Augmenting Task-Centered Design with Operator State Assessment Technologies

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Abstract. Task-Centered Design (TCD) of human-system interfaces focuses on supporting the user throughout all phases of tasks, from initiation to completion. TCD typically requires software that monitors aspects of system information to trigger tasks, develop user-friendly information sets, propose task solutions and actions, and confirm actions as directed and approved by the operator. The operator monitors tasks awaiting completion on a Task Manager display. We demonstrate that moment-to-moment operator workload monitoring is greatly facilitated by TCD. Workload estimates were obtained every 2-min over the course of a 35-min test session during an air defense command and control scenario. Workload was readily modeled by the task loading, and the density of track icons on the display. A second study related the unitary workload estimates to NASA TLX workload subscales. Unpublished data from our laboratory indicated that eye activity measures (e.g., blink frequency and duration, pupil diameter, fixation frequency and dwell time) did not improve the estimation of workload. These findings indicate that at least for well-executed TCD systems, eye tracking technologies may be best employed to monitor for fatigue and incongruities between the focus of attention and task requirements. Recent findings using EEG hold promise for the identification of specific brain signatures of confusion, orientation, and loss of situational awareness. Thus the critical element of human directed systems is good initial design. Understanding of the task will lead to system automation that can balance the workload of the operator, who is functioning in a normal state. However, physiological monitoring will be most useful if operators veer beyond their normal conditions and are confused, overloaded, disoriented or have other impairments to their abilities. By detecting the operator's loss of function early, inappropriate operator inputs can potentially be avoided.

1 Introduction

The purpose of this paper is twofold. The first is to describe how using appropriate design strategies can improve user performance and significantly mitigate task overload conditions. The second purpose is to describe how psychophysiological and augmented cognition methods can best be employed when "task management" design principles are used. There has been a plethora of studies examining how psychophysiological variables (e.g., electro-encephalogram, eye activity, heart rate and variability) change as a function of task workload (see Craven et al., 2006;

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Poythress et al., 2006; Wilson & Russell, 2003), and how these measures might be used to monitor human operators for task overload and/or used to trigger automated processes. Using a Task-Centered Design approach, where an operator's job is broken down into tasks, and subsequently decomposed into sub-tasks, provides an opportunity to accurately measure moment-to-moment workload fluctuations (see Campbell et al., 2003; Osga & Van Orden, 2000). Without the requirement to monitor for workload, the application of operator state monitoring technologies can focus on issues such as confusion, stress, drowsiness, and forms of loss of spatial and situational awareness. Some recent findings are discussed which suggest that neural markers for some of the aforementioned cognitive states may be detected when they are not consciously perceived.

The main tenet of Task Centered Design (TCD) is supporting the user through all task phases. This involves not only presenting the typical "alert" to the user, but building information sets specific to the task, recommending a course of action, and confirming that the task was completed upon approval of the actions by the system. For example, within the air traffic control domain, specific tasks might be triggered when automation detects aircraft within distances appropriate to begin descent for landing, when aircraft are on courses that will result in violated spatial separation, or when spacing for approach controllers could be improved. In such instances, a task icon could appear on a task manager display, which when selected, would open a task information set window. The information set pertinent for the task would contain background information and, more importantly, a recommended course of action for approval. For a spacing task, the recommended course of action might be to reduce the speed of a particular aircraft. Upon operator approval of the course of action, the system would generate an electronic voice command to the aircraft (or alternative data link) with new air speed guidance.

Several benefits of task managed design include an active (vice passive) control of the processes by the user, support through most or all phases of the task, and the potential ability of automation to forecast critical events and time tasks so that they occur sooner than would otherwise. In other words, tasks could be forecasted by the system and presented to the user prior to their typical trigger points as potential backlogs are detected. This form of task management is important, as it is well know that operators have a poor sense of time management under high workload conditions.

