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A driving simulator study to explore the effects of text size on the visual demand of in-vehicle displays ☆

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ABSTRACT

Modern vehicles increasingly utilise a large display within the centre console, often with touchscreen capability, to enable access to a wide range of driving and non-driving-related functionality. The text provided on such displays can vary considerably in size, yet little is known about the effects of different text dimensions on how drivers visually sample the interface while driving and the potential implications for driving performance and user acceptance. A study is described in which sixteen people drove motorway routes in a medium-fidelity simulator and were asked to read text of varying sizes (9 mm, 8 mm, 6.5 mm, 5 mm, or 4 mm) from a central in-vehicle display. Pseudo-text was used as a stimulus to ensure that participants scanned the text in a consistent fashion that was unaffected by comprehension. There was no evidence of an effect of text size on the total time spent glancing at the display, but significant differences arose regarding how glances were distributed. Specifically, larger text sizes were associated with a high number of relatively short glances, whereas smaller text led to a smaller number of long glances. No differences were found in driving performance measures (speed, lateral lane position). Drivers overwhelmingly preferred the 'compromise' text sizes (6.5 mm and 8 mm). Results are discussed in relation to the development of large touchscreens within vehicles.

1. Introduction

Increasingly, large multi-function displays (often utilising touch screens) are replacing traditional interactions in cars. For vehicle designers, the main benefits of using such interactive displays is twofold: (a) they can display a large amount of useful information, of increased complexity and a graphical nature, such as maps for satellite navigation and traffic updates, and (b) a greater number of in-vehicle controls can be accommodated in a smaller space. These developments are likely to have a considerable impact on drivers' interactions and attitudes for a number of reasons.

First, the use of touchscreens is likely to be particularly visually demanding. Interaction with any in-car device is a visual-manual secondary task that could potentially interfere with the primary task of driving. Traditional controls such as knobs, switches and buttons are 'tactile' and can often be controlled with little or no visual attention away from the road ahead. In contrast, touch screens have a uniform smooth surface and therefore require visual feedback in order to operate them. This increase in visual demand means that there is less time available for looking at the road and other driving-relevant stimuli, which is required for guiding steering and maintaining lane position [1] and detecting hazards [2]. Laing and Lee [3] have shown that visual distraction can lead to steering neglect and overcompensation, impaired hazard detection and frequent, long off-road glances. In particular, long off-road glances are associated with higher crash risk [4].

Second, touch screens can accommodate more complex information, such as menus, traffic reports or news bulletins, which increases cognitive demands on the driver. Reading even small sections of text requires cognitive resources that would otherwise be available for driving, but increasing semantic or syntactic complexity is likely to lead to increases in cognitive interference. Furthermore, text is likely to be particularly distracting when content is engaging and unrelated to the driving task (e.g. text messages; social media). As a consequence, the National Highway Traffic Safety Administration (NHTSA) in the US have recommended that certain tasks should be associated with 'per se lockout' in their latest guidelines [5]. This means that in-vehicle devices should be designed so that drivers cannot perform these tasks when a vehicle is in motion. Text-based tasks recommended for per se lockout include the display of automatically scrolling text and the display of text from books or periodicals, web page content, social media, advertising messages or text-based messages, as well as tasks that involve manual text entry for messaging or browsing. The Japanese

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Automobile Manufacturers Association (JAMA) recommends that text displays exceeding thirty-one characters should be prohibited while a vehicle is in motion [6], although it should be noted that these guidelines are not necessarily suitable for other languages or alphabets.

However, as noted by NHTSA [5], the per se lockout of all possible non-driving-related reading tasks is not feasible since this would impact on existing displays, for example that show time of day and radio station identifiers. Furthermore, the NHTSA guidelines are not intended to apply to text relating to safe driving, such as notifications of emergency situations that might present a safety risk or warnings of extreme weather conditions. Given that most in-car digital displays will result in drivers reading text at some point, a major issue for designers is how aspects of the display, such as text size, affect driving by influencing the visual demands placed on the driver. What, if any, are the implications of altering the size of text displayed on in-car touch screens, and are there optimal text sizes that minimise impact on the primary task of driving by minimising reading time and off-road glances? NHTSA guidelines incorporate ISO 15008 [7] criteria for image quality and legibility of displays to ensure that text can be read easily by a driver with at least 20/20 vision who is restrained by a seatbelt. However, to date, surprisingly little is known about the effects of text size on legibility under driving conditions, or about any subsequent impact on driving performance.

