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DYNAMIC DISPLAY OF IN-VEHICLE TEXT MESSAGES: THE IMPACT OF VARYING LINE LENGTH AND SCROLLING RATE

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This study examined the effect of varying dynamic display characteristics of in-vehicle text messages on visual sampling behavior. Sixteen participants navigated a simulated driving environment while reading text messages on an in-vehicle display. Each participant was exposed to four combinations of message segment length (short or long) and scrolling rate (slow or fast). Visual sampling was measured by the frequency and duration of glances to the display and the roadway, and comprehension of messages was measured by a series of post-drive questions. Results showed that varying segment length and scrolling rate affected the number of glances made to the display, but not their duration. Participants adjusted their reading rate to accommodate the rate at which messages scrolled, which protected reading comprehension but reduced the time spent viewing the roadway as the rate increased.

INTRODUCTION

Electronic billboard signs have long used continuous scrolling to extend the amount of information that can be presented in a limited display area. Commonly referred to as leading, Times Square, or marquise presentation, the approach involves moving text from right to left across a display in small increments at a consistent rate, producing the illusion of continuous motion. In automobiles, radio and CD receivers, as well as the more recently introduced MP3 and satellite radio systems, are beginning to support dynamic entry and exit of textual, iconic, and graphical information, offering the same information presentation efficiency experienced with billboards. The ability to free valuable dashboard space using dynamic presentation of information on smaller in-vehicle displays warrants examination.

Previous studies have investigated the effects of spatial and temporal variations of marquise text presentation characteristics on reading. Line length and scroll rate have been identified as influential variables (Chen & Tsoi, 1988; Duchnicky & Kolers, 1983; Juola, Tiritoglu, & Pleunis, 1995; Kang & Muter, 1989). Findings indicate that these variables affect reading rate more than comprehension, suggesting participants adapt their reading to achieve a desired level of comprehension. However, these studies examined reading on a desktop computer as a single task, providing little insight into how reading would be affected when driving.

Other studies have considered highway changeable message signs (CMS). Dudek (1992) presented roadside messages in a scrolling fashion on CMSs. In this study, drivers were able to process messages up to eight words in length without a decrement in comprehension, provided each word was presented with a one-second minimum viewing time. The roadside sign was only viewable for a limited period as the driver passed, and the messages were shorter and of different content than what would likely require the use of a marquise format on small in-vehicle displays. CMSs also have the added advantage of generally displaying messages in context, while in-vehicle messages could range from vehicle status updates to fast food advertisements.

Wierwille's (1993) model of visual sampling can describe the primary difference between a reading-only task and reading while driving. As a secondary task, reading from a display is performed in between glances to the roadway. Information must be extracted during these short glances (1-1.5 s) and consolidated into meaningful units in working memory to allow information from the driving environment to also be processed. When reading a static message, the driver has control over when and for how long information is displayed, allowing the driver to choose when to glance at the message to extract information while still leaving time to observe the roadway. A study using a driving simulator to examine reading of static, multi-line text messages presented on a dash-mounted display found that drivers used a series of 12-17 glances, each lasting 0.75-1.15 seconds, to read messages of 8-9 short lines (~4 words each) in length (Hoffman, Lee, McGehee, Macias, & Gellatly, 2006). However, when messages are dynamic and scrolling, information presentation is system-controlled rather than user-controlled. System parameters (e.g. display size and refresh rate) determine when and for how long information is available. Drivers must adjust their glance strategy to capture information when presented, or risk missing the information.

On in-vehicle displays, drivers do not have the luxury of reading long sentences or even paragraphs as a whole due to display size limitations. Rather, they must assimilate fractions of sentences across a series of glances. The marquise scrolling solution is then dependent on how much information can be presented during a glance (an artifact of the rate), and on how many glances are needed (a product of the length of a scrolled line).

This study considers how varying the scroll rate and line length of dynamically scrolled in-vehicle text messages affects visual sampling behavior. The methodology used follows from the static experiment described above, providing a basis for comparing sampling behavior between static and dynamic message display. Three general hypotheses guided this study:

- Increasing scrolling rate and line length will lead to continuous reading, as evidenced by longer glances to the display and a neglect of the roadway.
- Marquise scrolling rates will have a greater influence on visual sampling strategies than the amount of information presented. Drivers will adapt their reading rate to the rate of display and maintain it independent of line length.
- Drivers will adopt a sampling strategy that protects reading comprehension.

METHOD

Participants

8 males and 8 females, ages 25-55 (mean 36, s.d. 9.6), participated in this experiment. All participants had been driving for at least 5 years, possessed a valid driver's license, had normal or corrected-to-normal vision that did not require glasses, and were native English speakers. Participation lasted approximately 1.5 hours, for which drivers were compensated $25.

