Toward a Common Metric for Risk Assessment across Diverse Factors in Fatigue Risk Management Systems: Quantifying Human Performance in Terms of Signal-to-Noise Ratio

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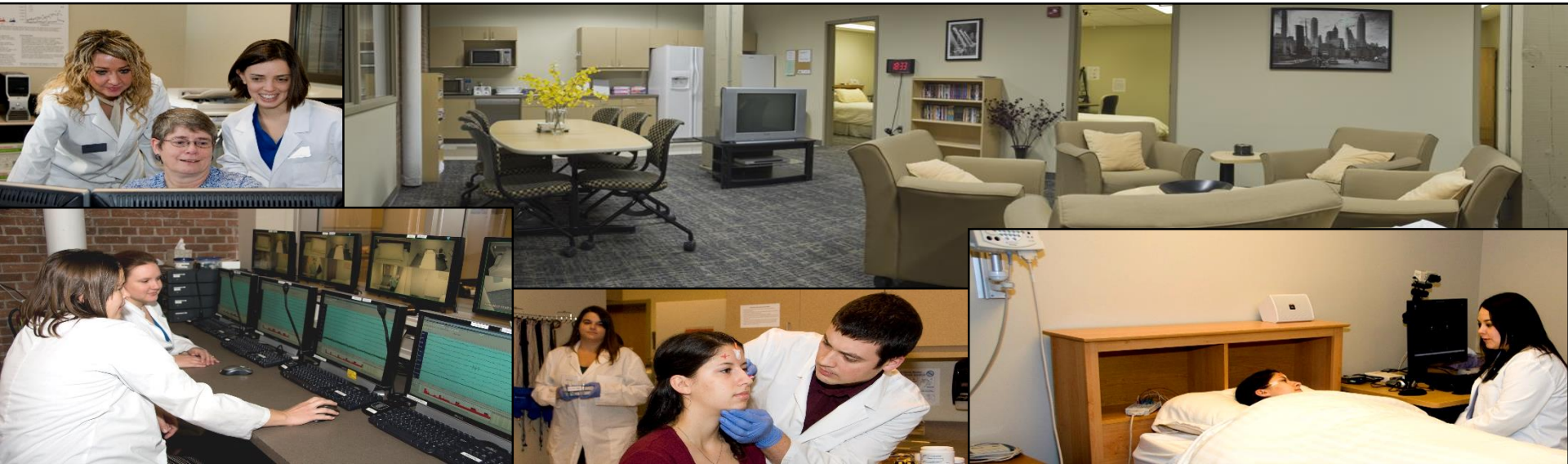
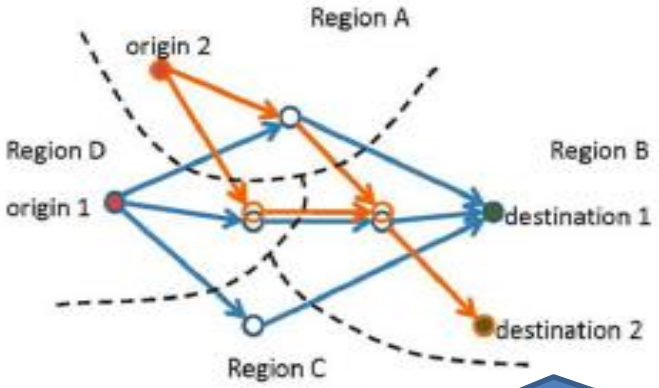
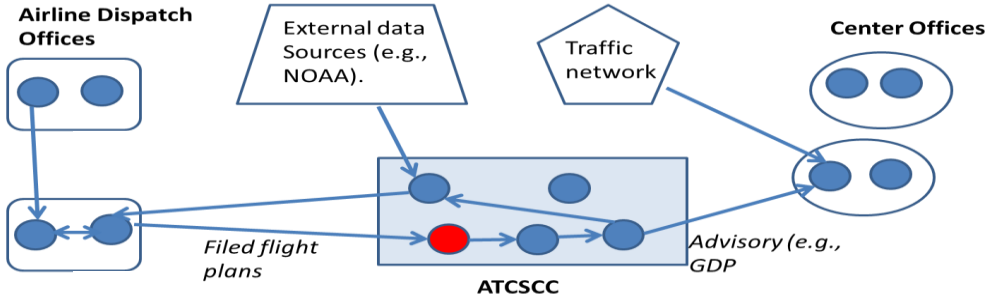
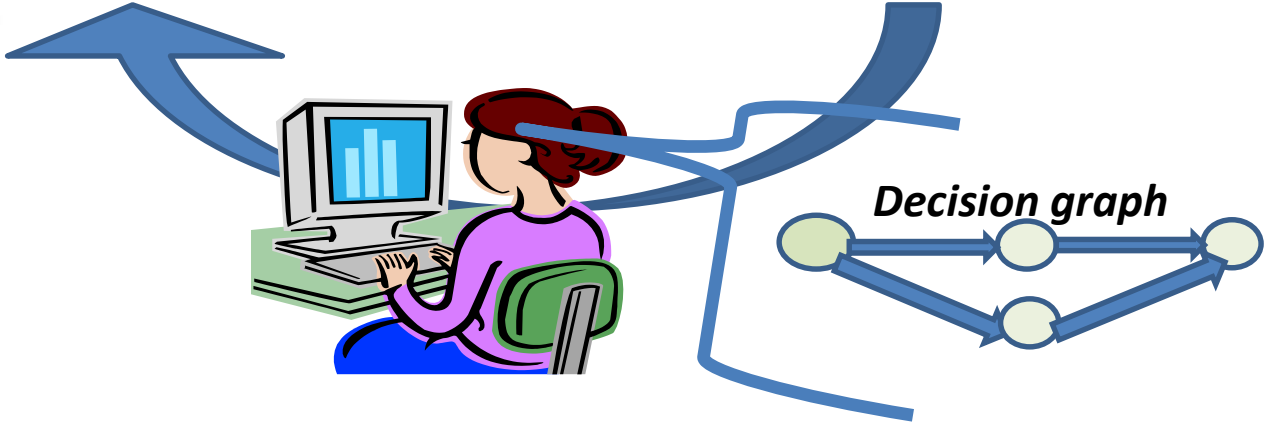