2 Task Centered Design and Workload Assessment

Van Orden (2001) examined how workload correlated with task loading and other variables in a 40-minute simulated air defense task hosted upon a TCD work station. Tasks included reporting new air contacts, reporting identification changes to air contacts, and sending messages to aircraft entering restricted areas. The participants provided subjective workload estimates every two minutes, and these were matched with the number of tasks appearing on a task manager display, and the number of air contacts present on the display. Results indicated that the number of air contacts present on the display combined with the number of tasks present correlated significantly with the subjective workload measure. For several participants, psychomotor activity (mouse clicks to reveal information about specific air contacts) was also included, in order to capture work associated with gaining awareness of the air contacts on the display. Data for one such participant is included in Figure 1. (Not shown are number of air contacts on the display, which varied between 15 and 30, and increased steadily over the duration of each experimental session.). Combined measures of contact density, number of tasks to be performed, and psychomotor activity accounted for 70 percent of the variance in subjective workload estimates for this participant. Interpolating subjective workload from the aforementioned variables produced a moment-to-moment workload series, shown in Figure 2.

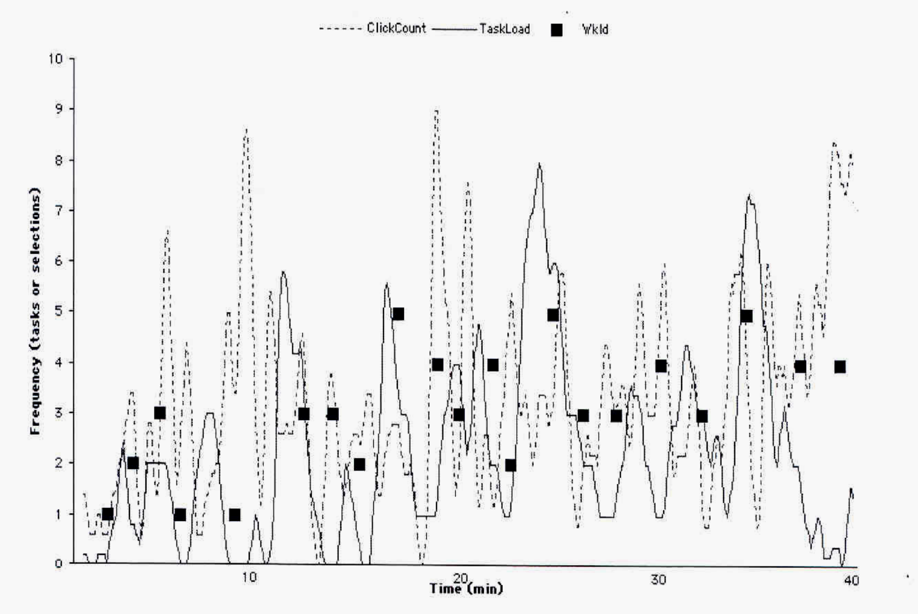

Fig. 1. Plot of frequency of mouse click activity (dashed line), task load (solid line) and subjective workload estimates (filled squares) over time in minutes for the test session

The preceding description on deriving a moment-to-moment workload time series from data easily obtained from system and user activity measures underscores two points: First, that task data from a TCD implementation is an important factor in the determination of workload. The second point is *that psychophysiological data would add little to improving the workload estimates*. However, data on the operator state could be very beneficial if applied for other purposes. It has been previously demonstrated that psychophysiological data would be useful for the determination of drowsiness (Van Orden, K.F., Jung, T-P., & Makeig, 2000;; Makeig & Jung, 1996) and loss of attentional focus (Makeig, Jung & Sejnowski, (2000). Recent findings suggest that brain activity and electroencephalographic (EEG) measures might provide information on cognitive states such as false memories (Garoff-Eaton, Slotnick, & Schacter, 2006; Schacter, Reiman, Curran et al., 1996) or spatial disorientation (Viirre et al., 2006). These findings indicate that similar measures

