An Ocular Measure of Drowsiness and the EEG: Changes with Sleep Deprivation

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Introduction:

Drowsiness is the intermediate state between alert wakefulness and sleep. We have developed a new scale, the Johns Drowsiness Scale (JDS), that measures different levels of drowsiness from minute to minute, particularly in people who should remain alert, e.g. while driving. It is based on a combination of oculometric variables, including the relative velocities of eye and eyelid movements, measured by infrared reflectance oculography (Optalert™) (1,2).

Others have shown that there are changes in EEG alpha and theta waves with sleep deprivation (3).

Our aim was to investigate the relationship between JDS scores and EEG power in the alpha and theta frequency ranges, as they changed with sleep deprivation.

Methods:

Nineteen volunteers (M/F = 11/8, aged 20-69 yr) had their eye and eyelid movements monitored by Optalert while performing a simple visual reaction-time test, the Johns Test of Vigilance (JTV). This is a PC-based test that presents a visual stimulus (change of shapes from circles to diamonds or squares) lasting 400 ms every 5 to 15 sec during a 15 min test. Participants responded by pushing a button as quickly as possible after any change of shapes.

The Optalert system calculated the mean and standard deviation each minute for many ocular variables effected by drowsiness. They included the relative velocity and duration of eyelid closure and reopening during blinks, the duration of eyelids remaining closed, the total blink duration and the relative velocity of saccades. The JDS (range 0-10) is a composite score based on regression weights from multiple regression analysis predicting alert and drowsy conditions from the ocular variables, minute by minute. Many made significant independent contributions to that regression, accounting for 63.5% of the total variance ($p<0.001$).

Participants were tested when alert after a normal night's sleep and again after sleep deprivation for 25 - 29 hours. For the analysis of JDS scores, minutes of data were selected in which all RTs were less than 500msec when alert ("alert and responding"), when RTs were less than 500msec after sleep deprivation ("sleep deprived and responding") and when there was at lease 1 failure to respond (error of omission) after sleep deprivation ("sleep deprived and not responding").

EEG data were collected from 6 midline sites but data presented here were from 02-A2. The data was collected with 16-bit resolution with a sampling rate of 400Hz. Power spectra were computed using periods of 2048 samples (5117.5 msec) before each visual stimulus was presented and for the same time after the stimulus began. Epochs were rejected that were contaminated by eye movements or other artifacts producing excursions of 50 µV or more in any of the EEG channels. Mean power density was calculated for alpha (8 – 12 Hz) and theta (4 – 7 Hz) frequencies. Changes in EEG power were also standardized as a percentage of each subject's power when alert. The results were compared in the same three conditions as above.

Results:

There was a significant difference in JDS scores between conditions $F(2, 2656) = 929.60$, $p<0.001$. Post-hoc Scheffé tests revealed that all conditions differed significantly from each other ($p < 0.001$).

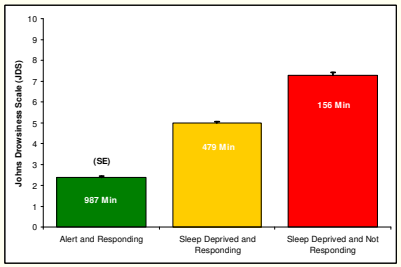

Fig. 1. Mean (+SE) of JDS scores for "alert", "sleep deprived and responding" and "sleep deprived and not responding" conditions.

Alpha Power

The absolute alpha power differed significantly between conditions ($F(2,6764) = 66.5$, $p<0.001$) but did not differ between the 5 secs before and the 5 secs during stimuli ($p>0.8$). Post-hoc tests showed significant differences between alert and the two sleep deprived conditions but not between responding and not responding sleep deprived conditions ($p>0.7$). When the alpha power was standardized within subjects the overall ANOVA showed significant differences between conditions, ($F(2, 6764)=119.4$, $p=0.001$) (Fig 2). There was no significant difference in standardized alpha power for the 5 secs before and the 5 seconds after the stimulus ($p>0.4$). Post-hoc analysis showed that all three conditions were significantly different from each other ($p<0.002$) and there was a tendency for alpha power in the sleep deprived condition to be higher when responding than when not.

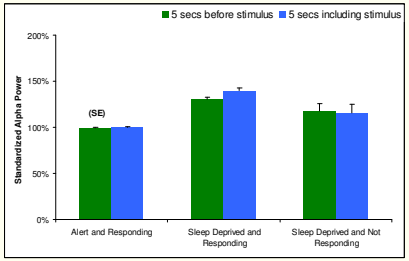

Fig. 2. Standardized alpha power for the 5 secs before and 5 secs during the stimuli when "alert" and when "sleep deprived", responding and not responding.

Theta power

Absolute theta power differed significantly between conditions ($F(2,6764) = 226.4$, $p<0.001$) but did not differ between the 5 secs before and the 5 secs during stimuli ($p>0.5$). Post-hoc Scheffé tests showed significant differences between all conditions ($p<0.001$). Standardized theta power showed significant differences between conditions, ($F(2, 6764)=90.2$, $p=0.001$) (Fig 3). Standardized theta power was significantly higher for the 5 secs before the stimulus than after it ($F(1,6764)=15.7$, $p<0.001$). Post-hoc analysis showed that all three conditions were significantly different from each other ($p<0.002$) with the highest power in the "sleep deprived and not responding" condition.

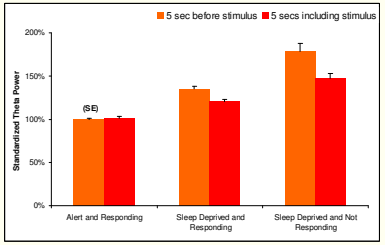

Fig. 3. Standardized theta power for the 5 secs before and 5 secs during the stimuli when "alert" and when "sleep deprived", responding and not responding.

Standardized theta power during the whole JTV test was significantly correlated with the mean JDS score ($r= 0.40$, $n=55$, $p <0.01$). Standardized alpha power was not significantly related to JDS scores ($p>0.1$). Nor was the absolute alpha or theta power correlated significantly with JDS scores ($p>0.1$).

Conclusions:

- **Drowsiness, as measured by JDS scores, increased with sleep deprivation and was higher when subjects failed to respond than when they responded in the sleep deprived state.**
- **Both alpha and theta power in the EEG increased with sleep deprivation whether expressed in absolute terms or standardized within subjects.**
- **As JDS scores increased with drowsiness, so did standardized theta power, but not alpha power.**
- **The results support the validity of the JDS as a new measure of drowsiness.**

References

1. Johns MW. The amplitude-velocity ratio of blinks: a new method for monitoring drowsiness. *Sleep*, 2003; 26(Suppl.): A51-52.
2. Tucker AJ & Johns MW. The duration of eyelid movements during blinks: changes with drowsiness. *Sleep*, 2005; 28 (Suppl.): A122.
3. Risser MR, Ware JC, Freeman FG. Driving simulation with EEG monitoring in normal and obstructive sleep apnea patients. *Sleep*, 2000; 23:393-398