A Typical Problem in Fatigue Risk Management: Assessing the System-Wide Risk from Fatigue in Coupled Physical and Cyber Infrastructures in 24/7 Operations with Humans in the Loop

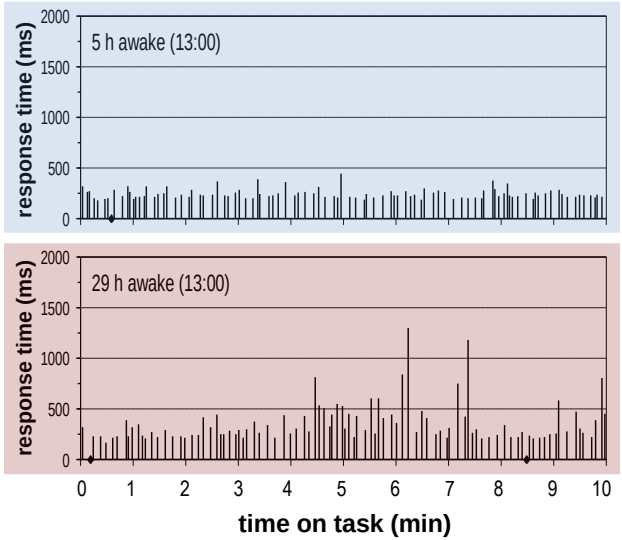




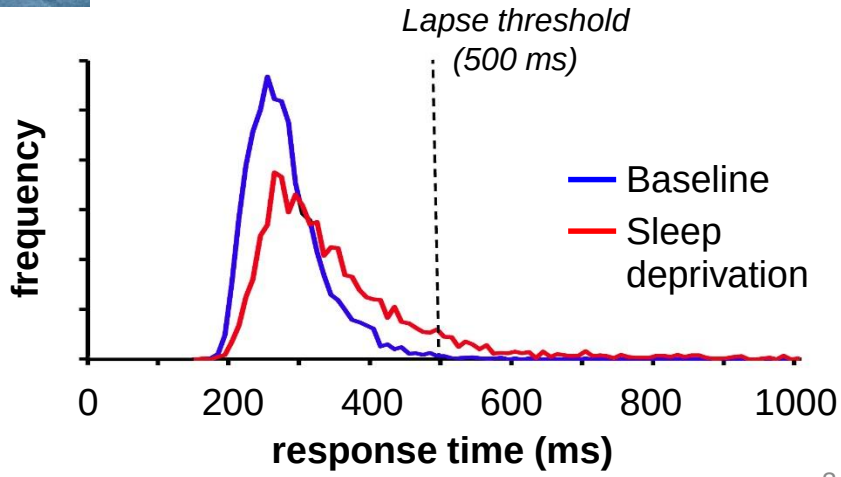


A Key Aspect of Fatigue Risk from Sleep-Deprived Humans in the Loop: Instability in Sustained Attention

Psychomotor Vigilance Test



Psychomotor Vigilance Test (PVT)



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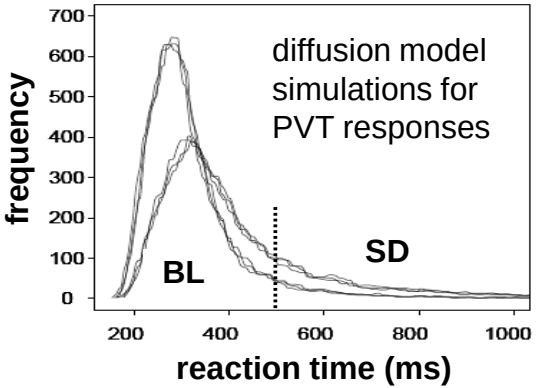
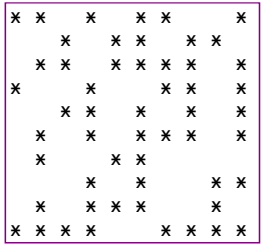
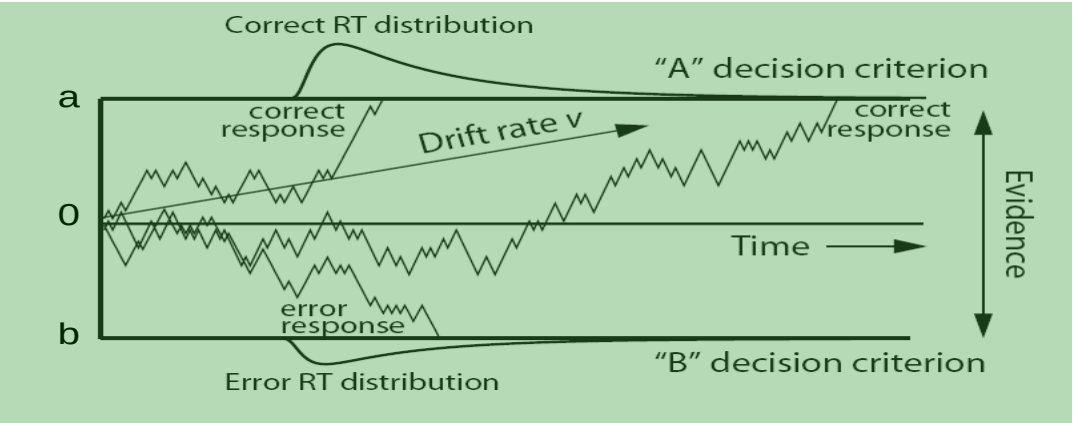
Sleep Deprivation Degrades Cognitive Processing in Neuronal Circuits Involved in Task Performance





Numerosity Discrimination

Diffusion Decision Model



Ratcliff R, Van Dongen HPA. Psychon Bull Rev, 2009; 16(4): 742–751.

