EFFECTS OF TASK DEMAND AND TIME-ON-TASK ON PSYCHOPHYSIOLOGICAL CANDIDATES FOR BIOCYBERNETIC CONTROL

Abstract:
Biocybernetic control is defined as the use of psychophysiology as a real-time input to a computerised system. This paper is concerned with the selection of psychophysiological variables to drive biocybernetic control of adaptive automation. The goal of the current study was to assess the sensitivity of psychophysiology to task demand over a sustained period of performance. Thirty participants performed the Multi Attribute Task Battery (MATB) under conditions of high and low task demand over a period of sixty-four minutes. EEG, ECG, EOG and respiration rate were recorded. A MANOVA indicated that power in the Q and a bandwidths (at sites P4 and Pz), heart rate, vagal tone and eyeblink duration were sensitive to task demand; all 3 EEG bandwidths (Q, a and b), 0.1Hz sinus arrhymia, respiratory rate and eyeblink duration were sensitive to time-on-task. The consequences of these findings for the selection of candidates for biocybernetic control are discussed.

Proposal:

EFFECTS OF TASK DEMAND AND TIME-ON-TASK ON PSYCHOPHYSIOLOGICAL CANDIDATES FOR BIOCYBERNETIC CONTROL

Stephen H. Fairclough & Louise Venables
School of Psychology
Liverpool John Moores University
UK.

ABSTRACT

Biocybernetic control is defined as the use of psychophysiology as a real-time input to a computerised system. This paper is concerned with the selection of psychophysiological variables to drive biocybernetic control of adaptive automation. The goal of the current study was to assess the sensitivity of psychophysiology to task demand over a sustained period of performance. Thirty participants performed the Multi Attribute Task Battery (MATB) under conditions of high and low task demand over a period of sixty-four minutes. EEG, ECG, EOG and respiration rate were recorded. A MANOVA indicated that power in the Θ and α bandwidths (at sites P4 and Pz), heart rate, vagal tone and eyeblink duration were sensitive to task demand; all 3 EEG bandwidths (Θ, α and β), 0.1Hz sinus arrhymia, respiratory rate and eyeblink duration were sensitive to time-on-task. The consequences of these findings for the selection of candidates for biocybernetic control are discussed.

INTRODUCTION

Biocybernetic control describes the use of real-time psychophysiology as an input to a computing system. This type of biological/machine control loop is represented by simple biofeedback systems wherein ongoing psychophysiological activity is relayed to the individual via visual or auditory feedback. Psychophysiological data may also be used in more complex ways: to relay information about the emotional status of the user to the computer system (Picard, 1997) and to characterise those psychophysiological states of functional impairment (Fairclough, 2001). The goal of biocybernetic control is to extend the adaptive repertoire of the computing system: to adjust system interface/functionality in order to optimise human-computer interaction and minimise the risk of error.

The biocybernetic control of adaptive automation utilises real-time psychophysiology in order to initiate and terminate periods of system automation, and to adjust the level and loci of automation within those periods (Byrne & Parasuraman, 1996). Initial research to identify psychophysiological triggers of adaptive automation began at NASA (Pope, Bogart, & Bartolome, 1995; Prinzel, Scerbo, Freeman, & Mikulka, 1995) and the benefits of biocybernetic control have been demonstrated in later work (Freeman, Mikulka, Prinzel, & Scerbo, 1999; Freeman, Mikulka, Scerbo, Prinzel, & Clouatre, 2000; Prinzel, Freeman, Scerbo, Mikulka, & Pope, 2000) (Scerbo, Freeman, & Mikulka, 2003).

Psychophysiological data may be recorded continuously and covertly, therefore, information is constantly available to the adaptive controller that does not necessitate any overt response from the operator. These qualities place psychophysiology at an advantage compared to alternative triggers such as overt task inputs. However, psychophysiological variables also bring a number of disadvantages, for instance: physical activities which confound data collection (e.g. movement artefacts), environmental confounds (e.g. temperature) and individual differences (e.g. issues of calibration) (Byrne & Parasuraman, 1996). In addition, different types of psychophysiological variables may vary in terms of sensitivity, diagnositicity, equipment requirements and user acceptance (Kramer, Trejo, & Humphrey, 1996). One particular issue for biocybernetic control concerns the relationship between the sensitivity of psychophysiological variables to key independent variables such as task demand/difficulty (Backs & Selijos, 1994; Brooking, Wilson, & Swain, 1996; Veltman & Gaillard, 1998) and time-on-task.

