Applied Ergonomics 70 (2018) 194–201

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Automation trust and attention allocation in multitasking workspace

Nicole D. Karpinsky[a], Eric T. Chancey[b], Dakota B. Palmer[a], Yusuke Yamani[a,*]

[a] *Old Dominion University, VA, USA*
[b] *Leidos, OH, USA*

ARTICLE INFO

Keywords:
Human-machine systems
Trust
Attention allocation
Human-automation interaction

ABSTRACT

Previous research suggests that operators with high workload can distrust and then poorly monitor automation, which has been generally inferred from automation dependence behaviors. To test automation monitoring more directly, the current study measured operators' visual attention allocation, workload, and trust toward imperfect automation in a dynamic multitasking environment. Participants concurrently performed a manual tracking task with two levels of difficulty and a system monitoring task assisted by an unreliable signaling system. Eye movement data indicate that operators allocate less visual attention to monitor automation when the tracking task is more difficult. Participants reported reduced levels of trust toward the signaling system when the tracking task demanded more focused visual attention. Analyses revealed that trust mediated the relationship between the load of the tracking task and attention allocation in Experiment 1, an effect that was not replicated in Experiment 2. Results imply a complex process underlying task load, visual attention allocation, and automation trust during multitasking. Automation designers should consider operators' task load in multitasking workspaces to avoid reduced automation monitoring and distrust toward imperfect signaling systems.

1. Introduction

A myriad of professional environments requires multitasking often involving partial or full automation, such as piloting an aircraft (e.g., Billings, 1997; Durso et al., 2015), air traffic control (e.g., Loft et al., 2016), healthcare (e.g., Collins et al., 2007), space teleoperation (e.g., Li et al., 2014), and military operations (e.g., Rovira et al., 2014). Unfortunately, automation not only supplants human activity, but can also alter the nature of tasks counterproductively (Bainbridge, 1983; Parasuraman and Manzey, 2010). Identified factors that influence human-automation interaction include operator workload and trust toward automation (Parasuraman and Riley, 1997; Lee and See, 2004). The goals of the present work are to characterize the effects of task demand on visual attention allocation in an attention-demanding multitasking environment and to investigate the mediating effects of subjective workload and trust toward imperfect automation.

1.1. Alerted-monitor system, trust, and attention

As automation prevalence has increased, humans' tasks have shifted to monitoring automated systems. Yet, research has shown that humans are poor monitors (see Warm et al., 2008). Consequently, alerted-monitor systems have become prevalent, consisting of two sub-systems: the task-engaged human monitor and the sensor-based signaling system (Sorkin and Woods, 1985). Signaling systems provide the human with information about automation trends and failures. Unfortunately, these systems are not perfectly reliable and, depending on sensor threshold settings, are apt to generate false alarms or miss critical events (Bliss and Gilson, 1998). Alerted-monitor performance, however, cannot be well predicted based on signaling system error rate alone, because system false alarms and misses uniquely affect the decisions and actions of the human sub-system (Bliss et al., 1995; see Wickens and Dixon, 2007, for review).

False alarms manifest in reduced or slowed signaling system responses, often referred to as the *cry-wolf effect* (Breznitz, 1984; Getty et al., 1995; Sorkin, 1988). Alternatively, misses create a situation in which the operator must crosscheck the signaling system to ensure nothing is overlooked, leading to increased workload and deterioration in task performance indices (Dixon and Wickens, 2006; Dixon et al., 2007). One of the key psychological factors thought to mediate the relationship between signaling system errors (misses and false alarms) and human responses is trust (Meyer, 2001; Rice, 2009; however, see Chancey et al., 2017, and Chancey et al., 2015a,b for an alternative perspective). Human-automation trust is defined as "an attitude that an agent will help achieve an individual's goals in a situation characterized by uncertainty and vulnerability" (Lee and See, 2004, p. 51). Indeed, research has shown that trust may affect operators' responses by altering attention and monitoring strategies (Bailey and Scerbo, 2007;

* Corresponding author. Department of Psychology, Old Dominion University, 236B Mills Godwin Building, Norfolk, VA 23529, USA.
E-mail address: yyamani@odu.edu (Y. Yamani).

https://doi.org/10.1016/j.apergo.2018.03.008
Received 25 December 2016; Received in revised form 8 March 2018; Accepted 12 March 2018

Molloy & Parasuraman, 1996).

For example, Bailey and Scerbo (2007) asked participants to perform a mock flight task and a system monitoring task consisting of three separate information displays (simulated engine instrumentation crew alerting system, or EICAS, display). The system monitoring task was assisted by imperfect automated systems with high or low reliability conditions. The participants rated their trust levels higher and detected system failure more poorly under the high than the low reliability condition, and critically, this effect was more pronounced when the monitoring task required greater attentional resources. Similarly, multitasking environments led to even poorer detection of automation malfunction than single-task environment (Parasuraman et al., 1993), suggesting that attentional demand of multitasking and trust both modulate operators' monitoring of automation.