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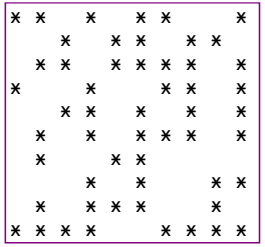
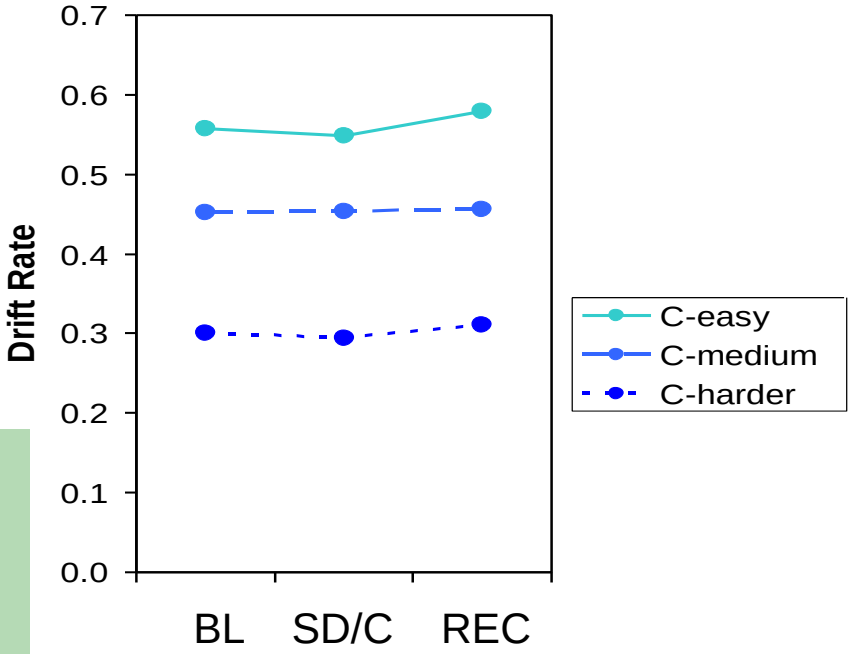


Numerosity Discrimination



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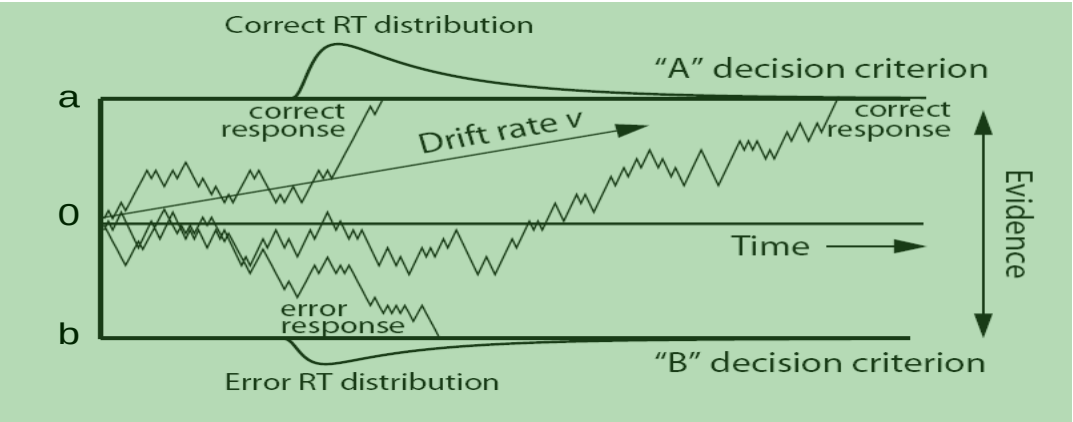

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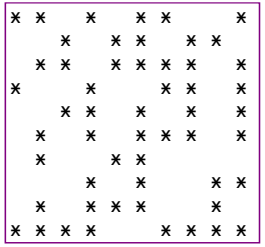