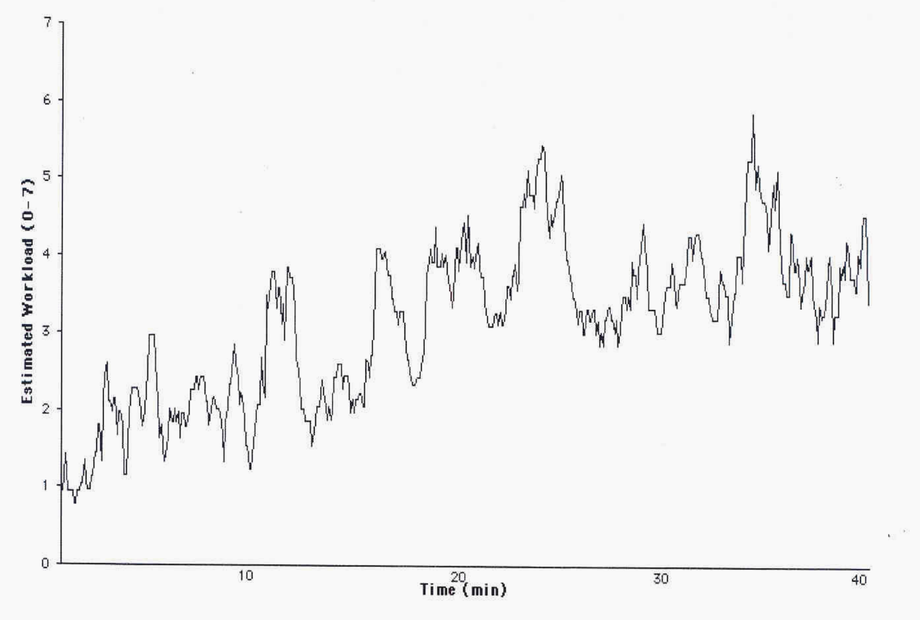

Fig. 2. Subjective workload for one participant based upon a regression model using psychomotor activity, task loading, and the number of aircraft on the display as input

might be capable of identifying such operator states as self-deception or loss of situation awareness; conditions beyond the normal scope of performance of trained operators. This type of monitoring could serve as a safe-guard, or used as a training tool, especially under grueling or stressful operating conditions, or in advanced training scenarios.

3 Uncertainty, Disorientation, and Self Deception

Schacter, Reiman, Curran et al., (1996) demonstrated that positron emission tomography (PET) recordings differed as a function of whether participants had accurately or falsely remembered words from a previously studied list. The PET activation differences between these conditions were greatest in the pre-frontal cortical regions of the brain. There were clear differences between correct assertions and incorrect ones. A rudimentary interpretation of this result was that in the incorrect assertion state, there was detectable neural activity reflecting uncertainty in the decision. Thus, as the subject was forced to make an assertion, there were clear differences between assertions that were made that were accurate and those that were wrong. The disconcordance of brain activation from conscious actions and underlying unconscious decision making has far reaching ramifications. An important practical application is that operator confusion or uncertainty can likely be detected. Thus, situations where an operator implements an input, but is uncertain about it, the operator, and their human or automated supervisors can be alerted to that state and provide further analysis. For example, if an operator is required to make an input, but has behavioral or neural markers that show uncertainty, the system or an instructor could respond to it and re-run the scenario or re-present the data to enable the operator to choose again.

Example: Three Dimensional (3D) Navigation

Given the ability to monitor neural activity related to decision making and memory assertions, an era where it will be possible to monitor operators during specific cognitive tasks is now upon us. Thus TCD will become more rigorous and instead of using global non-specific concepts such as "work load", we will be able to implement monitoring of conditions such as memory and decision processing.

