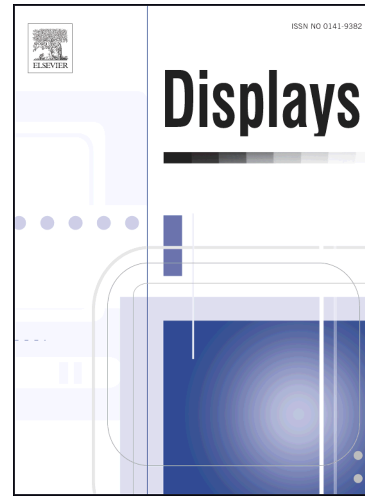
Accepted Manuscript



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PII: S0141-9382(16)30065-8
DOI: http://dx.doi.org/10.1016/j.displa.2016.05.003
Reference: DISPLA 1790

To appear in: *Displays*

Received Date: 11 March 2015
Revised Date: 22 April 2016
Accepted Date: 6 May 2016

Please cite this article as: E. Crundall, D.R. Large, G. Burnett, A Driving Simulator Study to Explore the Effects of Text Size on the Visual Demand of In-Vehicle Displays, *Displays* (2016), doi: http://dx.doi.org/10.1016/j.displa.2016.05.003

A Driving Simulator Study to Explore the Effects of Text Size on the Visual Demand of In-Vehicle Displays

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1 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 (9mm, 8mm, 6.5mm, 5mm, or 4mm) 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 (6.5mm and 8mm). Results are discussed in relation to the development of large touchscreens within vehicles.

Keywords: text-size, driving, simulation, visual demand, eye-tracking, pseudo-text

2 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 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.

2.1 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, 9, 10, 11]) and subjective measures (e.g. [10, 11, 12, 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.

2.2 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 (10mm 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 4mm 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 4mm minimum capital height for use on centre consoles.

2.3 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.

3 Method

3.1 Participants

Participants were self-selecting volunteers who responded to advertisements posted online and around the University campus. Other than driving experience, no specific criteria or restrictions were placed on volunteers. Sixteen people were recruited for the study (5 male and 11 female; mean age 34.8, range 19-51 years). All participants were experienced and active drivers (mean number of years driving 14.3, range 2-29 years; mean current annual mileage 7531, range 1000-20000), and gave written informed consent before taking part. Participants were reimbursed with £10 (GBP) shopping vouchers for their time. The study procedure had been approved by the University of Nottingham Faculty of Engineering ethics committee.

3.2 Design

A repeated measures design was used, with ‘text size’ as the independent variable. Five different capital letter heights were compared: 9mm, 8mm, 6.5mm, 5mm, or 4mm. Where appropriate, an additional level of this independent variable was included: a ‘baseline’ condition during which no text was presented. Dependent variables were task completion time, number of off-road glances, total and mean duration of off-road glances, mean and standard deviation of speed, and mean and standard deviation of lane position. We also included number of off-road glances greater than two seconds as a dependent measure, since it has been shown that off-road glances longer than two seconds increase near-crash and crash risks by at least two times that of normal, baseline driving [4].

3.3 Apparatus and Stimuli

The study took place in a fixed-based, medium fidelity driving simulator (see Figure 1), which provided a safe, repeatable and cost-effective method to conduct the research. The simulator comprised the front half of a 2001 right-hand drive Honda Civic SE car positioned within a curved screen providing approximately 270° viewing angle. The driving scenario was projected onto the screen using three overhead projectors, with rear views relayed to the side mirrors and behind the car using video cameras and LCD displays; the rear view could be seen by the driver using the existing rear-view mirror.

[insert figure 1 here]

Figure 1. Driving simulator showing motorway scenario.

Drivers were able to interact with the car and scenario using an authentic steering wheel which provided force feedback, accelerator, brake and clutch pedals and steering column controls, such as indicators, situated within the car. The simulated driving scenario and driving experience were created using STISIM Drive (version 2) software. A bespoke Java application was integrated with the STISIM Drive software to calculate road speed; this was presented on an 8 inch LCD display fitted into the instrument panel to mimic the car dashboard.

