Oculomotor assessment of diurnal arousal variations

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Abstract

Saccadic and pupil responses are reliable indices of arousal decrement (e.g. fatigue), that might be exploited to improve work schedule guidelines. In this study, we tested the sensitivity of a short 30-s oculomotor test to detect diurnal arousal variations. Eleven participants volunteered to be assessed every hour (66±20 min) for three consecutive working days, during their regular office-hours. We used a fully automated testing system, the FIT 2000 Fitness Impairment Tester (Pulse Medical Instruments Inc., Rockville, MD, USA), to measure and record saccadic peak velocity, pupil diameter, and latency and amplitude of the pupillary light reflex. In addition, we collected subjective levels of arousal using the Stanford Sleepiness Scale, and body core temperature. We analyzed the data using a linear mixed model approach for longitudinal data. Both saccadic velocity and subjective alertness decreased over the course of a day, while body core temperature increased (all p-values < .05). The data also weakly suggested an increase of the pupil diameter (p=.07). The findings support the use of oculomotor indices in the assessment of arousal and fatigue in applied settings.

Operator State Assessment

Human operators possess many advantages over fully-automated control systems, but they are not infallible. When humans are performing safety-critical tasks, it is desirable to employ monitoring technology to insure that operators remain alert and engaged.

Eye monitoring systems are likely to be an important component of future operator monitoring systems. Gaze direction can provide information about spatial allocation of attention, and slow eyelid closures are associated with imminent sleep. In this paper, we investigate *Peak Saccadic Velocity* (PSV) as a possible indicator of arousal decrements that occur long before the onset of sleep. Previous work (Diaz-Piedra et al., 2016) has demonstrated changes in PSV during helicopter missions lasting several hours.

Unfortunately, due to the brief nature of saccades, accurate measurement of PSV requires specialized equipment: the system used in this study (PMI FIT-2000, see right-hand panel) employs an analog optical servo system with high bandwidth; measurement of PSV with a video-based eye-tracker generally requires a high frame rate (500 fps or above). Mulligan (2008) has demonstrated a method employing multiple intra-frame flashes enabling measurement of PSV using a standard camera with 60 fps.

The PMI FIT 2000

The PMI FIT-2000 fitness-for-duty tester (Pulse Medical Instruments, Rockville MD) performs a brief (30 second) oculomotor test battery designed to detect impairment produced by fatigue or intoxication.

The subject presses a button to initiate the measurements; saccadic peak velocity (SPV) is measured first, by having the subject track the apparent motion between a pair of alternately lit LEDs. After a brief pause, the a series of flashes are delivered to measure the pupillary light reflex (PLR). Three pupil parameters are measured, the resting pupil diameter (PD), and the amplitude and latency of the PLR.

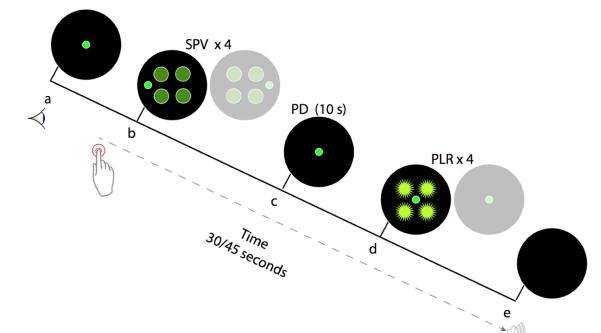






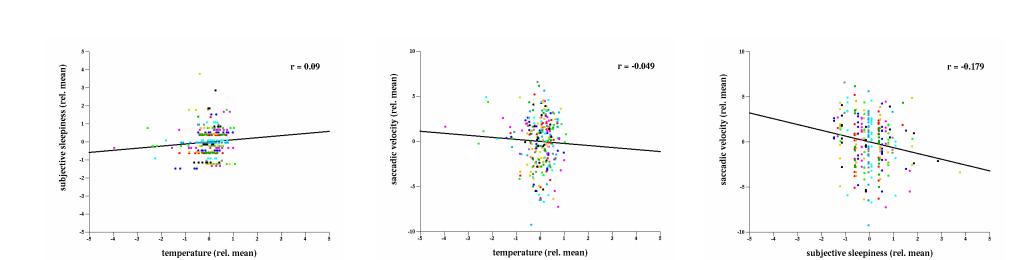
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Subjects used this ear thermometer to record body temperature before each FIT measurement.



