Developing a Predictive Model for Vigilance Performance

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Problem Statement

Vigilance, or sustained attention, refers to the ability of observers to maintain their focus of awareness and remain alert to stimuli in the environment over prolonged periods of time (Davies & Parasuraman, 1982). This topic has been extensively researched since the 1940s to elucidate the impacts of numerous factors on operators' ability to sustain attention for vigilance tasks, including those supporting national security. One critical gap that remains is the ability to predict the expected level of vigilance performance *a priori*, given a planned system design. The primary factor impeding efforts to build a predictive model is the inherent difficulty in designing a single research study to incorporate simultaneously all the variables that impact vigilance performance. One solution is to undertake a meta-analysis of the entire vigilance literature to create a comprehensive predictive model.

Background and Discussion

Vigilance Research. Many Department of Defense (DOD) and Department of Energy (DOE) missions require operators to monitor one or more sources of information for extended periods of time in order to detect relatively infrequent critical signal events such as security breaches, equipment state of health alerts, enemy threats, and other anomalies. Emergent semi-autonomous systems will also likely involve mixed human-machine decision making tasks requiring human vigilance. The source of information for vigilance tasks is often, but not always, some type of intermediate display (e.g., radar, sonar, pressure gauge) to which the observer must attend. Contrary to popular belief, vigilance tasks are effortful and mentally demanding. A steep decline in performance typically occurs within the first 15 to 30 minutes of an observation period—a phenomenon known as the *vigilance decrement* (Warm, 1984). As a result, tasks requiring sustained attention must be carefully designed in order to prevent degradations in performance that might result in equipment failures, accidents, or death.

Problems associated with the ability to sustain attention were first identified in real-world combat situations during World War II. Specifically, British radar observers on antisubmarine patrol over the Bay of Biscay failed with increasing frequency to notice the blips of light on their displays that indicated the presence of enemy submarines in the sea below. This decline in accuracy over time was particularly troubling not only because of its potential consequences but also because it occurred in the presence of an apparently high level of motivation on the part of the airborne radar operators. These observations prompted over 70 years of systematic research to better understand this phenomenon. The result has been an accumulation of a vast amount of data thoroughly documenting the impacts of multiple factors on vigilance performance—psychophysical, task, environmental, pharmacological, and individual factors.

The signal detection problems of World War II that prompted vigilance research persist in multiple real-world military and civilian situations today, and they continue to abound and evolve as new and different types of situations requiring vigilance arise. Military activities requiring vigilance include watchkeeping in surveillance missions, sentry duty, alarm monitoring for physical security, and target acquisition in armored combat. In the civilian arena, activities requiring vigilant behavior include industrial quality control, robotic manufacturing, air traffic control, airport baggage screening and inspection, nuclear power plant operations, long distance driving, transport operations, seaboard navigation, cytological screening, closed circuit television surveillance, and the monitoring of medical equipment in hospital settings (Beatty, Ahern, & Katz, 1977; Davies & Parasuraman, 1982; Mackie, 1977; Wiener, 1984).

Predicting Vigilance Performance. Despite the depth of research in the field of vigilance, the ability to predict the expected level of vigilance performance *a priori*, given a planned system design, has not been established. At present, the practitioner is able to identify expected high-level impacts of various factors in isolation, but is less able to predict the interactive effects among multiple variables. This constraint occurs because it is not practically possible to design a single study that incorporates all variables of concern for vigilance performance. However, the many hundreds of separate vigilance studies that have been conducted both in the laboratory and in the real world since World War II do provide a vast body of data that could be mined to build a predictive mathematical model of sustained attention, if combined appropriately.

A comprehensive meta-analysis of the entire vigilance literature could be conducted in order to develop an overarching predictive model. Any vigilance study reporting the percentage of correct detections for normal adult humans is a candidate for inclusion in the meta-analysis. The primary goal is to derive equations to predict the overall level of vigilance performance as well as the extent of the decrement by combining findings from multiple, diverse studies in the literature through meta-analysis. While data for other dependent variables are less frequently reported in the literature, measures such as reaction time and the signal detection theory indices of perceptual sensitivity and response bias could also be analyzed. In particular, predictive models for reaction time are of interest because research regarding the equivalence of accuracy (correct detections) and reaction time has not been entirely consistent (Warm, 1984).

Given the large number of variables that can impact vigilance performance, a modular approach for developing predictive equations may work best. First, separate predictive equations could be developed within each broad category of factors (psychophysical, task, etc.). Second, these predictive equations could then be combined into an overarching predictive model using mathematical and cognitive modeling (e.g., Pan, Johnson, & Williams [2009] use a relevance network model with a weight generating function and a generalized mixed operator to combine regression equations).

In addition to model development, model validation and verification would be an important component of the implementation of predictive models. Toward that end, the sample of studies within each module could be split in half, with one half of the studies used to develop the model and the second half used for validation. For verification, a true predictive test of the overarching model's validity is recommended. Namely, the model should be tested to determine whether it accurately predicts the outcome for vigilance research currently in progress, before the results are complete.

Recommended Research Strategies

The research necessary to support this effort would entail conducting a comprehensive meta-analysis of the entire vigilance literature. A typical meta-analysis involves a team of experts who generally work many months to years to complete the analysis. Given the extent of the proposed meta-analysis to build a predictive vigilance model, the expected level of effort would likely be much higher. Required tasks include the following:

- Conduct database searches for human vigilance research articles
- Retrieve articles and identify relevance for current effort
- Review retrieved articles for additional articles to include
- Select sample of studies to include in meta-analysis
- Code articles in terms of psychophysical, task, environmental, pharmacological, and individual variables relevant to the current effort
- Perform statistical analyses such as regression analysis to identify performance predictors
- Conduct modeling to combine regression equations into a single predictive model
- Validate and verify models
- Report results

Benefits

The proposed effort will have practical benefits and help advance the scientific discipline of vigilance. First, in terms of practical advantages, a valid predictive model will enable a vast amount of complex information that is currently widely scattered throughout the literature to be combined into a single source. This source will be more accessible to the operational DOD and DOE practitioners who require the information to optimize tasks with a vigilance component. A predictive vigilance model may also be used to support adaptive automation for semi-autonomous systems involving mixed human-machine decision making to counteract human vigilance problems. Potential benefits in the field are improved safety and security, enhanced performance efficiency, and greater personnel job satisfaction.

Second, in terms of research advantages, the meta-analysis and predictive model will identify weaknesses in the literature that require further research. A comparative analysis of the predictive models for accuracy versus reaction time will also clarify whether these measures provide congruent indicators of vigilance performance. Likewise, by weighting the relative importance of various factors across multiple vigilance studies, the overarching model may provide insight into theoretical explanations for vigilance to help guide future research and, ultimately, further optimize real-world performance. Finally, a comprehensive meta-analysis of the existing body of vigilance literature provides the foundation to update and augment the seminal treatise on vigilance, *Sustained Attention in Human Performance* (Warm, 1984).

In terms of the possible contributions identified in the *Second Call for White Papers*, this effort would advance knowledge by modeling and improving our understanding of behaviors relevant to national security. Vigilance is a critical component of many activities relied upon for national security, including sentry duty and alarm monitoring for physical security, and it may become increasingly important with the proliferation of autonomous agents. A true predictive model would help practitioners design tasks that more effectively support vigilance performance and enhance national security. The research would also build coordination and improve communication among researchers, analysts, policy and decision makers and among teams. For example, a predictive vigilance model could be used to influence policy and decision makers regarding requirements and architectures for optimal design and use of systems in which vigilance has a critical role.

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