Apparatus

This experiment used a fixed-base driving simulator equipped with a full-size vehicle cab and a 50-degree forward field of view. The driving environment consisted of a two-lane rural highway where drivers followed a lead vehicle and encountered ambient traffic at a rate of 3-4 cars per minute. Text messages were scrolled in marquise format from right to left in a 22-character wide space (88 mm) on a 7-inch display located above the center instrument panel. Messages contained information describing a series of three restaurants, including the name, average cost for an entrée based on a dollar sign rating, the quality and type of food served, and the distance of the restaurant from downtown. The following is an example of one of the messages presented: "The third restaurant, the Great Steakout, has an average entrée cost of $ and a quality rating of 3 stars. The Great Steakout specializes in steak. It is located 2 miles from downtown." For a more detailed description of the simulator, driving environment, and text messaging system, see Hoffman et al. (2006).

Experimental design

A 2x2 within-subject experimental design was used to compare line length and scroll rate. *Line length* defined how much of a message was displayed at any one time and could be either short or long; variable characteristics were based on display sizes described in an experiment examining static text display (Hoffman et al., 2006). In that experiment, a two-line display accommodated 44 characters, which became the length of the scrolled line in the short condition. The four-line display used in the static experiment presented up to 88 characters, establishing the length of the line to be scrolled in the long condition in this experiment.

Scroll rate defined how fast the text messages were scrolled across the display from right to left, and could be either slow or fast. In the slow condition, messages were scrolled at a rate of 3.4 characters per second (cps) or 40 words per minute (wpm), reflecting the amount of time a character was displayed in the two-line condition in the static message experiment. The marquise rate was doubled for the fast condition (6.8 cps or 80 wpm), for a scroll rate similar to other forms of media, such as CNN's Newsline.

Procedure

Upon arrival, consent was obtained and participants were introduced to the driving simulator and text messaging system. Following calibration of the eyetracking system, participants completed a five-minute practice drive where they experienced the four combinations of line length and scroll rate. Each of the four experimental drives lasted approximately 10 minutes, during which drivers read three target messages. Distracter messages separated the target messages and described the current weather conditions or the call sign of a radio station. At the end of each drive, participants answered six questions that required them to recall target message information and identify the corresponding restaurant name. They also rated perceived workload using NASA TLX. Following completion of the last drive, participants were debriefed and compensated for their time.

Dependent Variables

Dependent variables include the number and duration of glances to the display, the duration of glances to the roadway, and comprehension of the text messages. Driving performance was assessed by measuring lane position variability and brake response time.

RESULTS

Data were aggregated across each trial by calculating the mean value for all the dependent variables for each of the three target messages. The mean data were analyzed using SAS for Windows 9.0. The PROC MIXED function in SAS was used to develop a statistical model for each of the dependent variables listed above, and included line length, scroll rate, and the interaction between the two variables.

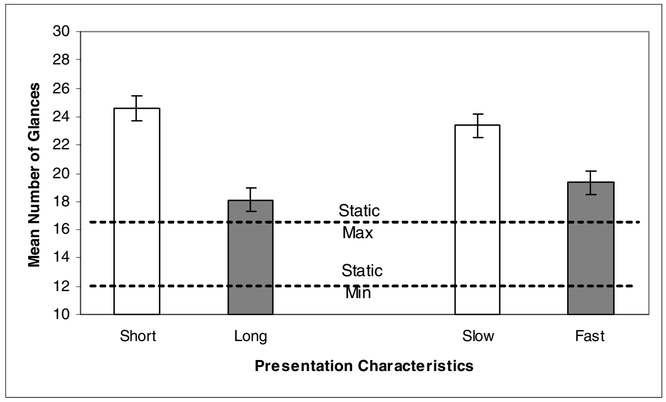

Figure 1. Mean number of glances made to the display, with the range of results from Hoffman et al. (2006) provided for reference

Displaying messages in longer segments and at a faster rate required fewer glances to read than shorter segments, and at a slower rate, respectively, $F(1,14) = 84.52$, $p < .0001$, $F(1,15) = 34.03$, $p < .0001$ (Figure 1). There was no significant interaction between the conditions.

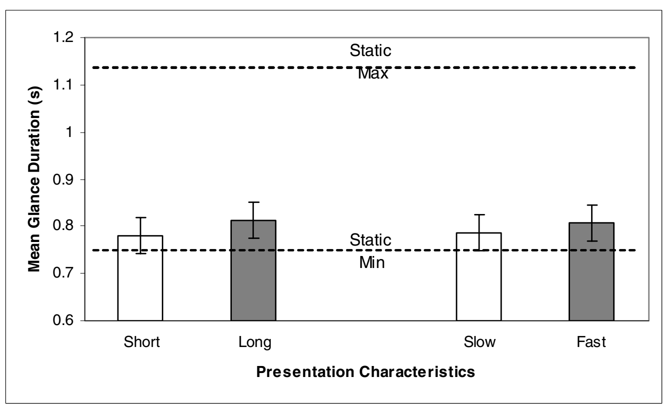

Figure 2. Mean duration of glances to the display, with the range of results from Hoffman et al. (2006) provided for reference

Mean glance durations to the display were similar for all conditions, ranging from 0.77 to 0.83 seconds, with 80% of the glances lasting less than one second, F (1,11) = 1.62, p = 0.2294 (Figure 2). These durations represent the lower range of values observed for the static messages, highlighting the tradeoff between number and duration of glances.