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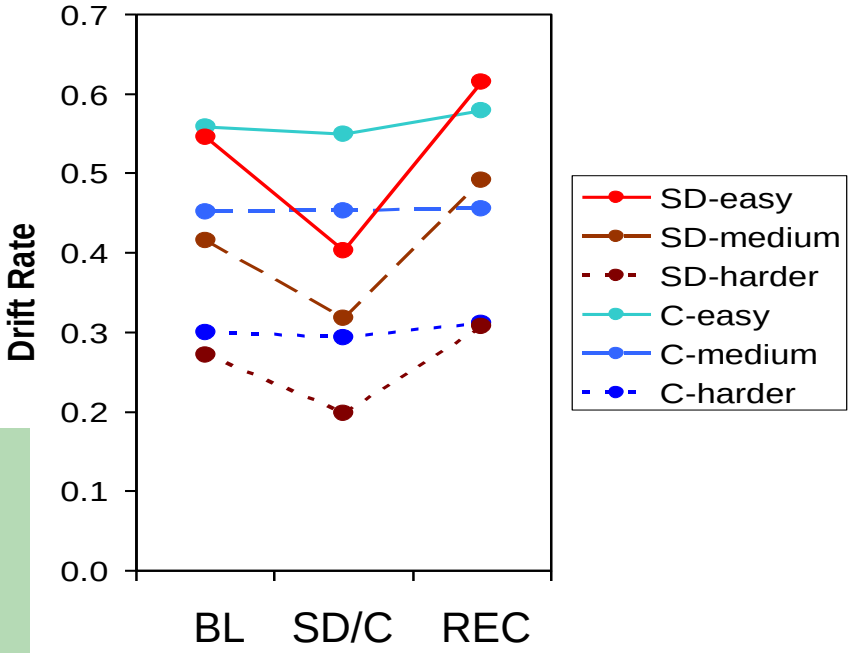

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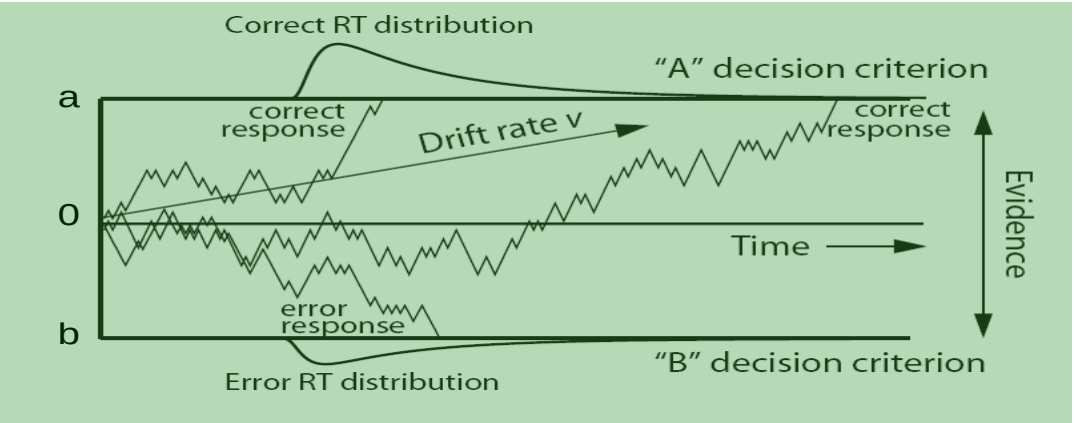

