Operator Functional State Assessment as a Critical Component of Automated System Operation

Glenn F. Wilson, PhD
U. S. Air Force Research Laboratory
AFRL/HECP
2255 H Street
Wright-Patterson AFB, OH 45433
UNITED STATES

Email: glenn.Wilson@wpafb.af.mil

The human operator is a critical component of automated systems and therefore must be kept in a state of optimal readiness to perform. The status of many of the components of automated systems is monitored to insure mission success. In aircraft systems the status of the propulsion system, fuel management, guidance, and so forth are continuously monitored. Deviation from acceptable parameters is used to prompt corrective actions. In many systems one of the key subsystems, the human operator, is not monitored to determine its functional state. While some systems utilize models of the human operator's expected performance to determine if the operator is functioning according to the model being used the actual state of the operator is unknown (Byrne & Parasuraman, 1996). Deviations from the expected performance in any given mission segment can result in warnings or implementation of some form of automation to assist the operator to achieve a successful mission (Scerbo, 1996). Our approach has been to directly monitor the functional state of the human operator using psychophysiological measures. These measures have been shown to be capable of determining when humans are in suboptimal states.

For example, high levels of mental workload are associated with characteristic changes in the operator's physiology (Kramer, 1991; Wilson & Eggemeier, 1991; Wilson, 2002a; Wilson, 2002b). At the other extreme, fatigue produces reliable markers in the physiological data (Angus & Heslegrave, 1985). Our experience has shown that the psychophysiological data can provide very useful information about the functional state of the operator (Russell, Wilson & Monet, 1996; Wilson & Russell, 1999). The operator's functional state pertains to that operator's ability to carry out the particular mission requirements at that moment in time. General operator state assessments, such as fatigue or illness, are useful but their impact on the ability of the operator to meet the current job demands is critical. That is, is the operator functioning at a level that is adequate to perform whatever job is currently required? While fatigue may produce lowered performance, it is possible for the operator to pool all available resources to complete the job. This may have dire consequences on future performance if all available resources are used. Our goal is to develop a set of metrics that provide moment-to-moment assessment of the functional state of the operators of complex systems.

Our approach has been to use a constellation of psychophysiological measures to determine the functional state of the human operator (Wilson, in press). This approach takes advantage of the unique response patterns among the various measures found in individual operators. Because the psychophysiological data are continuously available, on-line monitoring of the operators functional state is possible. For the most part the collection of the psychophysiological data does not interfere with the operator's task performance. The psychophysiological measures that have been used include brain activity as represented by the

Paper presented at the RTO SCI Symposium on "Critical Design Issues for the Human-Machine Interface", held in Prague, Czech Republic, 19-21 May 2003, and published in RTO-MP-112.

electroencephalogram (EEG), eye activity from the electrooculogram (EOG), heart activity as record by the electrocardiogram (ECG), skin conductance changes as represented by the electrodermal activity (EDA) and respiration. Usually the EEG is decomposed into the standard five spectral activity bands and the power is assessed. Heart rate and blink rate are derived from the ECG and EOG data and used to assess the functional state of the operator. The number of electrodermal responses and the tonic level are used as is respiration rate. These data are employed to find the response pattern of each person. These data are used to train classifiers that provide estimates of the operator's functional state either off-line or in real-time (Wilson & Fisher, 1991; Wilson, Lambert & Russell, 2000).

Both statistical and nonlinear classifiers have been used and have shown a high level of accuracy in determining the functional state of the human operator. In most situations that we have tested the accuracies are in the range of 85% to 98% correct. This is shown in Table 1. These classifiers have to be trained to recognize the various levels of operator state while the operator performs a number of different task types. The classifiers are given examples of psychophysiological data which represent each of the various functional states to be discriminated. The classifiers are trained to provide the best possible discrimination among the levels of operator functional state. Then the operator performs the tasks while the psychophysiological data are collected and the classifier makes estimates of the operator's state in real-time. In our testing we knew the task demands and the effects this had on the operators so we could make estimates of how well the classifier performed by matching the classifier estimate with the known task demands.

Table 1: Classifier accuracy levels from a number of projects providing laboratory, simulator and light data. The number of workload levels are shown as are the overall classifier accuracy values. TB is the Multiattribute Task Battery, Scud Hunt is a simulated air-to-ground search task, landing is a simulated aircraft landing task with variable landing conditions, ATC is a simulated air traffic control ask and flight are data from actual flights.

