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Physiological Assessment of Operator Workload During Manual Tracking : (1) Pupillary Responses

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SUMMARY

The feasibility of pupillometry as an indicator for assessing operator workload during manual tracking was studied. The mean and maximum pupillary responses of 12 subjects performing tracking tasks with three levels of difficulty (bandwidth of the forcing function were 0.15, 0.30 and 0.50 Hz respectively) were analysed. The results showed that pupillary dilation increased significantly as a function of the tracking difficulty which was reflected by the significant increase of tracking error (RMS). The present study supplies additional evidence that pupillary response is a sensitive and reliable index which may serve as an indicator for assessing operator workload in man-machine systems.

INTRODUCTION

The assessment of operator workload in complex man-machine systems has become more important for evaluating and enhancing the overall system performance as systems become more advanced and sophisticated. The traditional methods for evaluating the workload are subjective evaluation (Cooper, 1969), measures of primary and secondary task performance, and systems or engineering analysis. Results have shown that neither any single approach nor combination of methods can assess or predicate the workload adequately.

Physiological parameters, however, have manifested themselves as potential indicators in workload assessment (Wierwille and Williges, 1978). These indicators may reflect the dynamic change of the functional status of the operator induced by the task before or without performance decrement (Strasser, 1977). Of the physiological measures indicating momentary cognitive workload, pupillometric response appears to be most sensitive and reliable (Kahneman, Tursky, Shapiro, and Crider, 1969). For cognitive processing, multiple neurophysiological assessment has been emphasized recently since the hypotheses of multiple and hierachical resources were pointed out (Wickens,1980, Beatty, 1980). EEG seems to be a potential indicator both for general and specific brain activation if multiple channels of EEG could be analysed (Barth and Beatty, 1981, unpublished report). EEG studies during manual tracking show that the theta waves increase as a function of tracking difficulties (Jiang, Long, He and Zhao, 1977, unpublished report), lasting period and performance decrement (Kornfeld and Beat-

PAGE 40 INTENTIONALLY BLANK

ty, 1977). It seems plausible to interpret this phenomenon as due to either an increase of tracking difficulty or as a result of trying best to attain the desired performance as the experiment demands. The study of psychophysiological mechanisms of theta waves indicates that they are related to information processing and mental effort (Schacter, 1977).

Task-evoked pupillary responses have been studied extensively in cognitive tasks and practical implications for operator workload measurement has been suggested (Beatty, 1980). As a part of the study of multiple assessment of operator workload, the effect of tracking difficulty on pupillary responses was studied in the present experiment and the feasibility of pupillometry for assessing operator workload was discussed.

METHOD

Twelve university students participated this experiment as subjects. The manual tracking system consisted of an auditory display, a finger joystick and a controlled element (K/S, simulated by analog computer).

The difficulty of the task was determined by the bandwidth of the forcing function. The cutoff frequencies were low (0.15 Hz), medium (0.30 Hz) and high (0.50 Hz) corresponding to easy, medium and hard tracking respectively. The period of time of tracking for each trial was 10 seconds starting with a warning signal, the word "ready". One second after this signal, the tracking forcing function (converted to a single tone) appeared in either of the two earphones. The pitch of the tone was proportional to the voltage of the forcing function or the tracking error. The subject was asked to control the stick laterally away from the ear in which the tone was heard. This in turn reduced the magnitude of the tracking error and the perceived pitch of the tone. Zero error corresponded to 500 Hz of the tone. The positive error was displayed in the left earphone and the negative in the right. For each level of difficulty of tracking, there were 20 trials of practice in order to attain a steady level of performance. After practice the data of pupillary response and tracking error (RMS) were acquired and stored in the computer. Because of a programming malfunction, the RMS tracking error data was obtained for only 9 of the 12 subjects. There were 20 trials of tracking for each level of difficulty. The order of these levels for the subjects to track was counterbalanced.

Vertical pupillary diameter was measured by a TV Pupillometer System for 10 seconds following the warning signal. The tracking error were recorded for 9 seconds during tracking. Pupillary responses were analysed using the program of this laboratory, and the mean and maximum amplitude of dilation during tracking relative to the 1 sec. baseline were computed.

RESULTS and DISCUSSION

Tracking performance: Tracking error (RMS) increased significantly with the bandwidth of the forcing function ($F(2,8)=17.85$, $P<.005$). This result is consistent with other studies indicating that the bandwidth of forcing function can be used as a factor to modify the tracking difficulty.