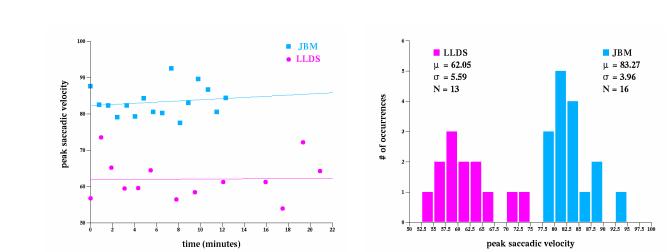
	JBM	LLDS	CDP	S4	S5	S6	S7	S8	S9	S10	S11	
Peak Saccadic Velocity	subject JBM slope = -0.455	subject LLDS slope = -0.439	subject CDP slope = -0.415 (8)	subject S4 slope = -0.591	subject SS slope = 0.047 (8)	subject S6 slope = 0.221 (2) 10 10 10 10 10 10 10 10 10 10 10 10 10	subject S7 slope = 0.292 (4) In	subject S8 slope = 0.325 (8) 10 10 10 10 10 10 10 10 10 10 10 10 10	subject 89 slope = -0.152	Subject S11 slope = -0.507 Summing to the subject S11 slope = -0.507 Summing to the subject S11 slope = -0.507	Subject S12 slope = -0.367 (8)	$\mu = 40.3469$ $p < 0.001$ $\frac{4}{47} \frac{1}{46} $
Pupil Diameter	subject JBM slope = 0.014 (Sign 7	subject LLDS slope = 0.044	subject CDP slope = 0.039 (All 11	subject \$4 slope = 0.035	subject SS slope = 0.009 (2)	subject S6 slope = 4.037 (April 1977) 1	subject S7 slope = -0.923 (signal of the control o	subject S8 slope = 0.027 Option Continue Continu	subject S9 slope = 0.006	subject S11 slope = 0.028	subject \$12 slope = 0.11 subject \$12 slope = 0.11 the part of th	μ = 0.0195 p = 0.063 p = 0.063 2 - 2 - 2 - 2 - 2 - 2 - 2 - 2 - 2 - 2
Pupil Constriction	subject JBM slope = -0.023	subject LLDS slope = -0.006 10	subject CDP slope = 0.004 Tim 4 to 10 to	subject S4 slope = -0.004 subject S4 slope = -0.004 40 junt 10 junt	subject SS slope = -0.012	subject S6 slope = 0.021	subject S7 slope = 0.002	subject S8 slope = 40.009 1	subject S9 slope = -0.009 subject S9 slope = -0.009 to the subject S9 sl	subject \$11 slope = -0.009 hour	subject S12 slope = 0.043 subject S12 slope = 0.043 the subject S12 slope = 0.043	μ = -0.0001 p = 0.49
Pupil Latency	subject JBM slope = 0.664 subject JBM slope = 0.664	subject LLDS slope = 0.944 subject LLDS slope = 0.944 subject LLDS slope = 0.944 population of the	subject CDP slope = 0.581	subject \$4 slope = -0.779 subject \$4 slope = -0.779 subject \$4 slope = -0.779 the continue of the continue	aubject SS slope = 0.492 subject SS slope = 0.492	subject \$6 slope = 4.553 subject \$6 slope = 4.553	subject S7 slope = -0.4S7 subject S7 slope = -0.4S7	subject S8 slope = 40.145 subject S8 slope = 40.145 subject S8 slope = 40.145 continued to the continue of	subject S9 slope = 0.162 subject S9 slope = 0.162	subject S11 slope = 1.416	subject S12 slope = 1.011 subject S12 slope = 1.011 by 1	μ = 0.3031 p = 0.086 1
Temperature	subject JBM slope = 0.004 subject JBM slope = 0.004 total	subject LLDS slope = 0.111 subject LLDS slope = 0.1111 subject LLDS slope = 0.1111 subject LLDS slope = 0.1111	subject CDP slope = 0.062 subject CDP slope = 0.062 poly limit to the poly limit t	subject S4 stope = 0.167	aubject SS alope = 0.123	subject S6 slope = 0.014 subject S6 slope = 0.014	310 subject \$7 slope = 0.032 310 to 10 to 1 to 10 to	subject SS slope = 0.042 100 100 100 100 100 100 100	subject S9 slope = 0.044	subject S11 slope = -0.026 su	subject S12 slope = 0.068	μ = 0.0583 p = 0.003
Subjective Sleepiness	subject JBM slope = 0.054 subject JBM slope = 0.054 tow1 tow2 tow2 tow3 tow4 tow2 tow3 tow4 tow3 tow4 tow3 tow4 tow3 tow4	subject LLDS slope = 0.164 subject LLDS slope = 0.164 though the long is the	subject CDP slope = 0.244 * bw 1 + bw 2 + bw 2 + bw 2 - bw 1 + bw 2 + bw 2 + bw 3 + bw 4 + bw 2 + bw 4 + bw 5 + bw 6 + bw 7 +	subject S4 slope = 0.023 subject S4 slope =	subject SS slope = -0.029 ** hog 1 ** hog 2 ** hog 2 ** hog 3 ** hog 4 ** hog 2 ** hog 2 ** hog 4 ** hog 2 ** hog 3 ** hog 4 ** hog 4 ** hog 4 ** hog 5 ** hog 4 ** hog 5 ** hog 6 ** hog 6 ** hog 6 ** hog 7 ** hog 7 ** hog 7 ** hog 7 ** hog 8 ** hog 8 ** hog 8 ** hog 9 ** hog 9	subject S6 slope = 0.119 subject S6 slope = 0.119 c	subject S7 slope = -0.03 **Dw1	subject 58 slope = 0.06 subject 58 slope = 0.	subject S9 slope = -0.026 **Dari + 1007 **Dari +	Subject S11 slope = 0.216 **Doy 1 **Doy 2 **Doy 2 **Doy 3 **D	subject S12 slope = 0.272 **Day **D	μ = 0.997 p = 0.007 μ = 0.997 p = 0.007