The driving scenario comprised a straight three-lane motorway, similar to that specified by NHTSA for distraction testing [5], with moderate traffic on both sides of the carriageway. Scenery was rural (fields, mountains, trees) to avoid including anything too visually distracting. Occasional directional road signs and slip roads were included for additional authenticity. At the start of the scenario, a yellow 'lead car' appeared in the inside lane and continued at a speed of 65mph. Participants were instructed to join the motorway and follow the lead car at a distance that they deemed to be safe and appropriate, in line with the NHTSA eye-glance testing using a driving simulator (EGDS) protocol [5].

Vehicle control data, such as road speed and lateral lane position, were recorded at one-tenth of a second intervals throughout the simulated drive using the STISIM Drive data logging facility. Audio-visual recordings of the participant and driving scenario were also made during the experiment using four miniature cameras strategically positioned for non-obtrusive data capture.

An ETG (Eye Tracking Glasses) system from SensoMotoric Instruments (SMI) was used to collect binocular gaze data at thirty Hertz. This system produces a gaze cursor overlaid onto a scene video recorded from the participant's point of view to provide a real-time video record of where the participant was looking throughout the experiment.

Pages of pseudo-text were generated in line with ISO 9241-3 [20]. These consisted of random strings of characters separated by single spaces to represent 'words'. Characters were taken from a specified character subset including upper and lower case letters and numbers (i.e. A to Z, a to z and 0 to 9). The total number of characters in a single page of pseudo-text was always 150 (including spaces), arranged as 30 characters per line over 5 lines of text. The blocks of pseudo-text were centre-justified.

Five different passages of pseudo-text were created, each in a different text size defined by capital letter heights of 9mm, 8mm, 6.5mm, 5mm, and 4mm, respectively. The largest text size (9mm) was chosen as the entire text provided maximum coverage of the display area. The median text size (6.5mm) was selected as it was very close (given the limitations of the rendering software and screen resolution) to the minimum suggested text size for standard panel viewing distance (700 mm) based on the Bond Rule [21]. The smallest text size (4mm) is comparable with the minimum cap height found to be acceptable and comfortable for reading English text in Viita and Muir's study [17]. The median text sizes – 8mm and 5mm – were chosen as they lay roughly half-way between the other sizes, given the limitations of the display and rendering software.

The text was presented in accordance with Green et al.'s [21] guidelines for driver information systems: text was presented in mixed case (guideline 5), in a plain (Helvetica) font (guideline 4), and in white on a black background (guideline 7). Lines and gaps between lines were at least 0.6mm wide (guideline 6).

Each passage of pseudo-text contained three, four or five occurrences of a target letter. The position of the target characters were randomly chosen with the restriction that a line did not start or end with the target character. Participants were advised to press a '+' button, provided below each passage of pseudo-text, each time they recognised the target letter and press a 'tick' button to indicate that they had completed the trial (see Figure 2).

The pages of pseudo-text were presented to participants using a 10.1 inch LED-backlit capacitive touchscreen (Motorola Xoom android tablet) located in the centre console of the car. The text was coded using HTML and rendered on-screen using a web-browser. Task completion time was recorded client-side using Javascript and saved to a server-side data file using PHP script.

[insert figure 2 here]

Figure 2. Example passage of pseudo-text showing on-screen 'count' and 'complete' buttons.

3.4 Procedure

Participants were given the opportunity to complete a short practice drive at the start of the experiment in order to become familiar with the controls and to determine whether they were likely to suffer from simulator sickness symptoms. Participants were instructed to drive the simulator as if driving a real car. For the experimental drive, they were asked to drive along a slip-road and join the motorway behind a yellow 'lead car' and to continue to follow the lead car for the duration of the experiment. The purpose of this was to (i) ensure that all drivers stayed in the inside lane, thus reducing variability in the results due to overtaking, (ii) encourage drivers to pay attention to the road ahead, (iii) discourage drivers from speeding, driving unsafely, or displaying 'racing behaviour' associated with playing driving games and (iv) discourage drivers from driving unnaturally slowly in order to score more highly on the reading task.