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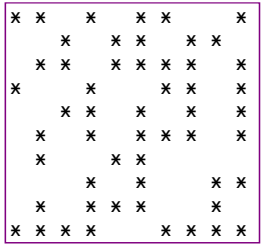
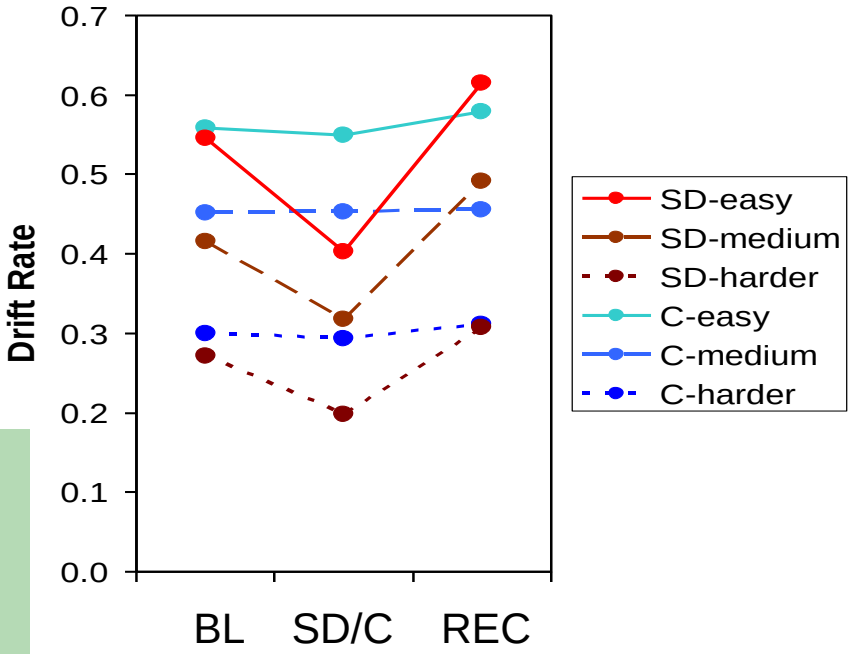
Sleep Deprivation Degrades Cognitive Processing in Neuronal Circuits Involved in Task Performance

Fatigue may make ***any*** cognitive processing harder and less reliable



Numerosity Discrimination



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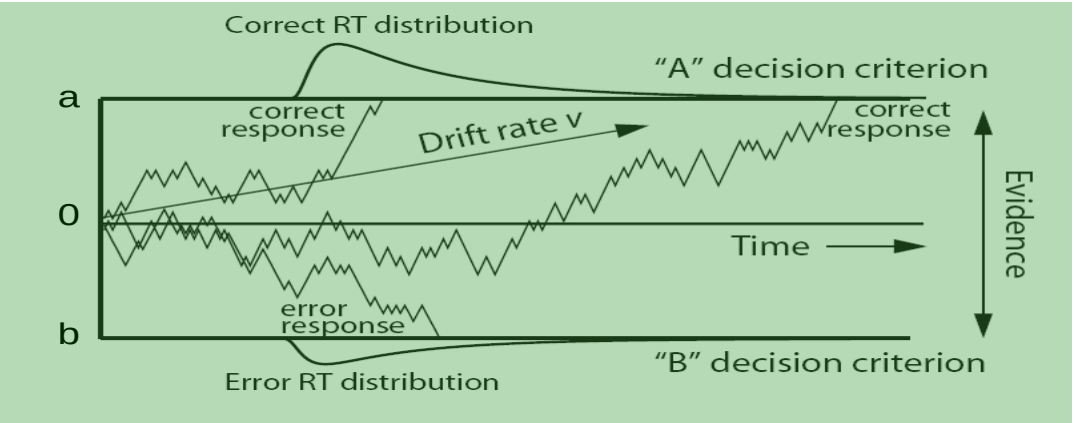

