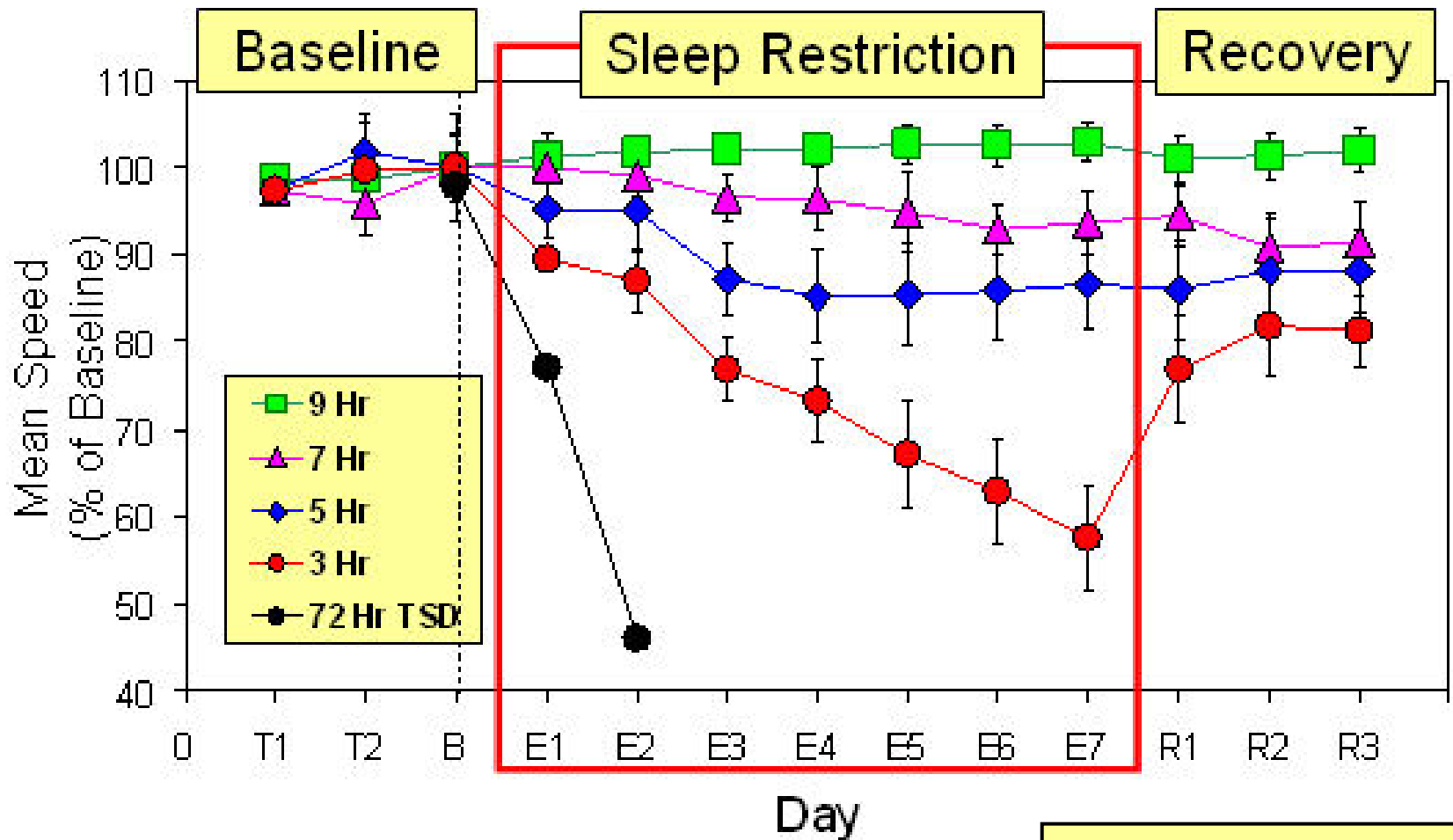


Mean Sleep, Baseline, Experimental Days, & Recovery





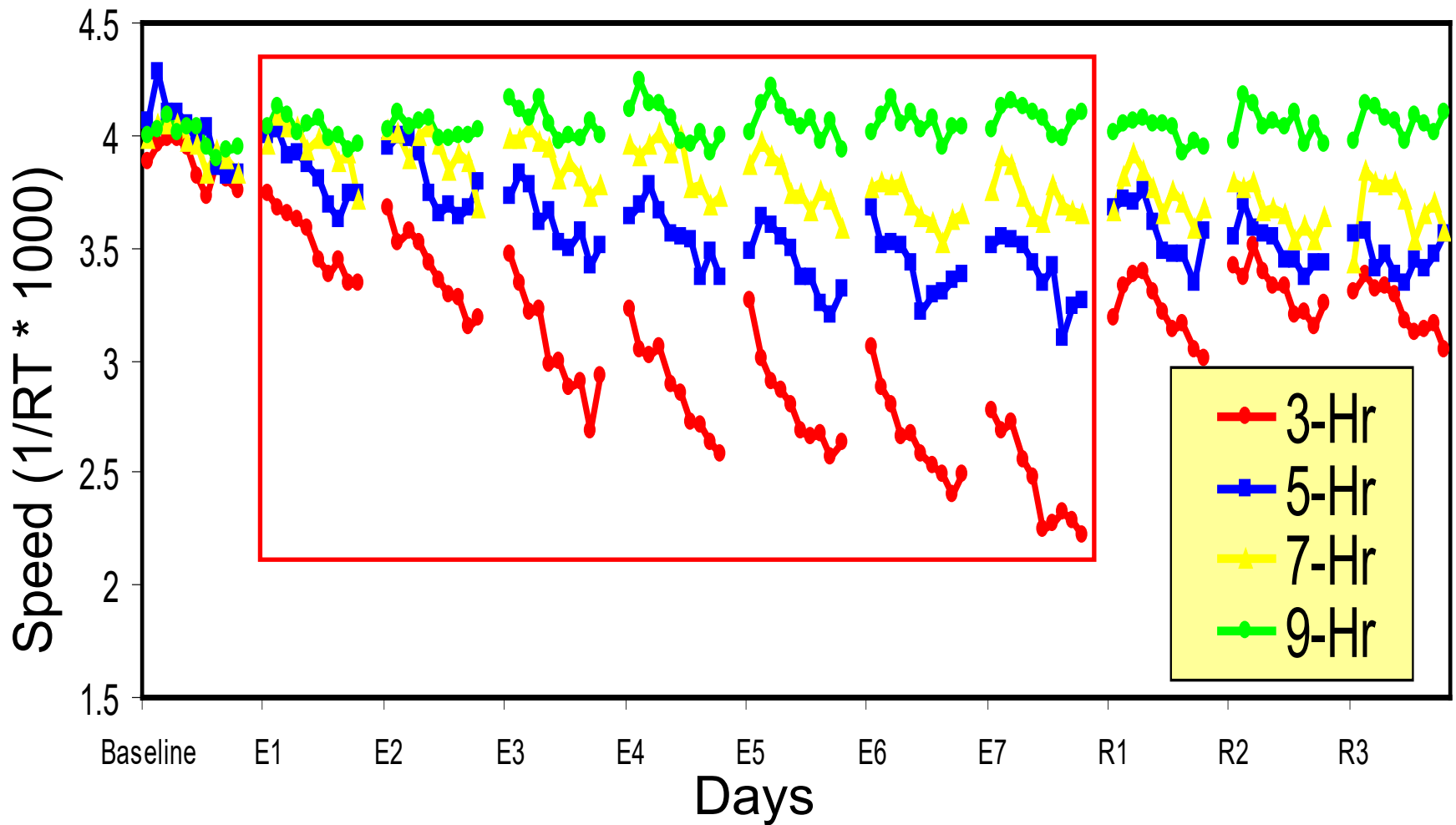
Psychomotor Vigilance Task



Belenky et al., 2003