Participants drove for two minutes in the simulator before the first passage of pseudo-text was presented in order to collect baseline driving data. During this time, the touch screen was blank. Baseline speed and lane position data were collected from the simulator during the second minute of the drive. The experimenter then initiated presentation of the first passage of pseudo-text. The five passages of pseudo-text were presented in descending order of text size (this was unfortunately a limitation in the software used to generate and present the pseudo text); passages of pseudo-text were separated by a delay of ten seconds, during which time the display was blank.

Participants were instructed to scan each piece of text by ‘reading’ it from the top left to the bottom right (as if they were reading a normal page of text), and identify the presence of a target character. The target character remained consistent for all scenarios (although the text passages varied), to avoid possible differences in ‘pop-out’ effects for different characters.

Participants were told to press the ‘+’ button every time they detected a target character rather than mentally count each occurrence, then touch the tick symbol when they had reached the end of the text (see Figure 2). Upon touching the tick symbol, the screen went blank and participants were asked by the experimenter to rate the suitability of the text size for driving on a scale of 1 to 5 (where 1=*too small*, 3=*about right* and 5=*too big*).

Participants were told to work as quickly and as accurately as possible and were advised to avoid trying to memorise their ‘counts’ or to re-read the text to ‘check’ their responses as this would distract them from carrying out the task properly.

4 Results and Analysis

4.1 Task Times

Task times were analysed using a repeated measures ANOVA with ‘text size’ as the independent variable. Unfortunately, two participants had to be excluded (from the task time analysis only) due to technical problems capturing the data. Summary statistics from the remaining fourteen participants are shown in Table 1. Results of the ANOVA test revealed no effects of text size on task time.

Table 1. Task times (in seconds) for each text size
[insert table 1 here]

4.2 Off-Road Glances

A series of one-way repeated measures ANOVAs were used to analyse number of off-road glances, total time spent looking off-road, mean off-road glance duration and number of off-road glances that were greater than 2 seconds, with 'text size' as the independent variable. There were five levels of text size: 9mm; 8mm; 6.5mm; 5mm and 4mm. Again, data from two participants had to be eliminated from the analysis due to technical problems, so the ANOVA tests were performed on data from the remaining fourteen participants. Graphs depicting the relationships between font size and each of the dependent measures are presented in Figure 3.

[insert figure 3 here]

Figure 3. Graphs showing relationships between font size and off-road glances (with standard error bars)

While there was no evidence of an effect of text size on the total amount of time spent looking off-road ($F_{4,52} = 0.578$; $MSE = 4.870$; $p = 0.680$), there was a significant effect of text size on both the number of off-road glances ($F_{4,52} = 10.433$; MSE = 3.956; $p<0.001$) and mean off-road glance duration ($F_{4,52} = 10.707$; MSE = 0.063; $p<0.001$). As shown in Figure 3, the number of off-road glances increased while the mean duration of off-road glances decreased with increasing text size. Therefore, participants made more frequent, shorter glances when the text size was larger, and less frequent, longer glances when the text size was smaller. Repeated contrasts revealed that this difference was significant between text sizes of 6.5mm and 8mm for both number of glances and mean glance duration ($p<0.01$ in both cases).

There was also an effect of text size on the number of off-road glances greater than 2 seconds ($F_{4,52} = 5.297$; MSE = 1.541; $p<0.01$), with the number of long off-road glances decreasing with increased text size (see Figure 3). Repeated contrasts revealed that this effect was largely due to a significant difference between text sizes of 5mm and 6.5mm ($p<0.05$).

4.3 Driving Performance

Mean speed and mean lane position were calculated for each participant during each task and during the baseline drive. Standard deviation of speed and standard deviation of lane position were also calculated for each participant during each task and during the baseline drive as a measure of speed and lane variation respectively. These measures were subjected to four similar one-way ANOVA tests with font size as the independent variable. Data from all sixteen participants were included in the analysis and means and standard errors are shown in Table 2. However, there were no significant effects of text size on any of the driving measures.