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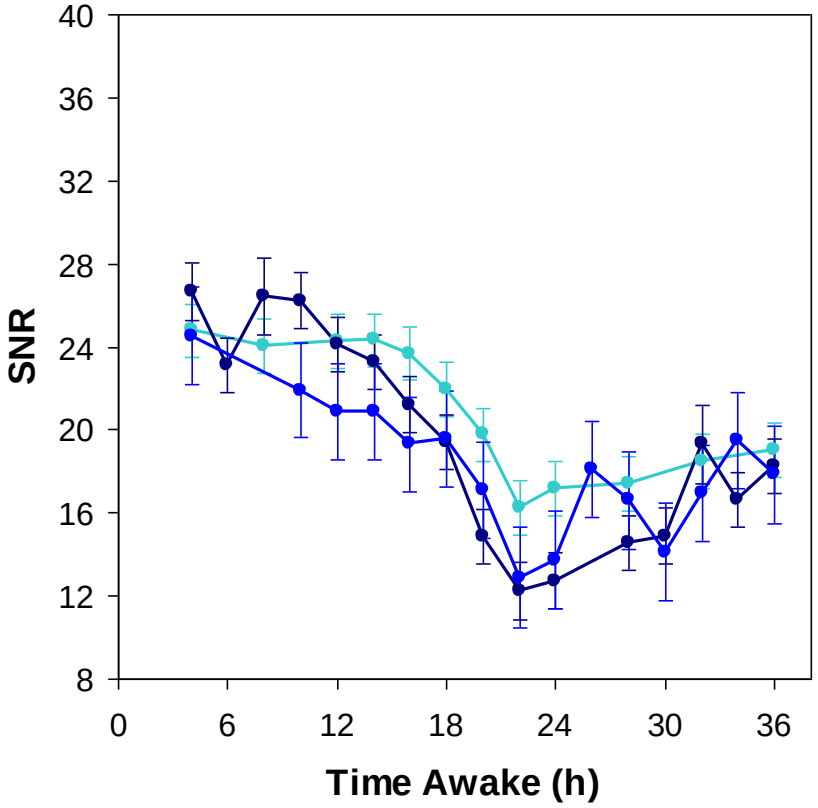
A Diffusion Decision Model-Based Metric of the Fidelity of Information Processing: PVT Signal to Noise Ratio (SNR)

$$SNR \approx \frac{N\left(\sum_{i=1}^{N} w_i S_i\right)^2}{\sum_{i=1}^{N}\left[w_i\left(S_i \sum_{i=1}^{N} w_i - \sum_{i=1}^{N} w_i S_i\right)^2\right]} + 1$$

$S_i = 1 / (RT_i - C)$, $w_i = 1 / (r^2 S_i + 1)$, $C = 100$ ms, $r^2 = 196$ ms,
RT_i is the ith response time (in ms), and N is the number of PVT stimuli

Chavali VP, Riedy SM, Van Dongen HPA. Sleep, 2017, in press.

Impact of Sleep Deprivation on PVT SNR in Laboratory Studies

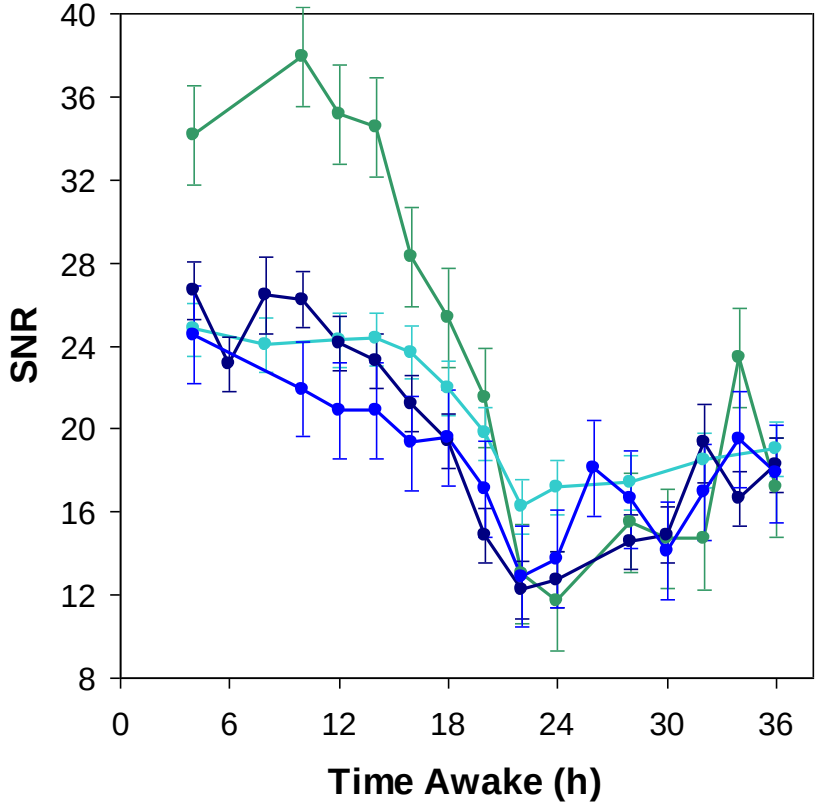


Medium effect size
($f^2 = 0.34$)

Chavali VP, Riedy SM, Van Dongen HPA. Sleep, 2017, in press.

