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The effect of navigation display clutter on performance and attention allocation in presentation- and simulator-based driving experiments

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ABSTRACT

Display clutter can have differential effects based on environmental factors, such as workload, stress, and experiment paradigm. The objectives of the current study were to assess the effects of display clutter on driver performance and attention allocation and compare results across two experimental paradigms. Forty-two participants searched high- and low-clutter in-car navigation displays for routine information either during a static, presentation-based experiment or in a dynamic, driving simulator experiment. Results revealed display clutter to significantly alter attention allocation and degrade performance in the presentation experiment, but had little to no effect on driver performance or attention allocation in the driving simulator experiment. Results suggest that display clutter may have its greatest effect on performance and attention allocation in domains requiring extended attention to the cluttered display compared to tasks in which the cluttered display acts as a support tool for secondary tasks.

1. Introduction

Advances in technology have led to the widespread use of information displays in automobiles. Driver information overload can have disastrous effects in safety-critical situations and, therefore, it is imperative that information displays be designed to ensure key information is presented to drivers without exceeding available attentional resources. Related to this, displays should be designed to reduce clutter, or *display imagery that unintendedly obscures or confuses other information or that may not be relevant to the task at hand* (Kaber et al., 2008). There is myriad research on the effects of display clutter on aviation task performance and workload (e.g., Kim et al., 2011), map search tasks (e.g., Wickens et al., 2000), and supervisory tasks (e.g., St. John et al., 2005); however, there has been little research investigating the effects of display clutter on driver performance and attention allocation.

1.1. Effects of display clutter

Trends identified in the existing literature suggest that response time (RT) to task demands increases as a function of increasing information display clutter (see review by Moacdieh and Sarter, 2015a). Boston and Braun (1996) reported RT to an unexpected event in a ship navigation task was significantly longer when participants used high clutter displays compared to low clutter displays. Similarly, pilots have been shown to respond 0.5 s slower (a statistically significant difference) to changes in display symbology and to the presence of targets in the environment when using higher-clutter displays, particularly when there was high contrast between display elements and the background (i.e., making any clutter more salient; Ververs and Wickens, 1996). Over a series of five experiments involving map search as part of military and aviation tasks, a statistically significant 4 s RT benefit was reported with low clutter maps compared to high clutter maps (Wickens et al., 2000). Further, in their military task, the authors found a highly significant linear relationship between the level of clutter and RT.

Several studies have also been conducted on visual target detection times. In a naval ship monitoring task, St. John et al. (2005) reported a statistically significant 25% increase in the time to identify high-risk intruders in high clutter displays compared to low clutter displays. (Beck et al., 2010) also reported a statistically significant increase in time to detect a target elevation marker in aeronautical charts with higher clutter. (Moacdieh et al., 2013) reported that increasing the level of clutter in a primary flight display significantly degraded detection time of visual alerts and messages that appeared on the display during high-workload phases of flight, but there was no statistically significant effect of clutter during low-workload periods. Findings suggested that the influence of clutter on performance may be sensitive to external or environmental effects, such as workload. Other research in the aviation

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domain indicates that using cluttered displays in an aircraft cockpit can lead to compromises in flight path control (e.g., Wickens and Long, 1994; Kim et al., 2011). These findings suggest that high levels of display clutter can be detrimental to task performance beyond simple RT effects and that the manner of information presentation is influential.

Recent research has focused on the effects of cluttered displays on attention allocation in various contexts. Moacdieh and Sarter (2012) presented a comprehensive list of eye tracking metrics that were significantly altered by varying levels of clutter in a *Where's Waldo?* search task. Interestingly, Moacdieh and Sarter (2012) reported a statistically insignificant effect of clutter level in a display on glance duration to target areas of interest (AOIs), which is counter to Lim et al. (2010), who found a significant effect of the level of clutter on the mean glance time in their driving experiment. In another study, Moacdieh et al. (2013) reported statistically significant differences in primary flight display clutter to affect various eye tracking metrics, including an increase in the number of fixations, fixation frequency, and fixation time on a target AOI. Similarly, in a mock warfare task, van Orden et al. (2001) found fixation frequency to be among the most predictive variables relating eye tracking to clutter. Finally, Moacdieh and Sarter (2015b) found significant effects of clutter on number of fixations, but reported no significant effect of clutter on mean fixation duration in an electronic medical record search task. On this basis, additional research is needed to clarify the relationship of display clutter to gaze behavior in target detection tasks.