PVT - Time on Task Effects



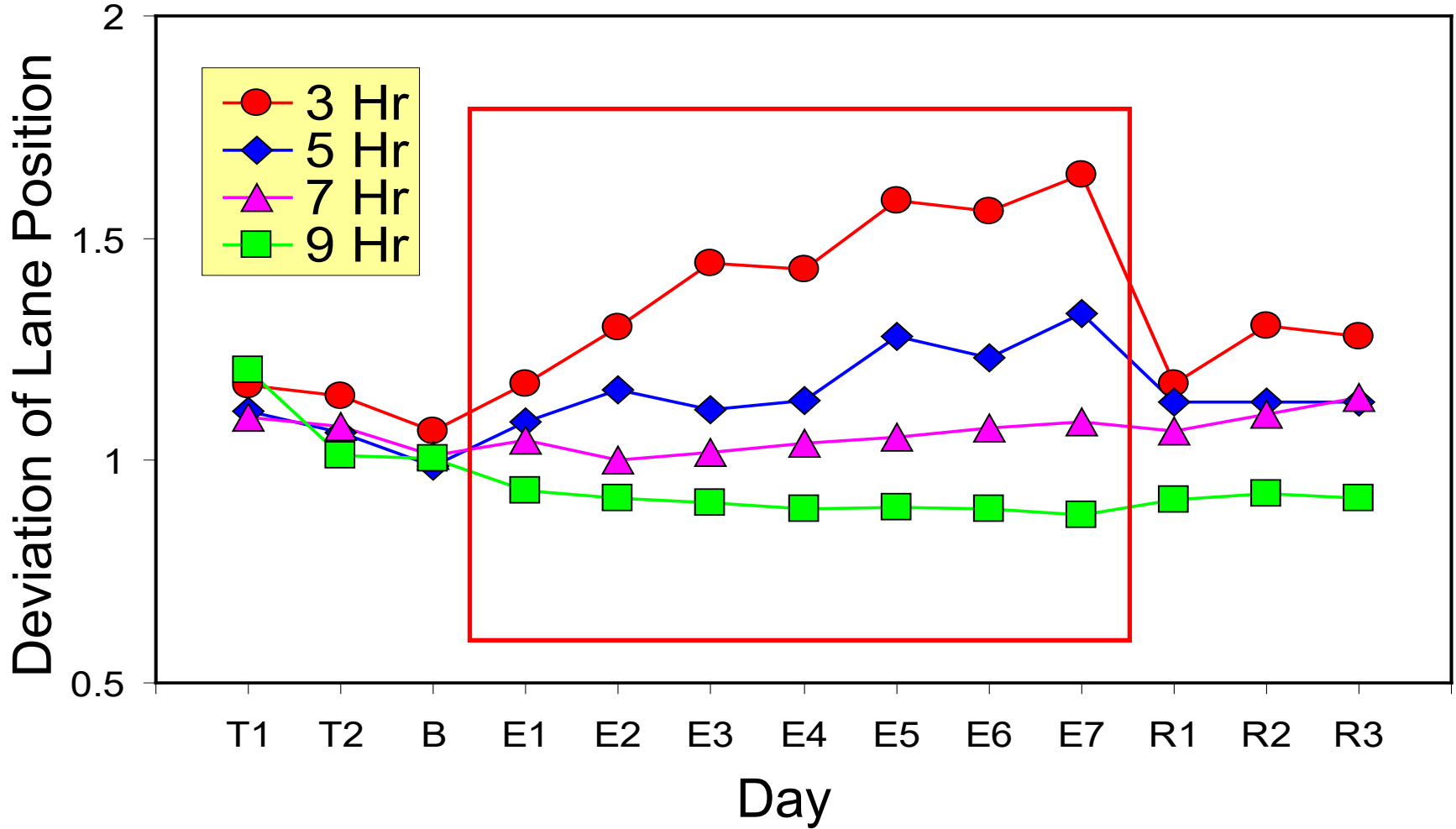


Driving Simulator



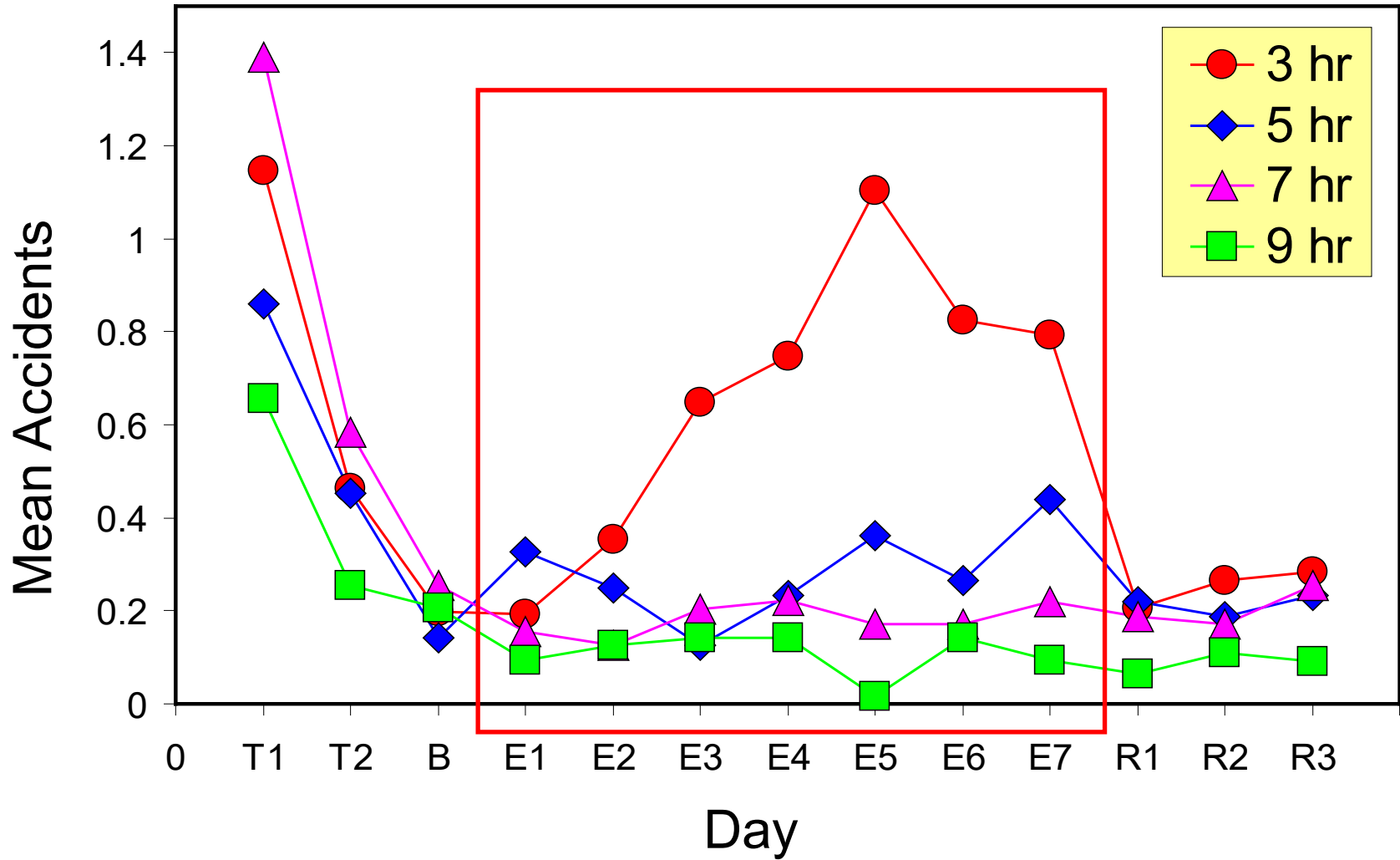


Driving Simulator – Lane Deviation