Pupillary responses: As shown in Fig. 1, the mean and maximum amplitude of the pupillary responses during tracking increased with tracking difficulty. These increases were significant ($F(2,11)=6.44$ $P<0.025$, for mean dilation; $F(2,11)= 6.13$, $P<0.025$, for maximum dilation). The mean pupillary dilations were 0.274 mm, 0.332 mm, and 0.377 mm, and the maximum dilations 0.377 mm, 0.440 mm, and 0.492 mm for the three levels of difficulty respectively. The peak dilations were approximately comparable to those evoked by short term memory tasks with 5, 6, and 7 items (Beatty, 1980), and the pupil dilation during easiest tracking even reached the magnitude evoked by a choice reaction time test with 8 alternatives (Beatty and Wagoner, 1980). The foundation of inter-task comparisons is based on the findings that the magnitude of pupillary responses during cognitive processing is independent of baseline pupillary diameter over a physiologically reasonable range of values (Bradshaw, 1969).

The grand averages of pupillary responses duing tracking over 12 subjects are plotted in Fig. 2, which shows the time history of the pupillary responses. It displays a stage of preparation for activation before tracking; a stage of fast dilation of pupil immediately following tracking; a stage of maintaining dilation; and a stage of a little constriction before stopping tracking. It is obvious that the effect of tracking effort on the pupillary response is dominantly reflected in the maximum difference but also in other stages. For instance the constricting stage lasted longer in the easy tracking just before rest and the magnitude of constriction was greatest in the hardest tracking case. Whether the latter phenomenon is due to the individual differences or due to overload of the task for some subjects as pointed out by Peavler (1974) should be tested by further study.

The available reports published so far on the physiological assessment of workload during tracking show that even though some physiological indicators are sensitive to significant differences between rest and tracking, they are unable to discriminate the different levels of tracking difficulty, for instance the heart rate variability (Hyndman and Gregory, 1975) and event related potentials (Isreal, Chesney, Wickens, and Donchin, 1980). The present result supplies additional evidence that pupillary response is a sensitive and reliable index for measuring mental effort.

As for the technique of the pupil recording, there is still a lot to be improved in order to be more convenient and less constraining for the subject, particullary for the operators performing tasks in a real working condition. Owing to the great individual differences in the size of the eyes and the pupil, the color of the iris, and the ability to keep the eyes relatively fixated without blinking, the subjects should be selected appropriately.

This study only analysed the effect of auditory tracking on the pupillary responses, but the individual studies using visual display also revealed the tendency of pupillary dilation as the difficulty increased and residual attention lowered (McFeely, 1972).

One can conclude that pupillary responses can discriminate operator effort during tracking and can be compared with those evoked by other tasks. Furthermore, the innovation for the recording system is possible, hence, pupillometry may serve as a promising indicator to assess the operator workload in man-machine systems, particularly with additional indicators such as EEG or others which can reflect the activities of specific resources of cognitive processing.

REFERENCES

Beatty, J. A pupillometric index of operator workload. Technical Report No.23. UCLA.,1980.

Beatty, J., Wagoner, B. L. Pupillometric signs of brain activation vary with level of cognitive processing. Science, 1978, 199, 1216-1218.

Beatty, J., and Wagoner, B. L. Effects of response selection and task evoked pupillary dilations: Inplications for a motor theory of attention. Presented at Western Psychological Association, Hawaii, 1980.

Bradshaw, J. L. Background light intensity and the pupillary response in a reaction time task. Psychonomic Science, 1969, 14, 271-272.

Cooper, G. E. and Harper, R. P., Jr. The use of pilot rating in the evaluation of aircraft handling qualities. Technical Report NASA TN-D-5153, 1969.

Isreal, J. B., Chesney, G. L., Wickens, C. D., and Donchin, E. P300 and tracking difficulty: Evidence for multiple resources in dual-task performance. Psychophysiology, 1980, 17, 259-273.

Hyndman, B.W and Gregory, T. R. Spectral Analysis of sinus arrythmia during mental loading. Ergonomics, 1975, 18, 255-270.

Kahneman, D., Tursky, B., Shapiro,D and Crider, A. Pupillary, heart rate and skin resistance changes during a mental task. Journal of Experimental Psychology, 1969, 79, 164-167.

Kornfeld, C. and Beatty, J. EEG spetra during a long term compensatory tracking task. Bulletin of the Psychonomic Society, 1977, 10, 46-48.

McFeely,T.E. Pupil diameter and the cross-adaptive critical tracking task; A method of workload measurement. AD 749075, 1972.

Peavler, W.S. Pupil size, information overload, and performance difference. Psychophysilogy, 1974, 11, 559-566.