Environment	Levels	Accuracy	Comments
Lab tasks	14	86%	7 tasks, each with 2 difficulty levels
MATB	3	99%	Low, medium and overload, including performance
MATB	3	86%	Evaluating effects of presentation order
MATB	2	84%	Evaluating day to day effects
Scud Hunt	6	96%	Rate of task changed
Scud Hunt	2	99%	Over redline versus below redline
Landing	2	83%	Simulated landing and level flight
ATC	7	80%	Volume of aircraft and complexity of task
ATC	4	85%	Volume/complexity separate (all features)
ATC	4	93%	Volume/complexity separate (feature reduction)
ATC	2	98%	Investigating day to day effects
Flight	2	79%	In-flight data with 22 segments
Flight	8	91%	Eight flight segments from air to ground training

In the laboratory we have taken the further step of using the operator state estimates to implement adaptive aiding (Wilson, Lambert & Russell, 2000). That is, when the psychophysiologically based classifier determined that the operator was in a state of mental overload the task was adjusted to reduce the demands on the operator. The Multiattribute Task Battery (MATB) was used to provide easy and difficult levels of task demand. The MATB consists of four subtasks that are independently controlled. Task difficulty is primarily controlled by the rate of changes that must be attended to by the operator. When the operator's functional state was determined to be such that their error rate would increase then the system closed the loop. This included the, included the operator's ability to carry out the task in the equation of system feedback. If the operator was over tasked then the system makes adjustments to adapt to the operator's momentary capabilities. In our laboratory study, closing the loop in this fashion improved operator task performance when compared to the unaided condition. While this was expected, the aiding could have interfered with task performance. However, significant improvement in task performance on the complex battery was found.

Implementation of psychophysiologically determined adaptive aiding will require that the operator's physiological responses and performance be viewed in the context of the ongoing task. For example, heart rate taken by itself with no regard to the task context could lead to erroneous consequences. For example, certain flight maneuvers, such as landing, are expected to produce increased heart rates. Adaptive aiding applied only on the basis of increased heart rate could well lead to catastrophic results if control of the aircraft were taken over by the system during landing. This simple example illustrates the need to evaluate the psychophysiologically based operator functional state estimate in the *context* of the current job demands. The operator's performance must also be evaluated to determine if it is appropriate for the current mission needs. The correct operator behavior can usually be inferred from knowledge of the immediate task situation and the overall task goals. If the operator's performance does not meet the current expectations then aiding may be required. The very nature of complex tasks places varying levels of cognitive demand on the operator over time and this variation must be included in the decision of whether or not to provide aiding. An adaptive aiding system must take the current level of cognitive demand into account when deciding if aiding is or is not required. The situational awareness of the operator should also be estimated and factored into any aiding decision. A diagram of the outline of a full operator functional state assessment and adaptive aiding system is shown in figure 1.

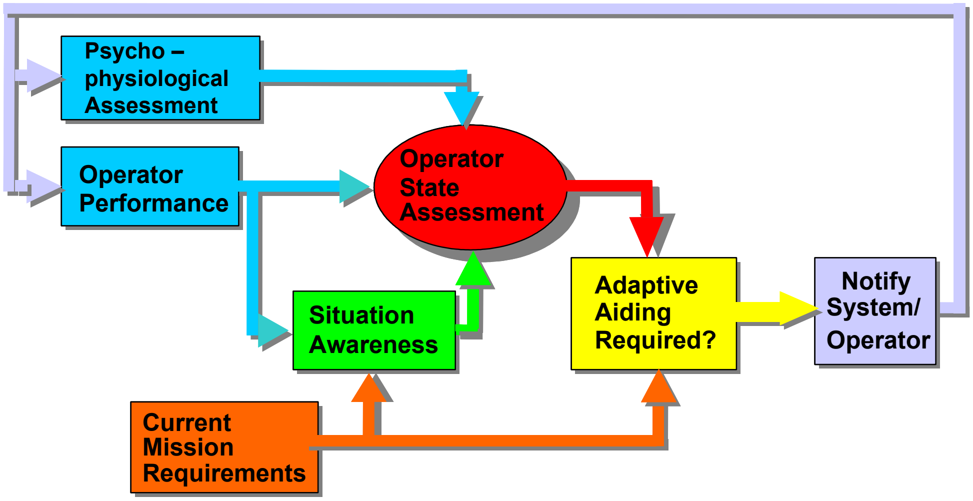

Figure 1: Schematic of Operator Functional State Assessment and Adaptive Aiding System with Psychophysiological and Performance Inputs. Mission context information is used for assessment of situation awareness and the need for adaptive aiding.