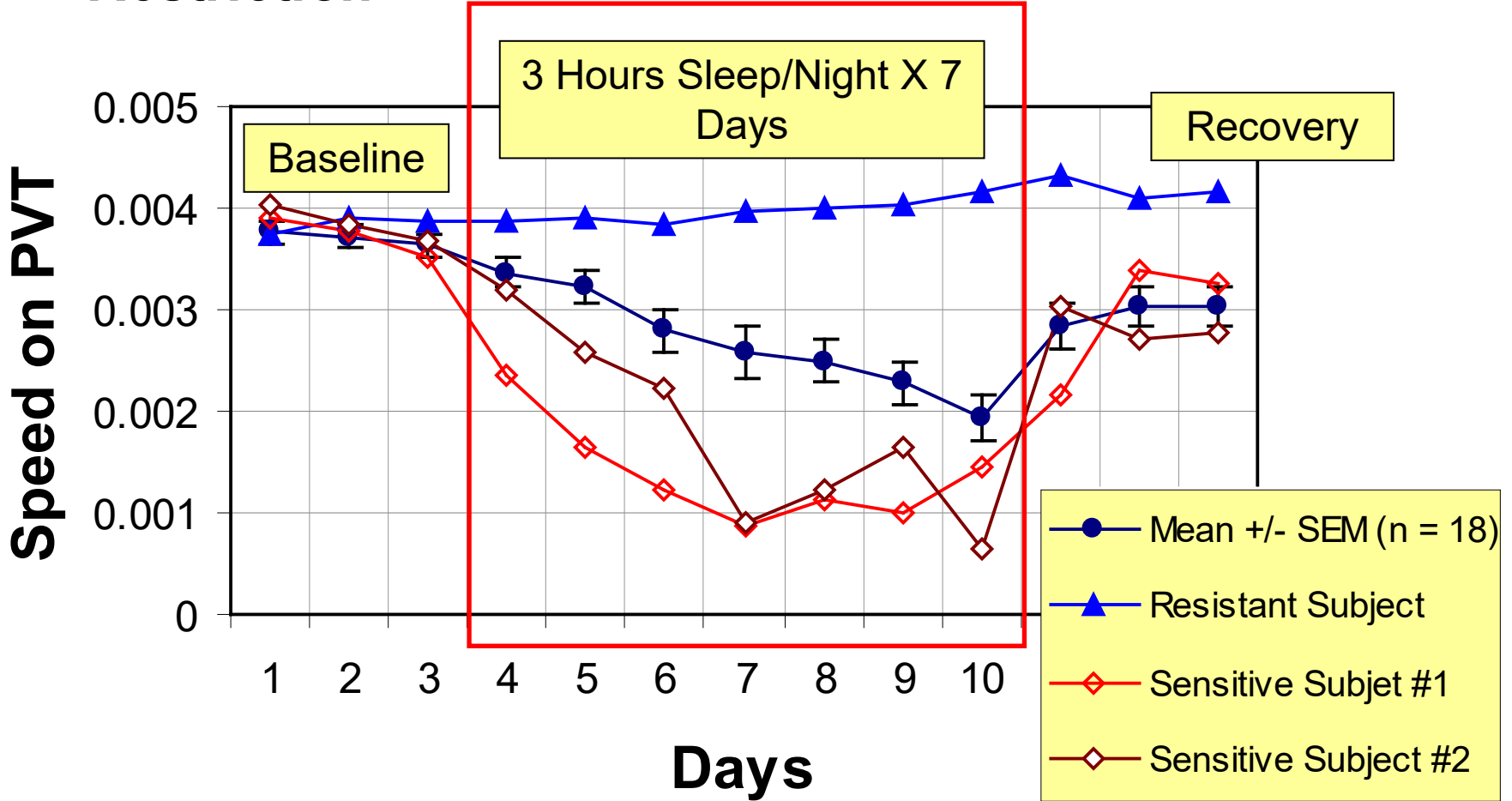
Driving Simulator - Accidents





Individual Variability in Resistance to Sleep

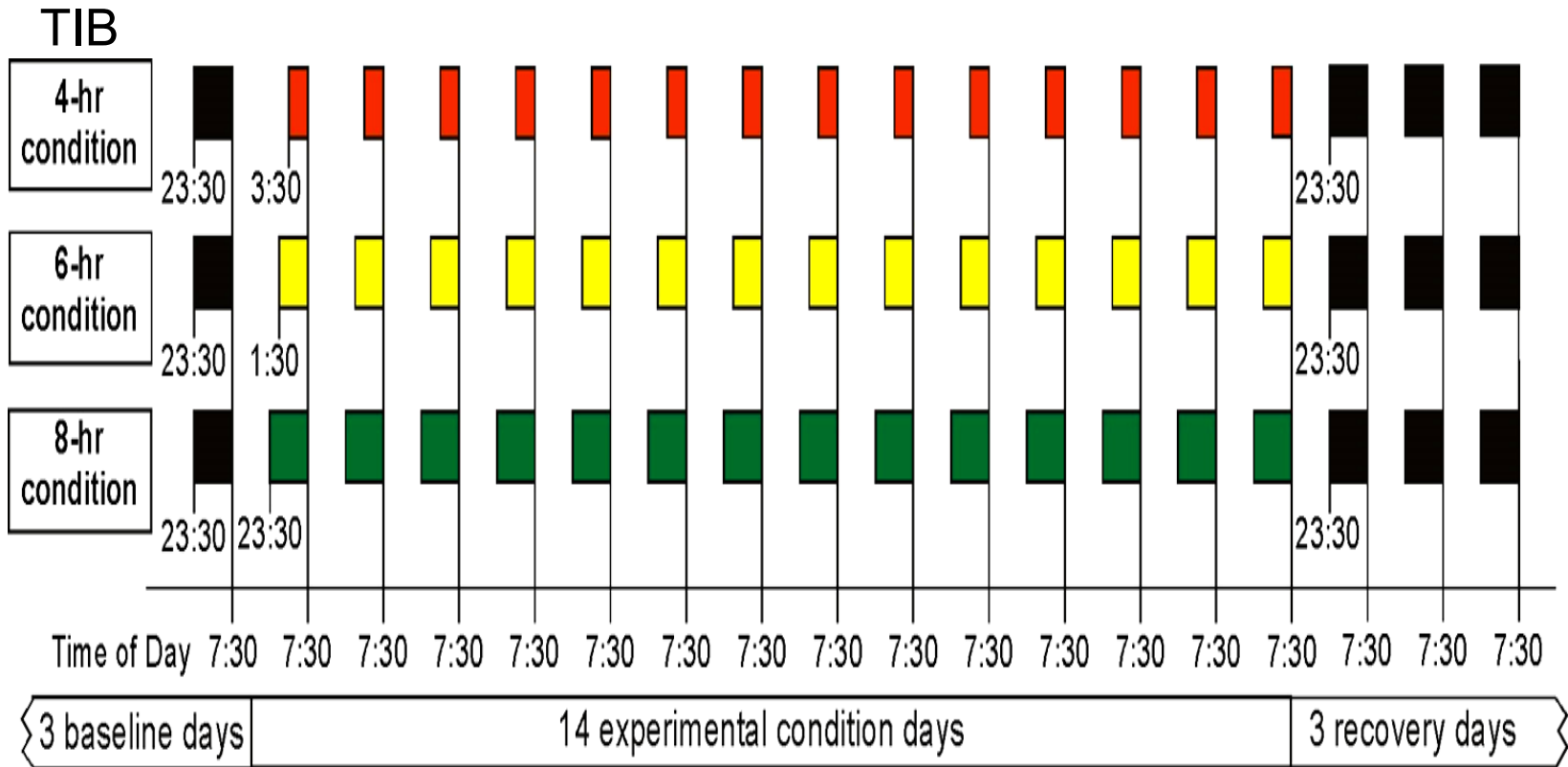
Restriction





Van Dongen et al. (2003)