The aims of the current study are to: (a) extend the range of psychophysiological candidates for biocybernetic control to include cardiovascular, respiratory and ocular variables in conjunction with the EEG measures used in previous research (Freeman et al., 1999; Pope et al., 1995), (b) contrast the relative sensitivity of psychophysiological variables to sympathetic activation (associated with increased task workload) and parasympathetic inhibition (associated with sustained time-on-task), and (c) assess the merits of psychophysiological variables to diagnose operator states of rest vs. low task workload vs. high task workload.

METHOD

A pilot study was performed to derive high and low workload levels of the Multi-Attribute Task Battery (MATB: (Comstock & Arnegard, 1992) to be used in the main experiment. Ten volunteers were exposed to high and low demand and subjective workload was measured via the raw version of NASA Task Load Index (TLX: (Hart & Staveland, 1988). Subjective ratings of high task workload were significantly higher than the low task workload condition.

The independent variables used in the experiment were: (1) task workload (high/low) derived from the pilot study, and (2) time-on-task.

Thirty participants took part in the main experiment, (12 female and 18 male). The age of participants ranged from 18-40 years, (M = 21.9 years, S.D. = 4.16).

Participants performed the MATB for sixty-four minutes, divided into four sixteen-minute blocks. Each 16min block incorporated 2 x 4min periods of high and low workload. The presentation order of high/low workload within each 16min block was counterbalanced.

Performance data were collected from three MATB sub-tasks: tracking, gauge-monitoring and fuel management. Four channels of electroencephalogram (EEG) data were collected (Cz, Pz, P3 and P4) and analysed via Fast Fourier Transform (FFT) to derive three bandwidths (Θ α β). Three sources of cardiovascular data were collected from an electrocardiogram (ECG) (heart rate, 0.1Hz sinus arrhymia, vagal tone). Respiratory rate was measured via an elasticated band worn around the chest, and a vertical electrooculogram (EOG) was collected to index blink rate and duration.

RESULTS

The main findings of the study were as follows:

High and low workload manipulation produced the expected findings for the tracking and fuel management components of the MATB, i.e. performance declined under conditions of high task workload. Performance on the gauge-monitoring task was counterintuitive and superior response accuracy was apparent during the high task workload condition. In addition, there was evidence of a learning effect over time-on-task for the gauge-monitoring task.

EEG bandwidths from all four channels were sensitive to time-on-task. However, increased Θ and suppressed α in response to increased task workload was only apparent at two parietal sites (P4 and Pz). The EEG engagement index derived from (Pope et al., 1995) based on the formula ($\beta/(\Theta+\alpha)$) was not sensitive to either task workload or time-on-task.

Heart rate and vagal tone significantly decreased under conditions of high task workload. The 0.1Hz sinus arrhymia was sensitive to time-on-task. Respiration rate significantly increased due to task workload but declined with sustained performance.

Blink rate increased with task workload but this effect disappeared after 32min of performance. Blink duration was sensitive to both workload and time-on-task, i.e. blink duration is suppressed with task demand and increases due to time-on-task.

A series of discriminant function analyses (DFA) were performed to classify the psychophysiological data into three groups (baseline, low workload, high workload) over four periods of performance. Classification accuracy varied between 71 and 77%. The psychophysiological variables with the heaviest loadings were consistent throughout time-on-task, these were: blink duration, Θ and α power (from Pz) and heart rate. However, whilst the DFA accurately classified baseline data from the two workload groups (95%), classification accuracy was poor between low and high task workload conditions (60-65%).

DISCUSSION

The study demonstrated the sensitivity of psychophysiological variables (ppv) to task workload and time-on-task. The implications of the results are as follows:

EOG and ECG measures are also suitable candidates for biocybernetic control, having equivalent sensitivity to independent variables as the EEG.