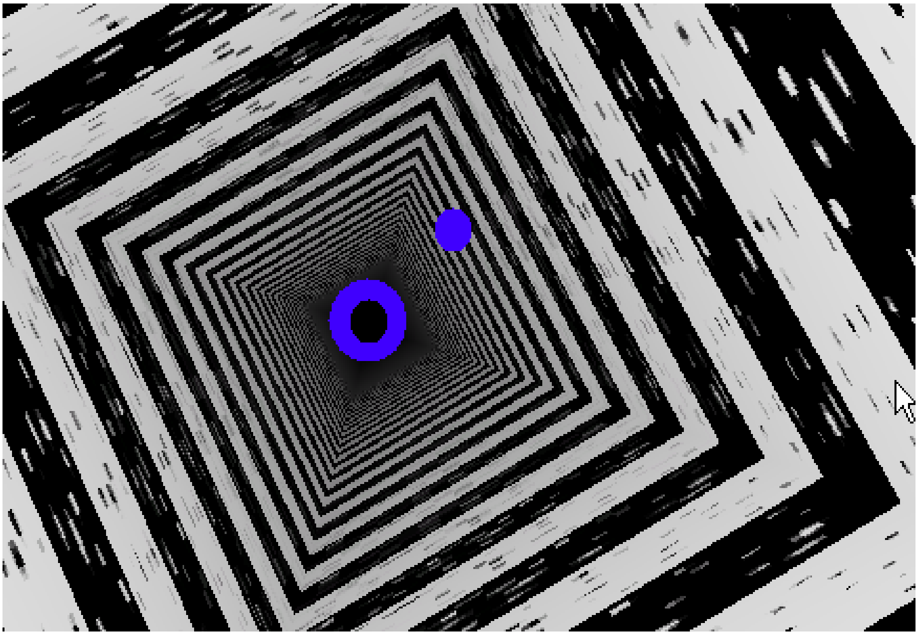

Fig. 3. Three Dimensional scene used during visual tracking task

Data from neural monitoring during a navigation task suggests an example. In Strychacz et. Al (2005), we had subjects carry out a tracking task while virtually traveling through a three-dimensional scene (See figure below). We then had subjects view another 3 dimensional scene that resulted in the onset of motion sickness. Monitoring neural patterns using high density EEG demonstrated a strong signature of Alpha wave and alpha harmonic peaks in the posterior mid-parietal region (See figure X below). These peaks were eliminated when the motion sickness appeared.

Further, we found similar neural activity changes in the same region during a navigation task where we implemented Schacter's paradigm (Viirre, et. al. 2006). Participants were asked to observe a rectilinear virtual environment on a computer screen (See Figure 3). The point of view of observer was randomly shifted and rotated

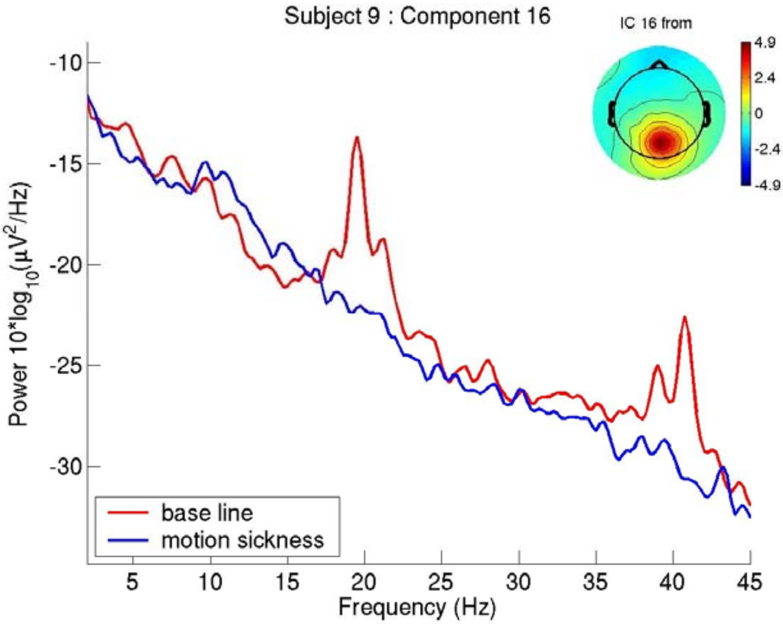

Fig. 4. Prominent power peaks at 20 and 40 Hz in ventral midline sources during the tracking (light colored line) that are suppressed during motion sickness (darker line)