Sleep-Dose Response Study Design

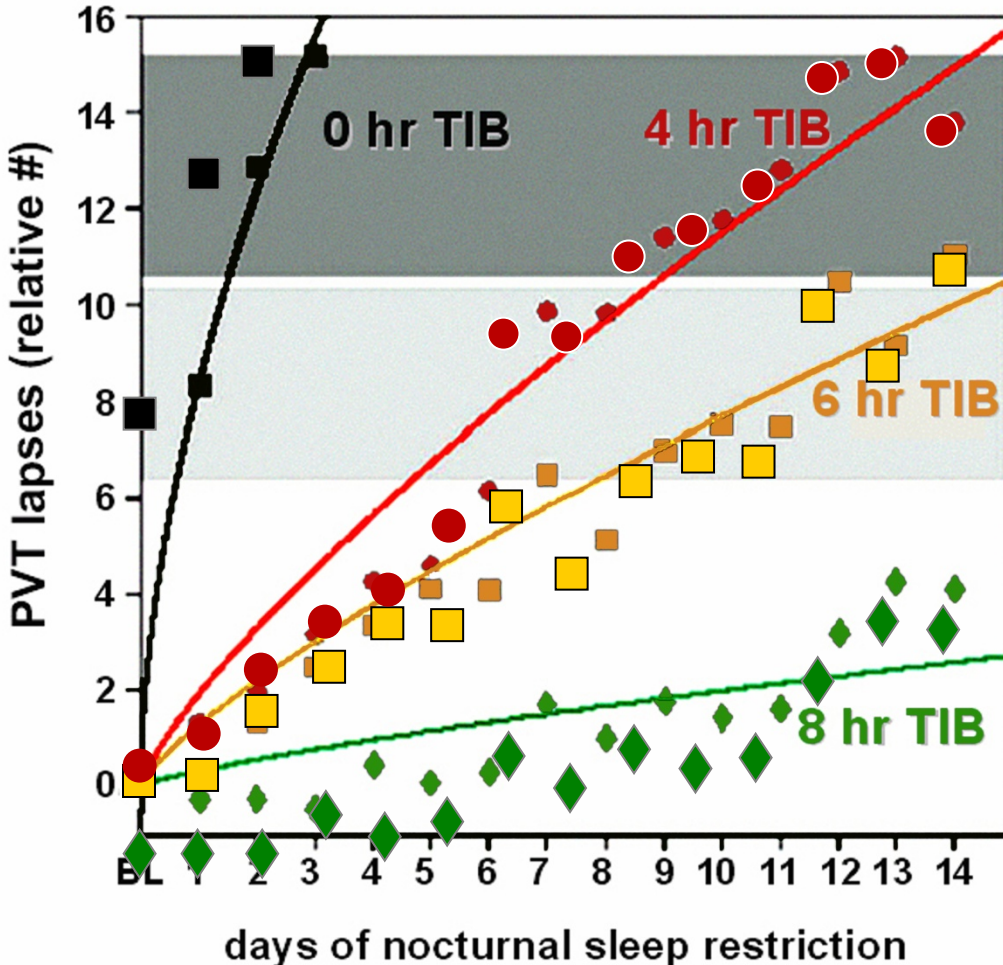




Van Dongen et al. (2003)

PVT Performance Lapses

Each point is a daily average of 9 test bouts from 0730h to 2330h.



↑ poor performance

Differences among conditions*
 $p = 0.036$

Curvature (SEM)
 $\theta = 0.78 (0.04)$

Effect sizes
4 hr vs 8 hr: **1.45**
6 hr vs 8 hr: **0.71**
4 hr vs 6 hr: **0.43**

*Results of non-linear mixed-model regression to optimally fit data.



Summary of Sleep Physiology and Performance

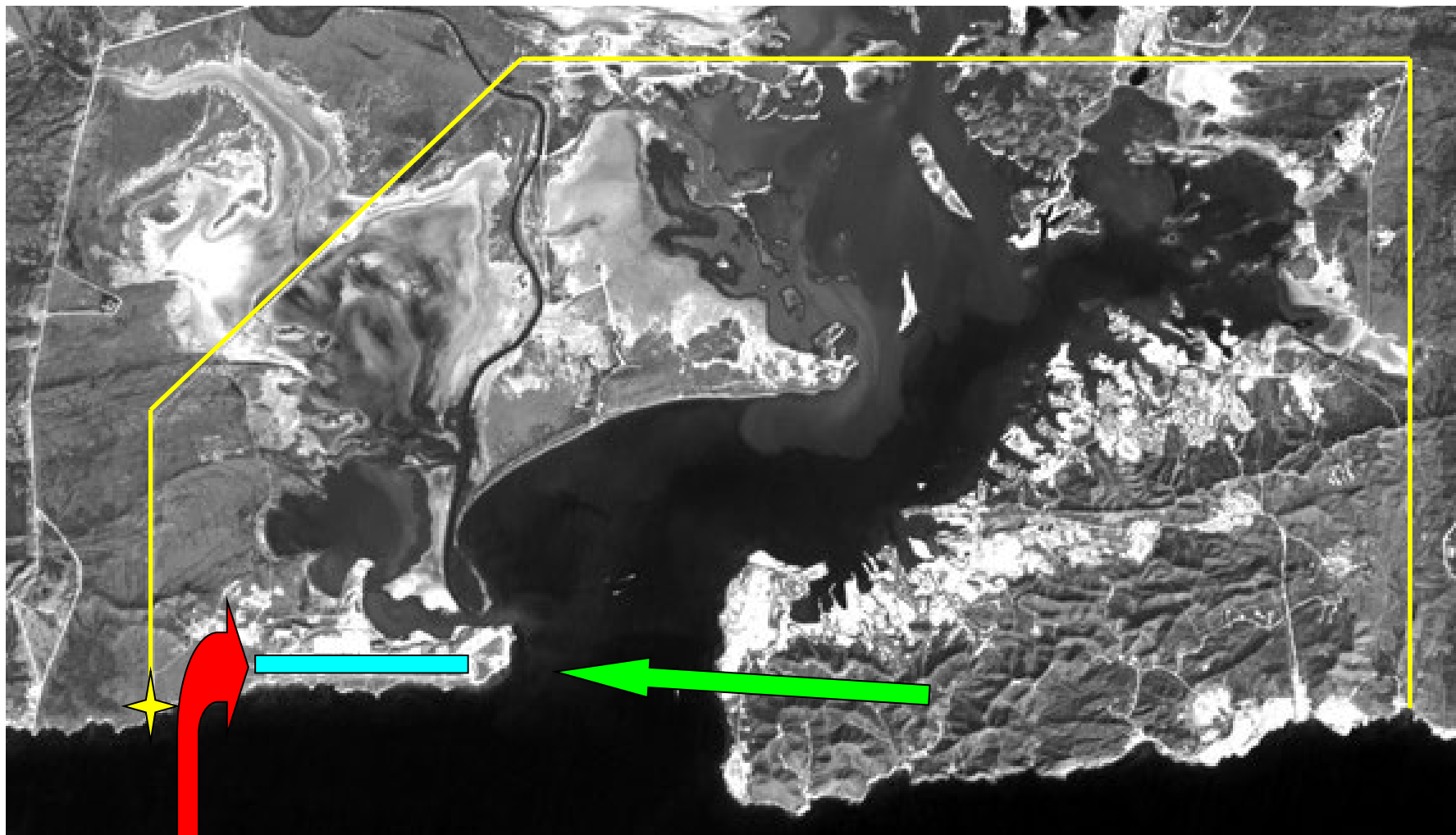
- ***Sleep loss degrades performance***
- ***Sleep restores it***
- ***All performance degrades***
 - ***Complex (anterior/forward in the brain) performance degrades more***
 - ***Example of anterior/posterior gradient – seeing a cup or other common object***
 - ***Evidence from objective brain imaging***
 - ***Perseverance slips into perseveration***
- ***Two states of sleep (NREM, REM)***
 - ***By EEG, different from each other as each is from waking***
 - ***50-year scramble to find unique function for REM***
- ***Total sleep time determines performance***
 - ***Naps add to total sleep time***
 - ***Divided is sleep is as good or better than consolidated***
 - ***Some times of day more sleep-conducive than others***



Acute Total Sleep Deprivation in a Air Cargo Flight Accident



Guantanamo Bay, Cuba





The Approach to Guantanamo



***Approach to Guantanamo
requires a sharp right bank to avoid
Cuban air space***





Crash Site



***All 3 crew members were rescued
from the cockpit and survived***



American International Flight 808

18 August 1993

Engineer: Slow, Airspeed

Co-Pilot: Check the turn.

Captain: Where's the strobe?

Co-Pilot: Right over here.

Captain: Where?

Co-Pilot: Right inside there, right inside there.

Engineer: You know, we're not gettin' our airspeed back there.

Captain: Where is the strobe?

Co-Pilot: Right down there.

Captain: I still don't see it.

Engineer: #, we're never goin' to make this.

Captain: Where do you see a strobe light?

Co-Pilot: Right over here.

Captain: Gear, gear down, spoilers armed.

Engineer: Gear down, three green spoilers, flaps, checklist

???: There you go, right there, lookin' good.

Captain: Where's the strobe?

Co-Pilot: Do you think you are going to make this?

Captain: Yeah... if I can catch the strobe light.

Co-Pilot: 500, you're in good shape.

Engineer: Watch the, keep your airspeed up.