Table 2. Simulator data (means and standard errors) for each text size

[insert table 2 here]

4.4 Subjective Ratings

Friedman tests were performed on participants' subjective ratings of suitability of text size for driving, comparing the five levels of font size. Median ratings for suitability are presented in Table 3. These ratings were given after performing the reading task while driving, on a scale of 1 ('too small') to 5 ('too big') where 3 indicated 'just right'. There was a significant difference in ratings of suitability for driving depending on text size (Chi squared = 35.602; df = 4; p<0.001). Wilcoxon comparisons between consecutive text sizes (e.g. 4mm vs. 5mm; 5mm vs 6,5mm; etc.) with Bonferroni corrections revealed that this difference was significant between 6.5mm and 8mm. The median rating for 8mm was 3 ('just right') while the median rating for 6.5mm was 2 ('slightly too small'), indicating that participants thought that the 8mm font size was more suitable.

Table 3. Median ratings for suitability of text size while driving (1 = too small; 3 =just right; 5 = too big)

[insert table 3 here]

5 Discussion

The study found no evidence to suggest that the overall visual demands of the pseudo-text search task changed with different text-sizes: there were no effects of text size on overall reading time and overall glance duration. However, the patterns of off-road glances were influenced by text size: participants made fewer, longer glances when smaller text sizes were displayed and conversely made more frequent, shorter glances when larger text sizes were displayed. This supports the suggestions made by Kingery and Furuta [8] that more information can be processed during one fixation when text is smaller. While we did not investigate individual fixations in this respect, the evidence does suggest that more information is processed during each off-road glance when text is smaller.

Under normal circumstances, this could be seen as an advantage. Using fewer, longer glances might be a more ‘economical’ way of processing information. However, in the case of driving, long off-road glances (i.e. greater than two seconds) are known to increase crash risk [5]. There was a significant increase in off-road glances greater than two seconds between the 6.5mm condition and the 5mm condition. On average, participants made 3.6 off-road glances greater than two seconds (out of an average total of 9.2 off-road glances) when text was 5mm, indicating that text sizes of 5mm or smaller may be inappropriate for use on dashboard-mounted consoles. This is particularly important given the emphasis given to reducing the number of long glances within existing guidelines documents [5].

Despite the effects on off-road glances, there were no significant effects of text size on driving measures. This does not correspond with the findings of Liang and Lee [3], who found that visual distraction had adverse effects on steering as well as increasing and prolonging off-road glances. It is possible that our measures were not sensitive enough or that the driving scenario was not challenging enough: presenting drivers with a straight motorway made it relatively easy to maintain a constant speed and lane position. A road with bends or potential hazards might have induced changes in driving behaviour in response to different text sizes. Nevertheless, the environment used during testing was equivalent to that specified by recognised distraction guidelines/protocols, such as NHTSA [5], which are intended to provide relative assessment of visual-manual distraction effects. It is also possible that drivers employ compensatory mechanisms: when they feel that the task is harder, it is possible that they pace their off-road glances more carefully, only looking away from the road when they believe they have sufficient available resources to do so safely.

Analysis of the subjective ratings showed that, despite there being no effects of text size on the primary driving task or on reading time, there were effects on participants' perceptions of the suitability of the different text sizes while driving. So, even though there were no significant detrimental effects on their driving speed and lane position, participants felt that text sizes of 6.5mm and smaller were too small for use in this context. These findings are consistent with previous studies, in which subjective measures are more sensitive than objective measures to changes in text size (e.g. [12, 13]). If drivers are employing compensatory or coping mechanisms that allow them to maintain their driving performance, even with smaller test sizes, the subjective results indicate that they do not necessarily feel comfortable doing so.

Together, the results suggest that text sizes of 6.5mm or smaller are unsuitable for use on central dashboard-mounted consoles, at least for the type face, colour and resolution tested, and within the context of the simulated driving environment used during testing. Other factors have been shown to influence legibility, such as colour [22], line length [23] and type face [24]. However, we followed Green et al.'s [21] guidelines in an attempt to optimise legibility in terms of colour, type face and spacing so while this undoubtedly warrants further studies, it is unlikely that variations in these factors will decrease the text size required for optimised performance. Therefore, we conclude that designers of interfaces for central dashboard-mounted consoles should avoid using text sizes of 6.5mm or smaller.