The sensitivity of the Θ and α bandwidths of the EEG to task workload was only apparent at two parietal sites (P4 and Pz). The engagement index used in previous research ($\beta/(\Theta + \alpha)$) was not sensitive to task workload or time-on-task.

The majority of ppv used in the study were sensitive to both sympathetic activation and parasympathetic inhibition. In some cases, the sensitivity of sympathetic activation was compromised by parasympathetic influence of time-on-task. This factor must be taken into account when selecting psychophysiological candidates of biocybernetic control.

The DFA revealed that ppv were able to distinguish baseline conditions from performance with greater accuracy than differentiating between high and low workload conditions.

Further research is required to understand the discriminative power of psychophysiological variables relative to subjective workload.

REFERENCES

Backs, R. W., & Selijos, K. A. (1994). Metabolic and cardiorespiratory measures of mental effort: the effects of level of difficulty in a working memory task. *International Journal of Psychophysiology, 16*, 57-68.

Brooking, J. B., Wilson, G. F., & Swain, C. R. (1996). Psychophysiological responses to changes in workload during simulated air traffic control. *Biological Psychology, 42*, 361-377.

Byrne, E., & Parasuraman, R. (1996). Psychophysiology and adaptive automation. *Biological Psychology*(42), 249-268.

Comstock, J. R. J., & Arnegard, R. J. (1992). *The Multi-Attribute Test Battery for human operator workload and strategic behaviour research* (No. 104174): National Aeronautics and Space Administration.

Fairclough, S. H. (2001). Mental effort regulation and the functional impairment of the driver. In P. A. Hancock & P. A. Desmond (Eds.), *Stress, Workload and Fatigue* (pp. 479-502). Mahweh, NJ: Erlbaum.

Freeman, F. G., Mikulka, P. J., Prinzel, L. J., & Scerbo, M. W. (1999). Evaluation of an adaptive automation system using three EEG indices with a visual tracking task. *Biological Psychology, 50*, 61-76.

Freeman, F. G., Mikulka, P. J., Scerbo, M. W., Prinzel, L. J., & Clouatre, K. (2000). Evaluation of a psychophysiologically controlled adaptive automation system, using performance on a tracking system. *Applied Psychophysiology and Biofeedback, 25*(2), 103-115.

Hart, S. G., & Staveland, L. E. (1988). Development of the NASA-TLX (Task Load Index): results of empirical and theoretical research. In P. A. Hancock & N. Meshkati (Eds.), *Human Mental Workload* (pp. 139-183). Amsterdam: North-Holland.

Kramer, A. F., Trejo, L. J., & Humphrey, D. G. (1996). Psychophysiological measures of workload: Potential applications to adaptively automated systems. In R. Parasuraman & M. Mouloua (Eds.), *Automation and Human Peformance: Theory and Application* (pp. 137-162). Mahwah, NJ.: Erlbaum.

Picard, R. W. (1997). *Affective Computing*. Cambridge, Mass.: MIT Press.

Pope, A. T., Bogart, E. H., & Bartolome, D. S. (1995). Biocybernetic system evaluates indices of operator engagement in automated task. *Biological Psychology, 40*, 187-195.

Prinzel, L. J., Freeman, F. G., Scerbo, M. W., Mikulka, P. J., & Pope, A. T. (2000). A closed-loop system for examining psychophysiological measures for adaptive task allocation. *The International Journal of Aviation Psychology, 10*(4), 393-410.

Prinzel, L. J., Scerbo, M. W., Freeman, F. G., & Mikulka, P. J. (1995). *A bio-cybernetic system for adaptive automation.* Paper presented at the Human Factors and Ergonomics Society 39th Annual Meeting.

Scerbo, M. W., Freeman, F. G., & Mikulka, P. J. (2003). A brain-based system for adaptive automation. *Theoretical Issues in Ergonomic Science, 4*(1-2), 200-219.

Veltman, J. A., & Gaillard, A. W. K. (1998). Physiological workload reactions to increasing levels of task difficulty. *Ergonomics, 41*(5), 656-669.