Impact of Sleep Deprivation on PVT SNR in Laboratory Studies

PVT testing
with chin rest



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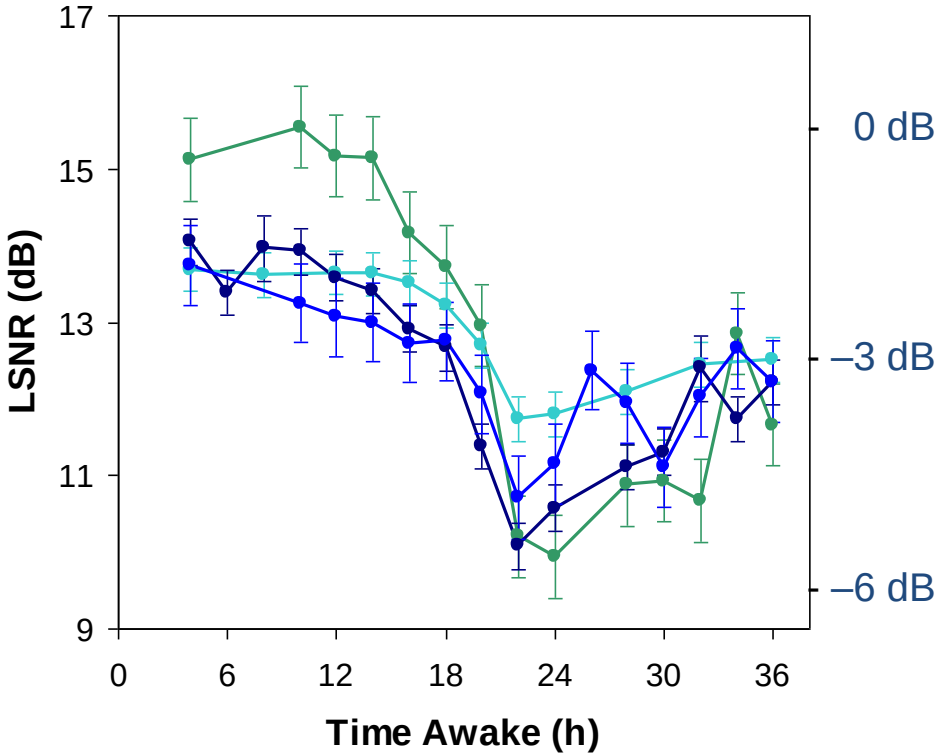
A Baseline-Invariant Version of the PVT SNR Metric

$$LSNR = 10 \log_{10}(SNR)$$

Large effect size
($f^2 = 0.40$)



Chavali VP, Riedy SM, Van Dongen HPA. Sleep, 2017, in press.

Conclusions

- The LSNR metric for the PVT quantifies the fidelity of information processing
- LSNR has high sensitivity to fatigue, high degree of statistical normality, and absence of floor and ceiling effects
- A given change in LSNR always has the same meaning regardless of absolute values – a reduction in LSNR of 3 units (i.e., a −3 dB change) represents a 50% drop in the fidelity of information regardless of the starting point
- The SNR baseline value may therefore be freely chosen to anchor the metric (0 dB point), which is helpful for mathematical models of fatigue
- LSNR provides a basis for calculations of the overall reliability of partially automated operational systems with sleep-deprived humans in the loop
- As such, LSNR may be a useful tool for systems-integrated fatigue risk management

Chavali VP, Riedy SM, Van Dongen HPA. Sleep, 2017, in press.

Acknowledgments

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