Weak correlations



Three variables (saccadic velocity, temperature, and subjective sleepiness) showed significant trends throughout the work-day (see data below). But these variables are only weakly correlated with each other. This may be due in part to measurement noise (see panels to the right). We have also, somewhat inappropriately, treated the sleepiness ratings as metric quantities.

Repeatability



Two of the authors made a number of measurements in rapid succession to assess precision. Measurement variability is large – the standard deviation is approximately 10 times the average hourly decrease in saccadic velocity. Ongoing work seeks to determine how much of this is due to behavioral variability, versus measurement noise in the instrument. It is not clear whether the instrument's velocity measurements are normalized with respect to the amplitude of the executed saccade.

Summary

Of the four oculomotor parameters measured by the PMI FIT-2000, only peak saccadic velocity appears to vary systematically during the work day. Although the measurements are noisy, saccadic velocity could be a valuable component of an operator monitoring system, because so many saccades are made in the course of normal behavior.

References

Diaz-Piedra, C., Rieiro, H., Suárez, J., Rios-Tejada, F., Catena, A., and Di Stasi, L. L. (2016). Fatigue in the military: towards a fatigue detection test based on the saccadic velocity. *Physiological Measurement*, **37**(9), N62-75.

Mulligan, J. B. (2008). Measurement of eye velocity using active illumination. *Proc. 2008 ACM Symposium on Eye Tracking Research and Applications (ETRA)*, 35-38.

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