1.1. Presenting text on displays

Previous research into the effects of text size on reading from screens in non-driving-related contexts, such as desktop computer displays, electronic books and handheld mobile devices, has revealed effects of text size on objective measures (e.g. [8–11]) and subjective measures (e.g. [10–13]). These studies are not comparable with each other as they adopt different type faces, display resolutions, ranges of text sizes, viewing distances, and tasks, making it difficult to draw any overall conclusions about optimal text sizes. However, in general, very small or very large text sizes tend to lead to poorer performance (in terms of reading speed and accuracy) and/or poorer subjective ratings (e.g. perception of legibility, sharpness and general preference). Kingery and Furuta [8] suggest that poorer performance associated with smaller text sizes can be attributed to a lack of definition in internal patterns of words. In contrast, poorer performance associated with larger text sizes is likely to be because less 'meaningful information' can be seen with one fixation.

1.2. In-car displays

It is important to note that optimum text sizes in non-driving contexts are not necessarily transferable to in-car devices. In contrast with a 'normal' reading experience, drivers are likely to read text in shorter, interrupted glances. Furthermore, the in-car device is often located in the centre console, requiring the driver to read text 'off axis', at an angle of about fifteen degrees or more [14] and potentially at greater distances than in sedentary environments. Fujikake et al. [15] report subjective ratings of readability of five different font sizes of Japanese and English text in two different viewing locations (directly in front of the participant and thirty degrees to the left). Significantly higher readability ratings were associated with text presented directly in front, and overall, the largest text size used (10 mm character height) was deemed most readable. However, in this case, reading was a primary task. Similarly, Cai and Green [14] develop equations to predict appropriate target heights for in-vehicle displays, and note the requirement for increasing character height in order to compensate for the increase in target distance, decrease in actual projected height and decrease in display luminance associated with off-axis viewing. However, these equations do not take into account factors associated with reading as a secondary task.

To the authors' knowledge, few studies to date have investigated the effects of text characteristics on reading under driving conditions, and none have investigated the effects of text size on objective reading measures or driving behaviour. Reimer et al. [16] compared two different typeface designs in a simulated driving task, both with a 4 mm capital letter height as measured at the screen face. Participants were required to select a target item from a five-item list while driving a simulation of a two-lane highway. Results indicated that the Humanist typeface was less visually demanding than the Square Grotesque typeface, as evidenced by shorter task times, shorter total off-road glance durations and fewer off-road glances, but only for male participants. Viita and Muir [17] established subjective levels of text readability for a centre console display and an instrument cluster display during a simulated driving task. The minimum capital letter height that users found comfortable and acceptable was generally larger for traditional Chinese text than English text, confirming that characters with higher density should be larger (see also [15]). Viita and Muir's [17] conclusions support a 4 mm minimum capital height for use on centre consoles.

1.3. The study

In the study described herein, a centre console touchscreen display was mounted in a driving simulator to investigate the effects of text size on both objective measures (i.e. reading time; off-road glance behaviour) and subjective measures, and to identify the optimal text size for use in a driving context. A further aim was to establish whether text size impacts on driving performance by measuring speed and lane position in the driving simulator. Since safety guidelines discourage reading large paragraphs of text for comprehension while driving, reading from in-car displays is more likely to be akin to a search task (e.g. looking for a menu heading or an item on a list) or a scanning task (i.e. scanning a piece of text for relevant information). For this reason, we decided to use the pseudo-text task employed by Huang et al. [11]. The pseudo text task involves searching for a target character amongst random strings of characters, presented to appear as words. This mimics actual reading in the sense that the participant is instructed to scan from left to right and top to bottom, but it removes the requirement for higher level processes involved in comprehension. Therefore, one of the main advantages of using pseudo-text as opposed to normal text is that it completely removes any variation caused by introducing semantic information. Furthermore, eye-movements when reading pseudo-text are thought to resemble eye-movements during normal reading [18,19].

In addition to measuring reading time, we monitored drivers' eye-movements, car speed and lane position in order to find out which text sizes (if any) increased the amount of time spent looking away from the road and which text sizes (if any) significantly altered driving behaviour. It was our hypothesis that any text sizes that are too large or too small would result in an increase in frequency and duration of off-road glances together with a subsequent increase in reading time. We also predicted that inappropriately sized text would result in a significant change in driving measures. For example, an increase in speed variation (i.e. drivers might inadvertently increase their speed because they are distracted or deliberately decrease their speed to compensate for the additional cognitive load). Given that we were predicting that inappropriately large/small text sizes would lead to drivers spending less time looking at the road, we also predicted that these text sizes would cause increases in the variation of lane position, as the driver requires visual feedback from the road to maintain lane position.