Schacter, D. L. EEG theta waves and psychological phenomena: a review and analysis. Biological Psychology, 1977, 5, 47-88.

Strasser, H. Physiological measures of workload - correlations between physiological parameters and operational performance. In K.E.Klein (Ed.), Methods to assess workload. AGARD Coference Print, No. 216,1977.

Wickens, C. D. The structure of processing resoureces. In R. Nickerson and R. Pew (Eds.). Attention and Performance VIII. New York: Erlbaum, 1980.

Wierwille, W. W. and Williges, R. C. Survey and analysis of operator workload assesment techniques. Technical Report S-78-101. Systemetrics Inc. Blacksburg, Va. 1978.

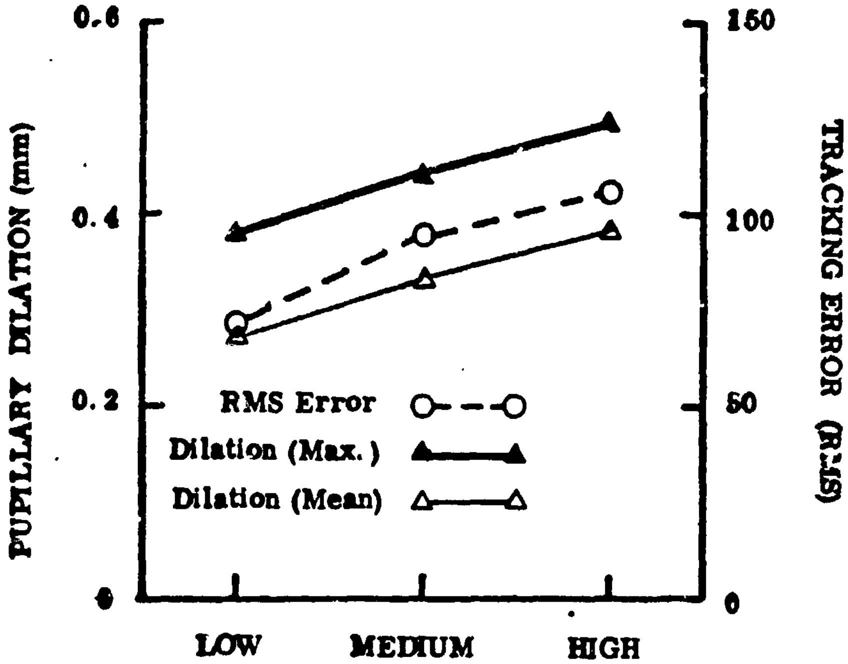

Fig. 1 Mean and maximum pupillary dilations and RMS tracking error (arbitrary units) for three levels of forcing function bandwidth (low, medium and high).

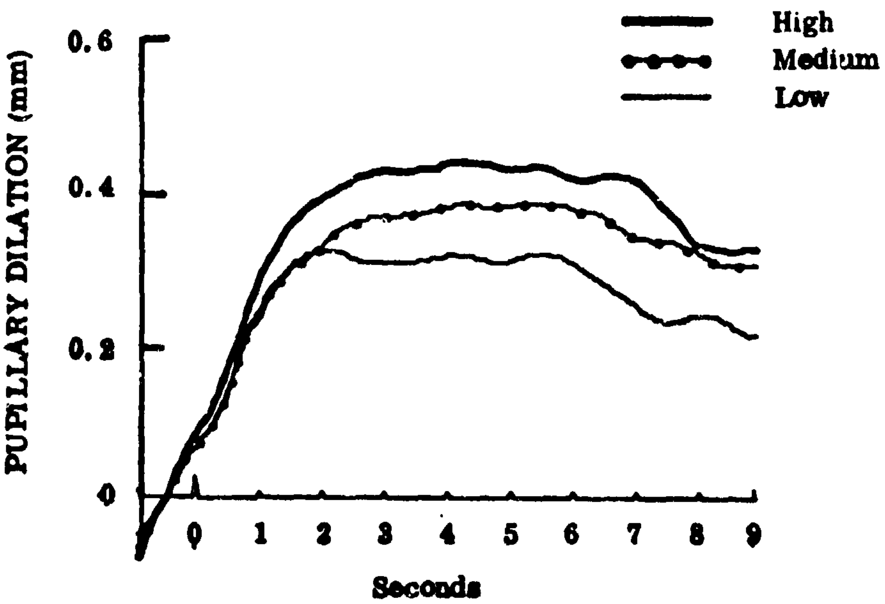

Fig. 2. Grand average of pupillary responses across 12 subjects for three levels of forcing function bandwidth (low, medium, and high).