1.2. Environmental factors and display clutter

Previous research suggests that the task domain or other environmental factors can influence the effects of display clutter and bias operator perceptions of clutter, particularly for simplistic measures of clutter (i.e., unidimensional overall clutter ratings). For example, in their experiment on the effects of clutter on physician use of an electronic medical records system, Moacdieh and Sarter (2015b) reported significant interactions between display clutter level and stress level (manipulated by imposing differing time limits on task completion) on search performance and attention allocation, suggesting that the effects of clutter were dependent on the environmental factor of stress.

In an earlier experiment in the aviation domain, Moacdieh et al. (2013) reported no significant difference in unidimensional clutter ratings between "medium" and "high" clutter displays, suggesting that a simple clutter rating (CR) response was not sensitive enough to differentiate between the two levels of clutter. The authors also commented that participants preferred the "medium" clutter displays to the "low" and "high" clutter displays due to the presentation of the ideal amount of information. Similar findings were reported for pilot performance in a runway approach by Kim et al. (2011) and Kaber et al. (2013a). These results suggest a lack of operator understanding of what information constitutes clutter compared to task-relevant information, leading to flawed perceptions of display clutter.

Finally, Kaber et al. (2013b) analyzed data over three experiments to assess how the environmental factors of display dynamics (static presentation vs. dynamic simulator) and flight domain (fixed-wing vs. vertical takeoff and landing) affected pilot perceptions of display clutter. The results revealed that CRs were smaller when the displays were used in conjunction with a flight simulation compared to when pilots were given a verbal description of a flight situation and then shown a static image of the same display configurations. Simple CRs were also reported to be higher in the more-complicated vertical takeoff and landing simulation than in the simpler fixed-wing simulation. The experiment also assessed differences in a structured Clutter Score (CS) developed by Kaber et al. (2008), which measured perceptions of display clutter as a rank-weighted sum of "clutter subdimensions," or dimensions that contribute to perceptions of clutter. Kaber et al. (2013b) also reported significant CS differences between the two simulation types, with higher CSs being reported for the more-difficult vertical takeoff and landing simulation than for the simpler fixed-wing simulation. Overall, these results suggest that performance and perceptions of clutter can be biased by various task and environmental factors.

1.3. Motivation

Most of the existing research on the effects of display clutter has been performed in the aviation and military domains, with relatively little research performed on the effects of display clutter on driver performance and attention allocation. There also appears to be some conflicting evidence on attentional effects of display clutter. Furthermore, the existing literature suggests that the effects of clutter are dependent on various factors, such as workload, stress, and task setup. Given these shortcomings in the literature, a dual-experiment paradigm was designed to assess the effects of display clutter on driver attention allocation and performance, including: (1) a static display image presentation experiment and (2) a dynamic driving simulator experiment. The task in both experiments involved asking drivers routine navigation questions, requiring them to search high- and low-clutter combinations of in-car navigation displays.

1.4. Hypotheses

Based on the literature, it was expected that high clutter displays would degrade task performance (Hypothesis (H)1), high clutter displays would require increased driver attention (H2), and high clutter displays would yield greater perceptions of clutter (H3) than low clutter displays. It was also expected that there would be differential effects of clutter based on the nature of presentation of the experimental stimuli (i.e., static presentation vs. dynamic simulation; H4).

2. Methods

2.1. Participants

Twenty-two participants were recruited for the presentation-based experiment, with balanced representation of male and female drivers. In order to recruit a uniform sample of participants in terms of driving skills, all participants were required to be younger than 60 years of age, as Chen et al. (2007) demonstrated that accident rates are uniform for drivers between the ages of 25 and 60. All drivers had 20/20 vision or corrective lenses. The sample as a whole had 9.7 ± 6.8 (mean ± sd) years of driving experience.

An additional 20 participants, also under 60 years of age, were recruited for the driving simulator experiment, with balanced representation of male and female drivers. All participants had 20/20 vision or corrective lenses, and had 10.05 ± 8.09 years of driving experience. There were no drivers that participated in both experiments. A t-test assuming unequal variances among the experiment samples revealed no evidence of a difference in experience between the presentation-based participants and the simulation participants ($t(37.3) = 0.139$, $p = 0.890$). Furthermore, analyses of data from both the presentation- and simulator-based experiments revealed no significant effect of expertise on any of the responses that were measured in the two experiments; consequently, the samples were considered uniform in terms of driver capabilities.

2.2. Apparatus

Both experiments used the driving simulator setup shown in Fig. 1(a), which included three 38-inch high definition television monitors providing a 135-degree field of view of the driving environment. To the right of the forward-view was a tablet computer (iPad 2, Apple, Inc.), which presented the navigation display corresponding to the driving scenario. In the presentation experiment, static images of various driving scenarios were presented to participants sitting in the