Additionally, Bliss and Dunn (2000) examined effects of workload on operators' alarm distrust toward unreliable signaling systems. The experiment required participants perform psychomotor tasks of the Multi-Attribute Task Battery (MATB; Comstock and Arnegard, 1992; see Methods below for more details) and concurrently react to an auditory alarm system. With increasing number of the psychomotor tasks, the results indicated that operators responded to the alarm less frequently and more slowly, which, as the authors suggested, represented distrust toward the signaling system. Taken together, preceding work (Baily and Scerbo, 2007; Parasuraman et al., 1993; Bliss and Dunn, 2000) suggests that attention-demanding environments, especially those requiring multitasking, compromise operators' calibration of trust toward automation, increase their workload, and change their attentional performance.

One account of these data patterns centers on operators' strategic allocation of attentional resources to multiple, concurrent tasks with trust as a construct partly driving attention to an automated task (Parasuraman and Manzey, 2010). Attentional resources can be conceptualized as a single pool of energy necessary for task performance (Kahneman, 1973) that activates each information processor (e.g., Lindsley, 1951; Wickens et al., 2013). To illustrate, for an operator performing a manual tracking task and a system monitoring task with an imperfect automated aid, if the attention demand of the tracking task is low, then the operator may allocate the reserve attention to monitoring the aid's behavior and accurately calibrate his/her trust to match the trustworthiness of the aid (Lee and See, 2004). If the addition of another manual task to the existing tasks (e.g., resource management task) or elevated complexity of the tracking task increases operators' overall attention demand, then they may no longer have resources to effectively monitor the aid's behavior and inaccurately calibrate their trust to match the trustworthiness of the aid.

1.2. Current study

Of the current interest is to examine the effects of a manual tracking task demand on operators' visual attention allocation and trust toward imperfect automation in a system monitoring task. Similarly with Bailey and Scerbo (2007), we asked participants to concurrently perform a manual tracking task and a system monitoring task with the assistance of an imperfect signaling system in the MATB paradigm. While participants performed the tasks, their eye movements were recorded and served as a measure of their attention allocation (Horrey et al., 2006). Models of visual sampling generally conceptualize the eye as a single-server queue (e.g., Carbonell, 1966; Senders, 1964, 1983), as the range of focal vision is severely restricted at the fovea, and operators must fixate to extract relevant information from a set of areas of interest in dynamically changing visual environments. Thus, although it is possible to decouple locations of visual attention and gaze (Posner et al., 1980), patterns of eye movements serve as a proxy to distribution of visual attention in applied dynamic environments (Wickens and McCarley, 2008).

Relating the current study to the literature of visual attention in supervisory control, the SEEV model is one model that integrates four independent factors – salience, effort, expectancy, value – that influence operators' eye movements in the visual workspace (Moray, 1986; Wickens et al., 2003; Wickens, 2015). Briefly, salience refers to the extent to which rudimentary features of visual objects attract attention (Itti and Koch, 2000) and effort defines the cost of scanning. Expectancy refers to the levels of uncertainty at task-relevant information sources (e.g., Senders, 1964) and value refers to the importance of the information to perform the task. Salience and effort are grouped as bottom-up factors because physical environment parameters characterize attention, whereas expectancy and value are top-down factors because operators' knowledge and experiences drive attention.

We conducted two experiments, in which participants performed the MATB task with varying levels of tracking task difficulty and the reliability of the aid remained consistent but erred by making only misses or only false alarms. We predict that participants under higher task load will 1) report greater levels of subjective workload and 2) exhibit lower levels of trust toward the automation. According to the SEEV model, an operator prefers attending to an area of interest that has higher levels of salience, value, and expectancy and a lower level of effort; thus, we predict 3) lesser allocation of visual attention toward the system monitoring display as measured on percentage dwell time (PDT) of their gaze. Furthermore, previous research indicates that FA-prone systems are more salient than miss-prone systems perceptually (e.g., Dixon and Wickens, 2006) and cognitively (Rice and McCarley, 2011); thus, we predict the effect of task load on visual attention allocation arises more pronouncedly with False Alarm (FA)-prone systems compared to Miss-prone systems. Finally, we investigate roles of trust and subjective workload as mediators affecting their visual attention allocation strategy by using mediation analyses (Hayes, 2013; Montoya and Hayes, 2016; see below). We predict that trust (Bailey & Scerbo, 2007) and workload (Bliss and Dunn, 2000) will mediate the relationship between task load and visual attention allocation.

2. Experiment 1

Participants performed the compensatory tracking task and the system monitoring task with the assistance of FA-prone or Miss-prone signaling systems.

3. Method

3.1. Participants

Forty students (24 females, M = 20.15 years old, SD = 3.49 years) were recruited from Old Dominion University (ODU). All were screened for normal color perception and normal or corrected-to-normal visual acuity. Participants received credit for fulfilling course requirements.

3.2. Apparatus

Stimuli were presented on a 13" CRT monitor (1024 × 768 pixel) with a refresh rate of 75 Hz. Participants viewed the display at a distance of 80 cm, fixed by a chin rest. The revised Multi-Attribute Task Battery (MATB-II; Santiago-Espada et al., 2011) was run on a Windows computer (Dell OptiPlex 9020). Responses were collected via keyboard and joystick. Eyelink II (SR Research, Mississauga, Ontario, Canada) recorded eye movements via desk-mounted eye-tracking system at a sampling rate of 250 Hz. The experiment was conducted in a quiet room with dimmed lights.

3.3. Flight-simulation task

The MATB-II is a low-fidelity flight-simulation program consisting of four tasks of tracking, system monitoring, fuel management, and communication. Each task can be performed manually or under