Co-Pilot: 140. [sound of stall warning]

???: Don't – stall warning.

Captain: I got it.

Co-Pilot: Stall warning.

Engineer: Stall Warning

Captain: I got it, back off.

???: Max power!

???: There it goes, there it goes!

???: Oh no!



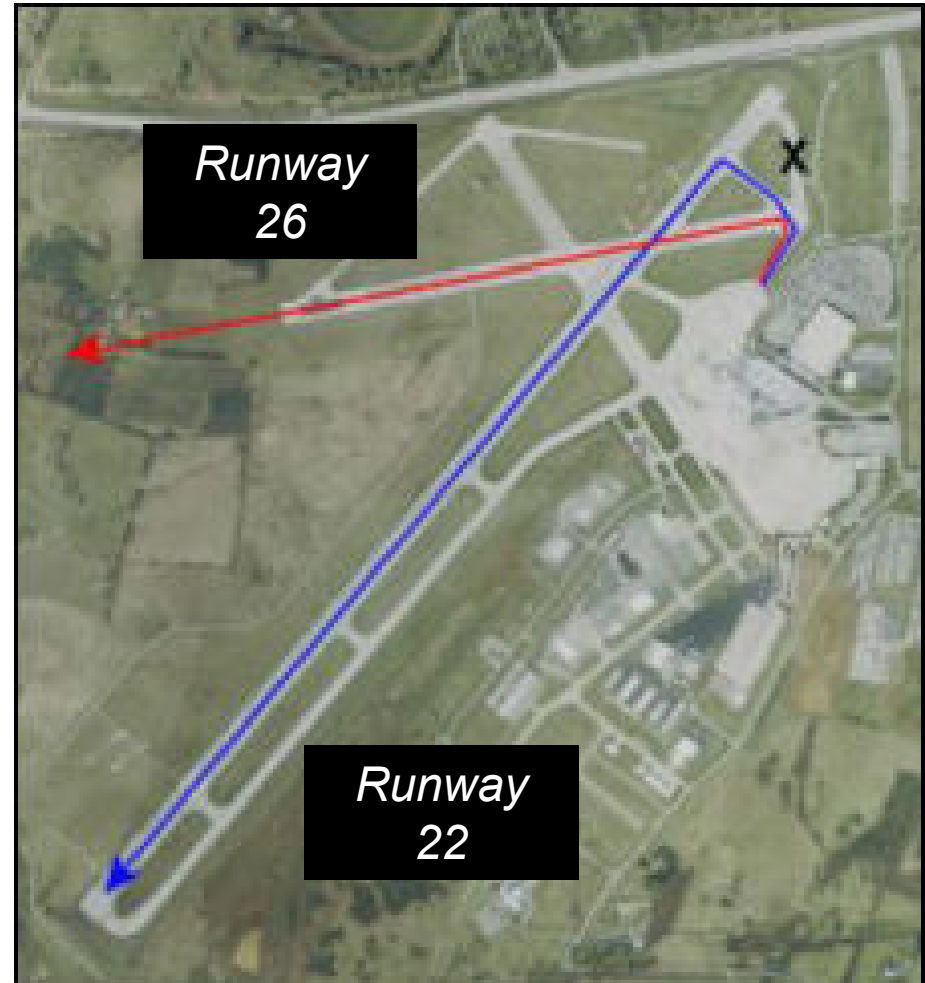
Acute Partial Sleep Deprivation in an Air Traffic Control and Pilot Error Accident



Comair Flight 5191



- **Lexington, KY to Atlanta, GA**
- **Take off ~ 0630 hrs**
- **Assigned the Runway 22**
- **Used Runway 26**
- **Pilot took wrong turn onto unlit Runway 26**
- **Neither pilots nor air traffic controller noticed error**
- **Turned aircraft over to First Officer for take off**
- **Crashed just past the end of the runway**
- **Killed all 47 passengers and two of the three crew**
- **Similar error in 1993**
 - **Caught prior to take-off roll**
 - **By both pilots and air traffic controller**





Sleep in Air Traffic Controller and Pilots

- ***Air traffic controller (a 17-year veteran) working alone at an airport in Kentucky***
 - ***Worked early day shift from 0630-1430 hours (6:30 AM – 2:30 PM)***
 - ***Had the mandatory by FAA rules 8 hours off***
 - ***Slept ~ 2 hours in the late afternoon***
 - ***Went back to work at 2330 (11:30 PM)***
 - ***Worked through the night until the accident at ~0600 hrs***
- ***Pilots and co-pilot scheduled for take-off at 0600 hrs***
 - ***Likely in bed no earlier than 2200 hrs (10:00 PM)***
 - ***Awake at 0400 hrs.***
- ***Both air traffic controller and pilots were sleep restricted and at low point in circadian rhythm***



Other Sleep-Related Catastrophes

- *Three-Mile Island Nuclear Reactor Accident 1979*
- *Challenger Launch Decision 1986*
- *Chernobyl Nuclear Reactor Accident 1986*
- *Exxon-Valdez Grounding 1989*