and the subject was asked to keep track of their apparent compass heading. Randomly, the scene movement would stop and the subject was presented with a compass rose and a "lost button". They indicated which heading they believed they were facing or, if they were not confident of the heading, they pushed the "lost" button. Continuous EEG and eye movement data were recorded during the trials on 128 scalp and 2 eye channels. EEG activities were labeled "correct" (heading fashion to the data presented above in Figure 4. Similar to word recall tasks, frontal midline sources were found to show significant differences between correct and incorrect in the interval 500 ms after the button press, indicated within +/- 45 degrees), "incorrect" or "lost". Subjects were found to make incorrect heading assertions approximately 20-30% of the time, even though they were given the option to indicate they were lost. Significant differences between "correct" and "incorrect" responses were apparent in neural activity in ventral posterior midline sources in all subjects in the time interval 500 ms prior to the button response. These differences occurred in the alpha EEG frequency range in similar.

These results suggest that it may be possible to detect in near real-time neural activity markers of operator task attention to a three dimensional task and to the loss of that attention. Thus when training pilots to perform instrument maneuvers or when training radiologists to interpret moving three-dimensional images such as ultra sound, an automated augmented cognition system or an instructor would be able to detect when the operator was not on task. This information could be used to enhance task performance by notifying the trainee pilots to re-orient using navigation instruments; or provided feedback to trainee radiologists to re-establish their orientation.

4 Conclusion

Task Centered Design is an important process in the Human Factors component of systems development. The combination of TCD and augmented cognition technologies – used to detect neurophysiological state -- is exciting and offers the potential to improve human-machine interactions. However, significant challenges remain with regard to how an operator's state is monitored, and different approaches should be carefully examined in the earliest phases of system design. Careful task-centered design review of a system will yield more benefit than grafting neurophysiological state assessment onto an existing interface. TCD should yield a thorough understanding of the vast majority of system states that might arise, and then reveal opportunities to appropriately manage them.

Neurophysiological state assessment is best used to detect operators who are "out-of-range" for normal operator conditions: such as - overstressed, over-loaded, disoriented or other situations. Neurophysiological assessment is becoming refined in the ability to detect specific state conditions in a variety of real-world environments. Instead of a pilot being in a state of "high workload" (which the computer could already determine), state assessment could provide more detailed information such as; they are not correctly monitoring their three dimensional orientation. Such state assessments would provide greater opportunity for detecting and mitigating human-system failures.

As the technological advances occur, the difficulty in using these technologies will become designing paradigms for identifying the appropriate neural signals. For example, the operational aviation environment is vastly different from a laboratory setting. Two technologies that may offer some promise for real-time detection during operations on moving platforms: advanced electro-encephalography (EEG) and functional near infrared (fNIR) recording. EEG systems now incorporate miniature amplifiers at the electrode that greatly enhance signal to noise and reject local interference sources. Portable wireless EEG sets now exist. FNIR is a newer technology that can measure regional blood oxygenation changes in the outer layers of the cerebral cortex using infrared light. EEG and fNIR have been used to look for signatures related to GLOC and related phenomena. It provides reliably repeatable measures that are empirically useable if not perfectly correlated to known physiologic changes. Further, limited studies relevant to target detection and loss of SA can be carried out in functional magnetic resonance imaging (fMRI) systems. FMRI can be used with some simulations of disorienting conditions, but can not be applied to operational conditions. Fortunately, with its fine spatial resolution, it can greatly assist in identification of specific brain areas involved in motion processing and thus be used to compare data across subjects and further refine operational tools and measures.

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