Between glances to the display, drivers were able to look at the roadway for almost three quarters of a second longer when the message was scrolled slowly (M = 2.48 s) than quickly (M = 1.82 s), F (1,15) = 25.96, p = 0.0001. Glance durations to the road were similar for short (M = 0.78 s) and long (M = 0.81 s) line lengths, F (1,14) = 3.5, p = 0.0823.

Reading a message resulted in a significant increase in response time to a lead vehicle braking, F (1,15) = 6.38, p = 0.0233, however the increase was not influenced by the display manipulations. Overall, drivers responded 0.25 seconds more slowly when reading a message (1.14 s) compared to when they were not (0.89 s). Finally, on the post-drive comprehension questions, drivers responded correctly to the post-drive questions approximately 80% of the time, regardless of scroll rate or line length.

DISCUSSION

Line length and scroll rate had little effect on glance durations to the display, but substantially influenced glance frequency. Reading messages scrolled at 3.4 cps required fewer, more closely spaced glances than did those scrolled at 6.8 cps. Because glance durations to the display were consistent across conditions, the effect on reading rate is only apparent through the length of time between display glances, or glances to the roadway. The absence of an effect of line length on glance durations to the roadway supports the hypothesis that reading rate is primarily dependent on marquise scrolling rate. The similar duration of glances to the roadway for different line lengths suggests that the reading rate, once adapted to the scrolling rate, does not depend on how much text is displayed.

Our hypothesis that continuous reading would result from increasing line length and scroll rate only held true for the latter. Increasing the rate reduced the amount of time drivers monitored the roadway because drivers had to sample the display more frequently to ensure that information was read while it was available. This may reflect the desire to protect reading comprehension, where missing information would reduce the ability to accurately answer the post-drive questions. A threshold may exist where increasing the presentation speed to more closely match reading speeds will allow for continuous reading. The danger of continuous reading lies in the reduction or elimination of time available to view the forward roadway, or to strategically adjust sampling of the display to accommodate changing roadway demands. Intermittent glances to the roadway led to a 250 ms increase in response time to braking events, similar to findings of speech-based e-mail interaction (Lee, Caven, Haake, & Brown, 2001) and nearly double the distraction-related delay resulting from cell phone conversations (Horrey & Wickens, 2006). A simulation of driver performance in response to imminent collision situations showed that a delay similar to what was observed in this study (300 ms) caused a large increase in the percentage of collisions and collision velocities across a range of collision situations (Lee et al., 2001).

The dynamic display of text messages resulted in a greater number of short glances compared to the same messages presented statically. In addition, compared to static presentation, dynamic presentation led to longer glances to the roadway, suggesting the scroll rates examined here were slower than what drivers might otherwise choose. Juola et al. (1995) found the highest reading accuracy with marquise scrolling rates of 260 words per minute (wpm), which is more than three times faster than the fast condition (80 wpm) tested here. However, the display used consisted of only eight characters and reading was the primary task, where no time was needed to accommodate glances elsewhere.

Rather than setting a slow, conservative rate that frustrates drivers as they wait for information, or an extremely fast rate that leaves no time to view the roadway, an adaptive display system that monitors glance durations to the roadway as a function of driving demand may be most effective for determining the rate of display of information that best suits a driver. This would be particularly valuable for inexperienced drivers, who are poor at adapting visual sampling strategies to match roadway demands (Crundall & Underwood, 1998).

The visual sampling behavior observed in this study followed a pattern consistent with Wierwille's (1993) framework of alternating roadway and in-vehicle glances, but the duration of glances varied from the reported range. The Wierwille framework suggests in-vehicle glance durations of between 1 and 1.5 seconds, which has been validated by studies examining a variety of in-vehicle tasks (Bhise, Forbes, & Farber, 1986; Gellatly & Kleiss, 2000; Hoffman et al., 2006; Rockwell, 1988). The glance durations observed when reading dynamic messages were much shorter and more frequent, suggesting drivers were limited in the amount of information they could extract in a glance when reading scrolling text. The number of glances with slowly scrolling text suggests that rather than waiting for more information, drivers chose to glance to the roadway while the display updated.

It should be noted that while drivers looked at the roadway less, on average, when reading static messages, drivers had the option to interrupt reading at any time for any duration of time. This ability to control interaction timing is not possible under system control where the messages scroll automatically. Therefore, if inappropriately designed scrolling is used to present long text messages, drivers will be forced to weigh the value of missed in-vehicle information against the need to monitor the roadway to maintain vehicle control and respond to events.

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