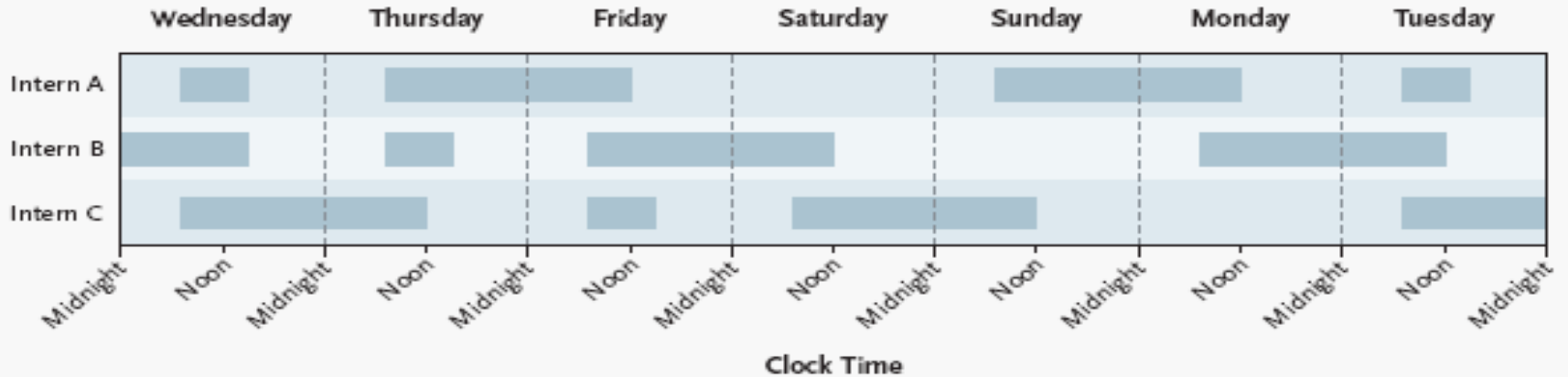


***The Harvard Intervention Studies:
Embedded and Superimposed Performance Metrics***

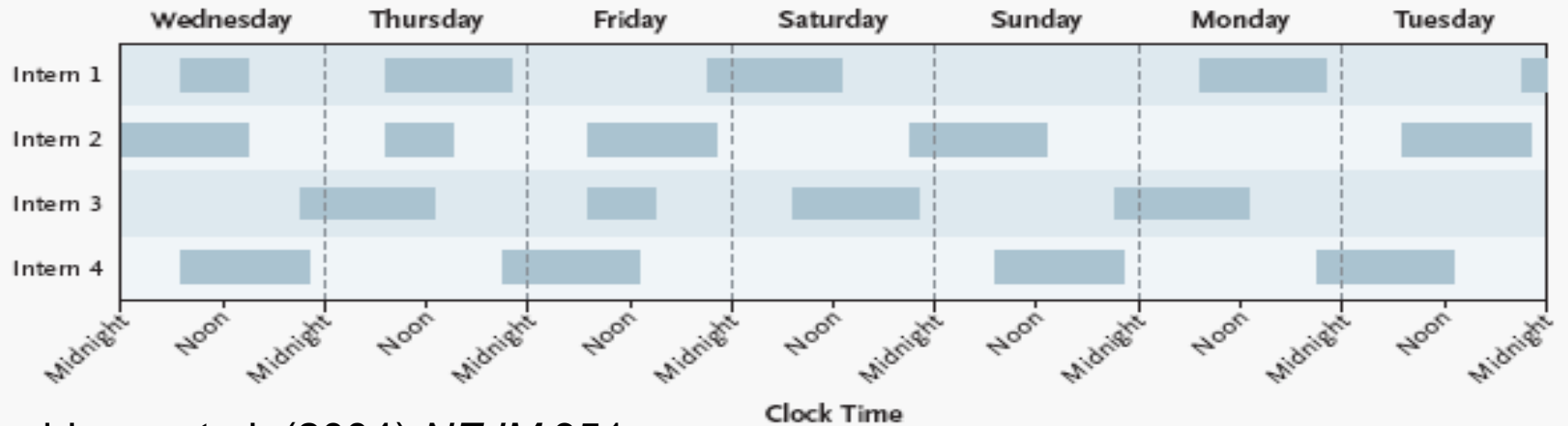


Traditional vs. Intervention Schedule

A Traditional Schedule



B Intervention Schedule

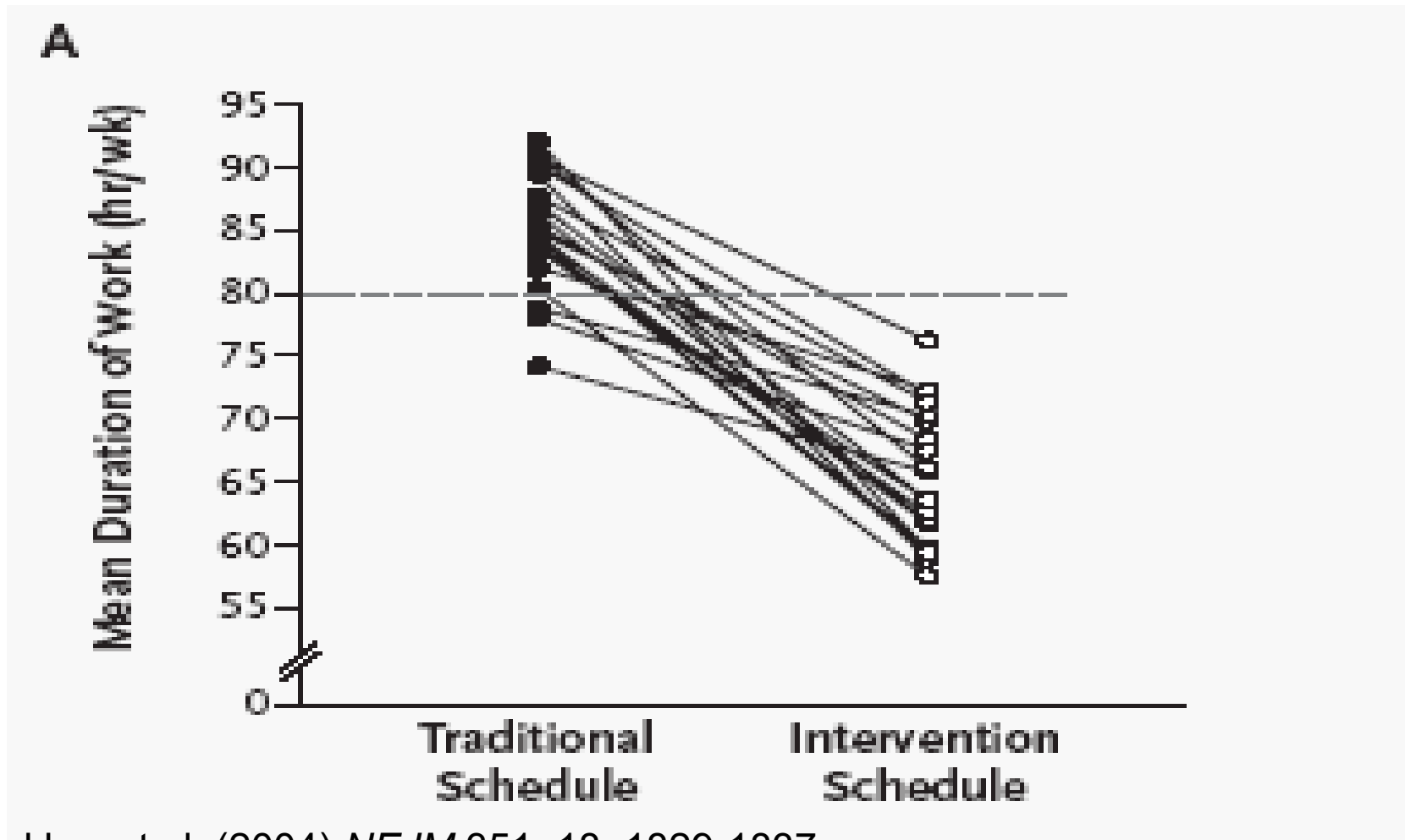


Landrigan, et al. (2004) *NEJM* 351:

18, 1838-1848



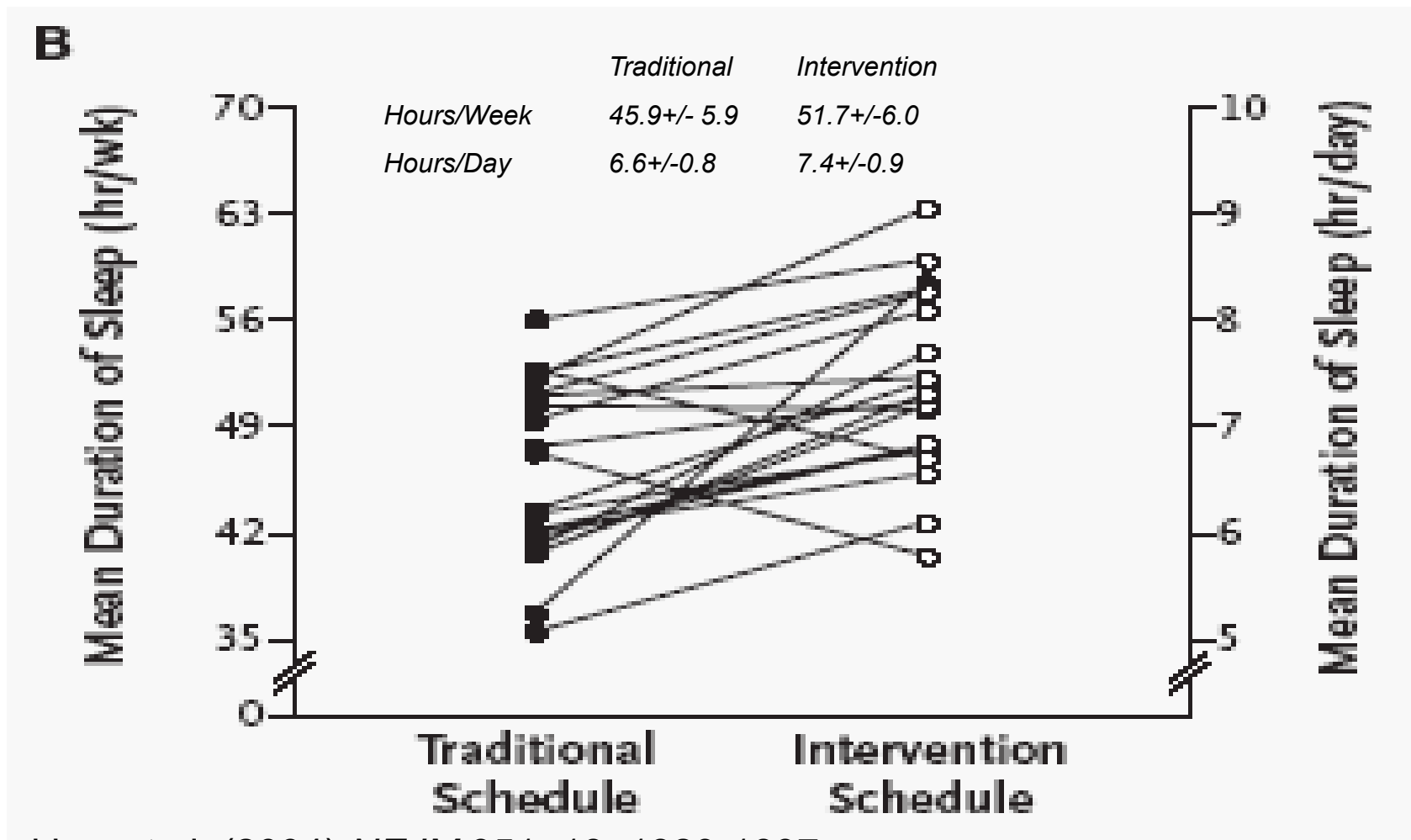
Duration of Work



Lockley, et al. (2004) *NEJM* 351: 18, 1829-1837



Duration of Sleep

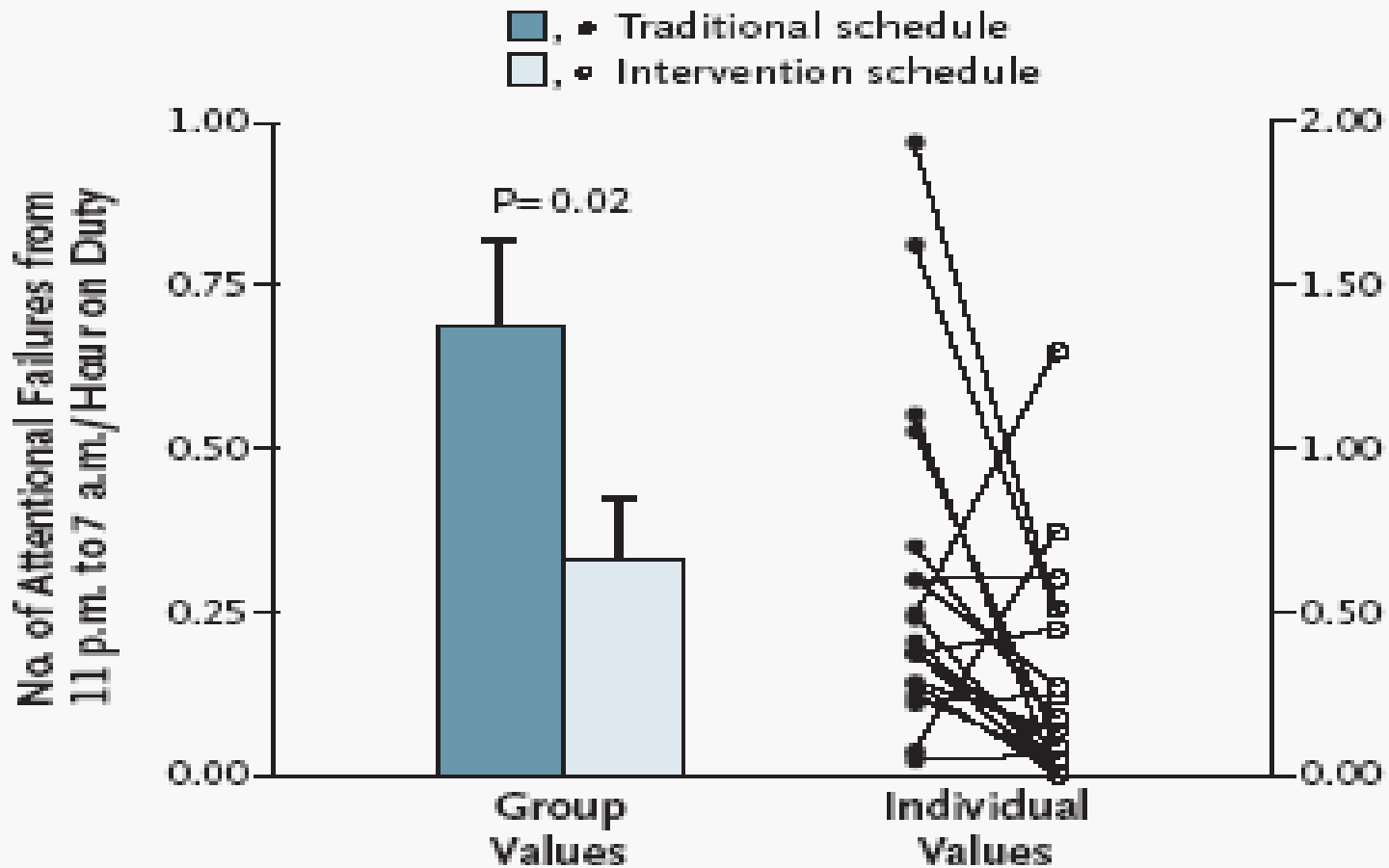


Lockley, et al. (2004) *NEJM* 351: 18, 1829-1837



Limiting Work Hours:

Attentional Failures



Lockley, et al. (2004) *NEJM* 351: 18, 1829-1837



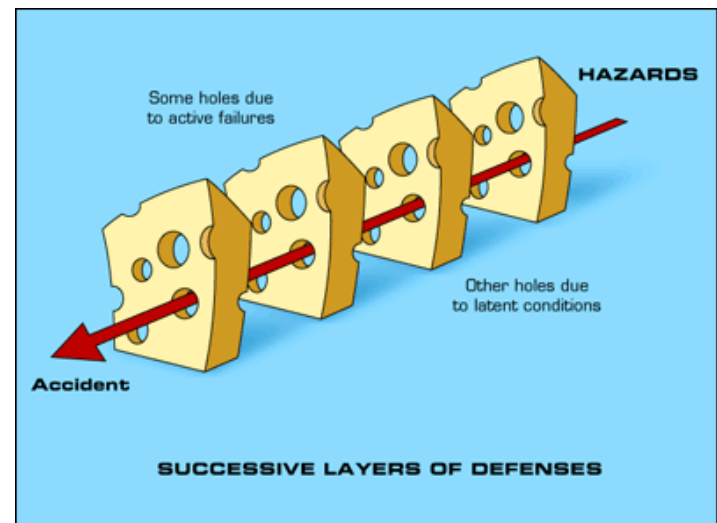
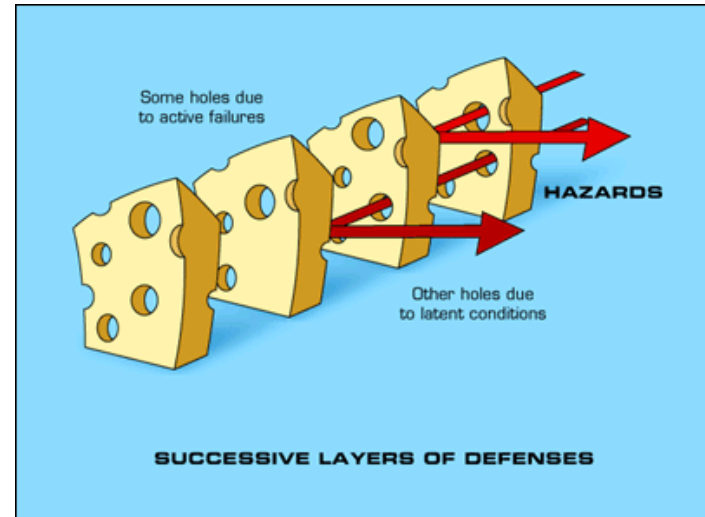
Limiting Work Hours: Effect on Serious Medical Errors

Variable	Traditional Schedule	Intervention Schedule	P Value
	<i>no. of errors (rate/1000 patient-days)</i>		
Serious medical errors made by interns			
Serious medical errors	176 (136.0)	91 (100.1)	<0.001
Preventable adverse events	27 (20.9)	15 (16.5)	0.21
Intercepted serious errors	91 (70.3)	50 (55.0)	0.02
Nonintercepted serious errors	58 (44.8)	26 (28.6)	<0.001
Types of serious medical errors made by interns			
Medication	129 (99.7)	75 (82.5)	0.03
Procedural	11 (8.5)	6 (6.6)	0.34
Diagnostic	24 (18.6)	3 (3.3)	<0.001
Other	12 (9.3)	7 (7.7)	0.47



Reason's Swiss Cheese Model of Accident Causation Applied to a Medical Error

- *Anatomy of a fatal sleep-loss-related medical error*
 - Carelessness
 - Indifference
 - Ignorance
 - Inattention
 - Failed communication
- *5 clear changes to deflect error from reaching the patient*



