# Tenth International Conference on Managing Fatigue: Abstract for Review

## 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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**Problem:** Fatigue risk management systems are concerned with mitigating risks in integrated operational systems with fatigued humans in the loop. Tools have been developed to measure and mitigate fatigue risks. However, it is not clear how fatigue combines and interacts with other risk factors in the operational environment. Quantifying and minimizing overall risk is challenging due to the lack of a common metric for risk assessment across diverse risk factors. We seek to address this issue by means of signal-to-noise ratio (SNR), an index of process reliability already used in many operational areas such as electrical engineering and communication.

**Method:** Human fatigue can be measured with the psychomotor vigilance test (PVT). The PVT is a widely used reaction-time task sensitive to impairment from sleep deprivation and sleep displacement. PVT response-time distributions can be described with a diffusion model for one-choice reaction-time tasks. This conceptualizes cognitive performance as a diffusion process characterized by a drift rate that corresponds to the speed of evidence accumulation in central cognition. The effects of sleep deprivation on PVT response-time distributions are captured by a decrease of the drift ratio, which is the ratio of the mean to the standard deviation of the drift rate across response trials. The decrease in the drift ratio reflects a decrease in the fidelity of information processing. In this framework, we derived an equation for PVT performance in terms of log-transformed SNR (*LSNR*) serving as an index of the fidelity of information processing:

$$LSNR \approx 10\log_{10}\left\{ \frac{N\left(\sum_{i=1}^{N} w_i S_i\right)^2}{\sum_{i=1}^{N}\left[ w_i\left( S_i \sum_{i=1}^{N} w_i - \sum_{i=1}^{N} w_i S_i \right)^2 \right]} + 1 \right\}.$$

Here, $S_i=1/(RT_i - C)$, $w_i=1/(r^2 S_i+1)$, $C$=100 ms, $r^2$=196 ms, $RT_i$ is the $i^{\text{th}}$ response time (in ms), and $N$ is the number of trials in the PVT session (not including false starts). *LSNR* is expressed in decibels (dB). We computed *LSNR* for a total of 1,284 PVT sessions collected from 88 healthy young adults (aged 22–40 years; 43 males, 45 females) who participated in one of three laboratory studies. The subjects underwent 38 hours of total sleep deprivation and performed the PVT at 2- to 4-hour intervals. The *LSNR* data from the three studies were analyzed as a function of time awake using mixed-effects analysis of variance.

**Results:** The *LSNR* data captured the well-established homeostatic and circadian regulation of fatigue and the attendant effects on PVT performance. That is, the fidelity of information processing degraded across time awake, modulated by time of day ($F_{16,1003}$=31.4, $P$<0.001) – see Figure 1. The effects of sleep deprivation on *LSNR* are readily interpretable, with a given change in *LSNR* always having the same meaning regardless of the absolute values pre and post. A –3 dB change in *LSNR*, for example, always corresponds to a 50% drop in the fidelity of information processing. The change in *LSNR* from baseline (4–14 hours awake) to sleep deprivation (28–38 hours awake) was –1.7±0.1 dB (mean ± standard error). This corresponds to a 32.6% reduction in the fidelity of information processing. At the trough of PVT performance in the early morning (22 hours awake), the change from baseline was –2.7±0.3 dB (mean ± standard error). This corresponds to a 47.2% reduction in the fidelity of information processing. The sensitivity of *LSNR* to sleep deprivation was high (effect size $f^2$=0.32). The intra-individual stability of *LSNR* was high as well (intraclass correlation coefficient ICC=0.48).

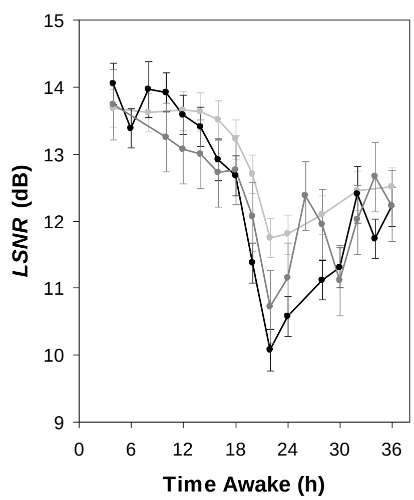


**Figure 1:** *LSNR* (means ± standard error) as an index of the fidelity of information processing in PVT sessions performed at 2- to 4-hour intervals during 38 hours of total sleep deprivation in the laboratory. The three curves correspond to the three laboratory studies.

**Discussion:** We developed a new metric for PVT performance, *LSNR*. This metric may serve as a quantitative measure of the fidelity of information processing in cognitive performance. The metric has high sensitivity to sleep deprivation, high intra-individual stability, and no floor and ceiling effects. Furthermore, a change in *LSNR* always has the same meaning, regardless of the absolute baseline value. This implies that baseline *LSNR* may be set to 0 dB to anchor the metric, without loss of generality. Metric anchoring has been a concern in the area of mathematical modeling of fatigue, and *LSNR* provides a novel solution for this issue. *LSNR* also connects fatigue research with a broad literature in information theory and other fields regarding process reliability under noisy conditions. As such, this work links PVT performance with a common metric to quantify the overall reliability of partially automated systems operated by fatigued individuals (e.g., air traffic control). The *LSNR* metric could thus be a useful new tool for fatigue risk management systems.

**Summary:** We derived a signal-to-noise-ratio metric, *LSNR*, for a widely used fatigue assay, the PVT. We thereby produced a new tool to express performance impairment in fatigued individuals in terms of the fidelity of information processing in human cognition. *LSNR* is sensitive to sleep deprivation and has desirable psychometric properties such as consistent interpretability of the magnitude of observed changes regardless of baseline values. *LSNR* is therefore quite suitable as a prediction metric for mathematical models of fatigue. Furthermore, *LSNR* may serve as a common metric for risk assessment across multiple risk factors. It thus provides a basis for quantifying and minimizing overall risk in integrated operational systems with fatigued humans in the loop.