In order for this technology to be accepted by the user community it will be necessary to provide convincing evidence that it is both reliable and when implemented improves operator/system overall performance. The operator functional state assessment must be shown to be very accurate, 90% to 95% correct. Otherwise the assessment will not be useful. If the assessment is part of a larger approach then lower levels of accuracy may still be helpful when combined with other variables. Inaccurate assessment will cause inappropriate implementation of aiding which will degrade performance. Further, performance improvement must be demonstrated. Highly accurate operator functional state assessment will not be of value if it can not be shown that adaptive aiding based on this results in significantly improved performance. The aiding must be implemented so that it does not interfere with the operator's job performance. If the operator does not want the aiding or if the aiding adds confusion the it will not be used.

As procedures for operator functional state assessment improve these techniques should find applications where they produce enhanced system performance. Our understanding of human cognition, hardware and software advances should lead to implementation of these procedures in the foreseeable future.

REFERENCES

Angus, R.G., & Heslegrave, R.J. 1985. Effects of Sleep Loss on Sustained Cognitive Performance During a Command and Control Simulation. *Behavior Research Methods, Instruments, and Computers*, 17, 55-67.

Byrne, E.A. and Parasuraman, R. (1996). Psychophysiology and Adaptive Automation. *Biological Psychology, 42*, 249-268.

Kramer, A.F. (1991). Physiological Measures of Mental Workload: A Review of Recent Progress. In D. Damos (Ed.), *Multiple Task Performance* (pp. 279-238). London: Taylor and Francis.

Russell, C.A., Wilson G.F. & Monett, C.T. (1996). Mental Workload Classification Using a Backpropagation Neural Network. In C.H. Dagli, M. Akay, C.L.P. Chen, B.R. Fernandez & J. Ghosh (Eds.). Intelligent Engineering Systems Through Artificial Neural Networks (pp. 685-690), Vol. 6. New York: ASME Press.

Scerbo, M.W. (1996). Theoretical Perspectives on Adaptive Automation. In R. Parasuraman & M. Mouloua (Eds.), *Automation and Human Performance: Theory and Applications* (pp. 37-63). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Wilson, G.F. (2002a). Psychophysiological Test Methods and Procedures. In S.G. Charlton & T.G. O'Brien (Eds.). *Handbook of Human Factors Testing and Evaluation* (pp. 157-180). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Wilson, G.F. (2002b). An Analysis of Mental Workload in Pilots During Flight Using Multiple Psychophysiological Measures. *International Journal of Aviation Psychology*, 12, 3-18.

Wilson, G.F., Pilot Workload, Operator Functional State and Adaptive Aiding. In G.R. Hockey, A.W.K. Gaillard & O. Burov (Eds.), *Operator Functional State: The Assessment and Prediction of Human Performance Degradation in Complex Tasks.*

Wilson, G.F. & Eggemeier, F.T. (1991). Physiological Measures of Workload in Multi-Task Environments. In Damos, D. (Ed.). *Multiple-Task Performance* (pp. 329-360). London: Taylor and Francis.

Wilson, G.F., & Fisher, F. (1991). The Use of Cardiac and Eye Blink Measures to Determine Flight Segment in F4 Crews. *Aviation, Space and Environmental Medicine,* 62, 959-961.

Wilson, G.F., Lambert, J.D., & Russell, C.A. (2000), Performance Enhancement with Real-Time Physiologically Controlled Adaptive Aiding. *Proceedings of the IEA 2000/HFES 2000 Congress*, Vol. 3, pp. 61-64.

Wilson, G.F. and Russell, C. (1999). Operator Functional State Classification Using Neural Networks with Combined Physiological and Performance Features. *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting*, 1099-1102.