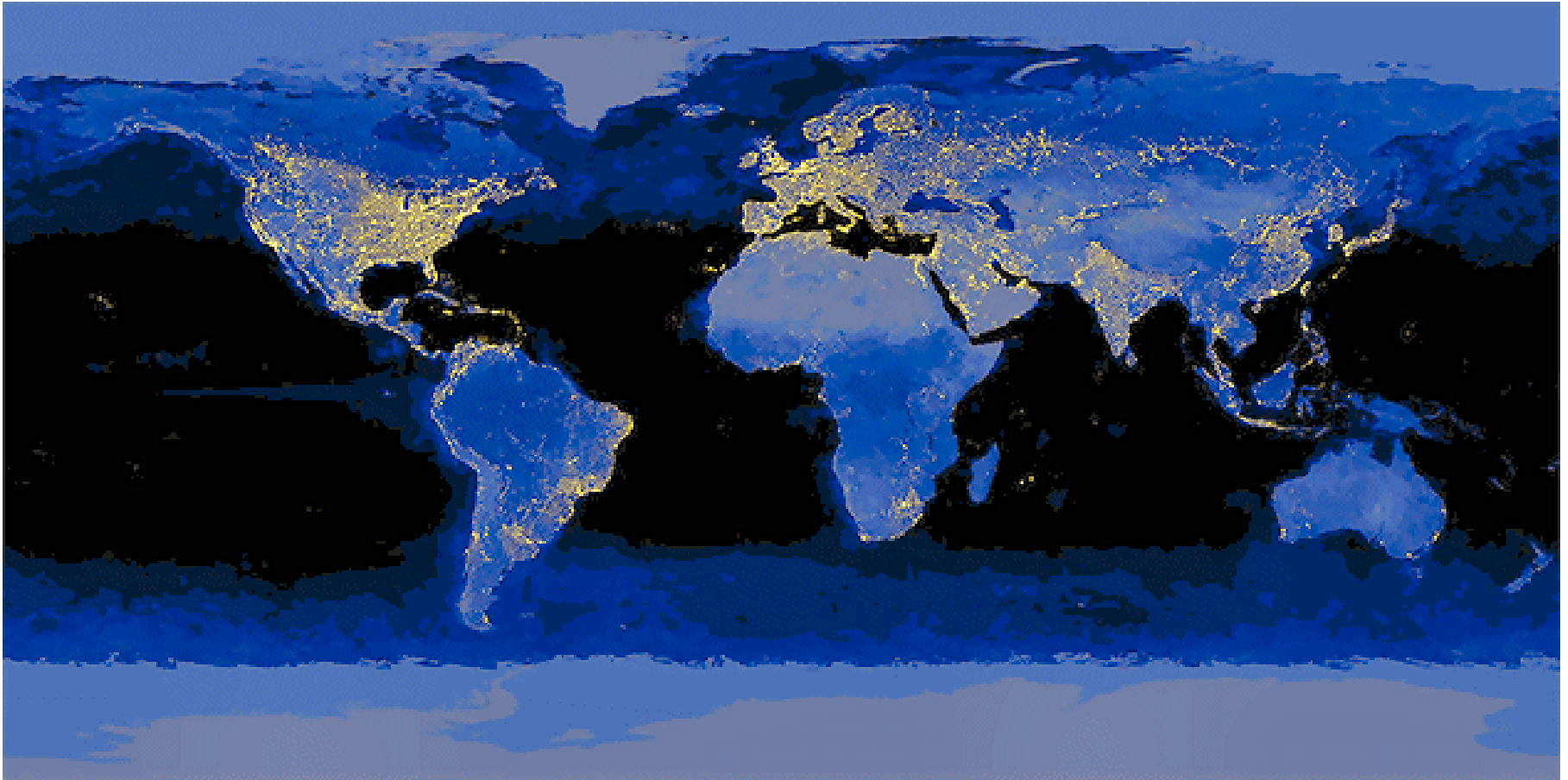


Shiftwork



The Earth at Night:

The Problem of 24/7 Operations





Types of Shifts

- **Day**
- **Afternoon/evening**
- **Night**
- **Early morning**
- **Sleep disruption/truncation greatest for night and morning shifts, least for afternoon/evening**
 - **Primarily the result of sleeping or awakening at adverse circadian phase**
 - **Sleeping in the evening**
 - **Awakening in the early morning**



Shift-Work and Sleep

- ***~Twenty percent of workers in industrialized countries are shift workers***
 - ***Working night shifts***
 - ***Working rotating shifts***
- ***~Ten percent of shift workers suffer from shift-work sleep disorder, with primary complaints of***
 - ***Insomnia and/or***
 - ***Excessive sleepiness***
 - ***In association with work shifts that occur during the habitual circadian entrained sleep phase***
 - ***Shift-lag, similar to jet-lag (trans-meridian desynchronization), except it is chronic***



Shiftwork Sleep Disorder

- ***Results from interaction of human physiology with environment***
- ***Are people with shift work sleep disorder more at risk for error, incident, accident, illness, or other untoward health consequence?***

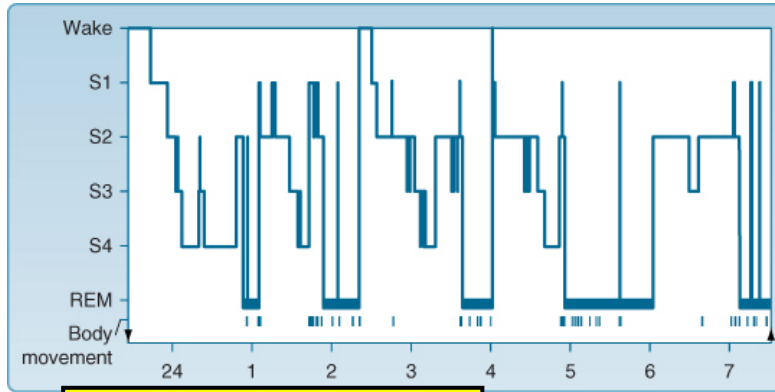


Individual Differences

- ***Individual differences in ability to sleep at non-sleep conducive times of day (phases of circadian rhythm)***
- ***Individual differences in performance response to restricted sleep***
- ***These combine to yield wide individual variability in tolerance to night shifts.***

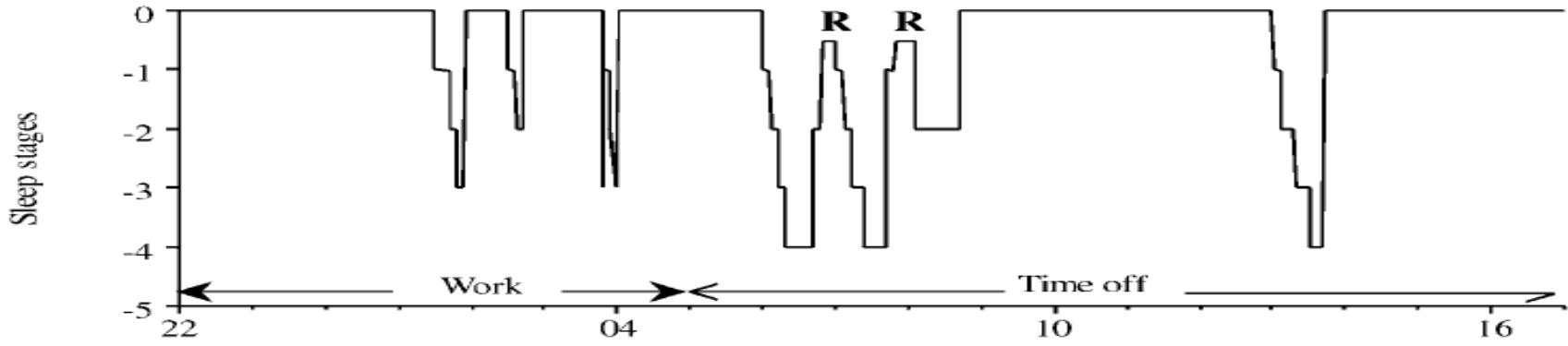


Normal vs. Night Shift-Work Sleep



Normal Sleep

- **Graphs matched on time scale**
- **Note naps during work shift and in late afternoon**
- **Note truncated main daytime sleep**



Shift-Work Sleep



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for Part 2
of Presentation***