Are the results of this study transferrable to real text reading on dashboard-mounted displays? The pseudo-text reading task by definition forces the reader to read letter-by-letter. However, when reading genuine, meaningful text, it has been argued that words are not recognised serially. Evidence to support this includes 'word superiority effect': the finding letter recognition is better when letters are presented within the context of words compared with when letters are presented in isolation or within the context of non-words [25, 26], suggesting that we read by processing the overall shape of words rather than individual letters. However, many eye-tracking studies have provided evidence against the word shape model [27, 28], and now most psychologists accept a parallel letter-recognition model of reading, where letters within a word are recognised simultaneously.

This suggests that normal text reading is dissimilar to pseudo-text reading in terms of how the visual information is processed, even though eye-movements when reading pseudo-text are thought to be similar to those during normal reading [18, 19]. As mentioned earlier, normal text reading involves comprehension of semantic information, and it has been shown that factors that affect legibility (such as walking with a mobile phone, or indeed driving) can have differential effects on reading for comprehension and reading pseudo-text [29]. Therefore, we do not assume that the effects of text size shown in this experiment will extend to reading news items or e-mails from dashboard-mounted consoles. However, we believe that our results are ecologically valid for the primary use of dashboard-mounted consoles in cars, which is likely to be the presentation of lists and menus, involving searching and scanning rather than reading.

6 Conclusion and Further Work

Text size is a significant factor in determining the quality and legibility of text-based content on displays and, although the text provided on in-vehicle displays can vary considerably in size, little was known about the effects this has on how drivers visually sample the interface, and the potential implications for driving performance and user acceptance. The study revealed that, although there were no apparent decrements to driving performance associated with reducing text size, drivers naturally extended glance duration when text size became smaller as they attempted to process more information during each glance. Drivers also indicated strong preferences for the median sizes tested. Based on these results, it is recommended that designers of interfaces for central, dashboard-mounted consoles should avoid using text sizes of 6.5mm or smaller. To support the findings, further work should investigate different reading tasks and different driving conditions and contexts, such as urban or night-time driving. It would also be of interest to consider older drivers, whose declining visual acuity, due to the natural ageing process, may represent a further limiting human factor. All additional work should aim to optimise text size to minimise distraction but also consider how this impacts on visual sampling strategies and information processing.

7 Acknowledgements

The research was undertaken in collaboration with Honda R&D Europe Ltd. and the authors would like to gratefully acknowledge their support.

8 References

[1] M. Land, J. Horwood, Which parts of the road guide steering? Nature 377.6547 (1995): 339-340.

[2] D. Crundall, P. Chapman, S. Trawley, L. Collins, E. van Loon, B. Andrews, G. Underwood, Some hazards are more attractive than others: Drivers of varying experience respond differently to different types of hazard. Accident Analysis & Prevention, 45(2), (2012) 600-609.

[3] Y. Liang, J.D. Lee, Combining cognitive and visual distraction: less than the sum of its parts. Accident Analysis & Prevention, 42(3), (2010) 881-890.

[4] S. Klauer, T. Dingus, V. Neale, J. Sudweeks, D. Ramsay, The Impact of Driver Inattention on Crash Risk: An Analysis using the 100-car Naturalistic Driving Study. National Highway Safety Administration, Report No. DOT HS 810 594 (2006)

[5] Department of Transportation, Visual-manual NHTSA distraction guidelines for in-vehicle electronic devices. National Highway Traffic Safety Administration, Department of Transportation, NHTSA-2010-0053 (2013)

[6] Japan Automobile Manufacturers Association, Guidelines for In-vehicle Display Systems – Version 3.0 (2004)

[7] ISO 15008, Ergonomic aspects of transport information and control systems – Specification and test procedures for in-vehicle visual presentation. International Standards Organization, Geneva, Switzerland (2009)

[8] D. Kingery, R. Furuta, Skimming electronic newspaper headlines: A study of typeface, point size, screen resolution, and monitor size. Information Processing & Management, 33(5), (1997) 685-696.

[9] T. S. Tullis, J. L. Boynton, H. Hersh, Readability of fonts in the windows environment. Conference Companion on Human Factors in Computing Systems, (1995) 127-128.

[10] M. L. Bernard, B. S. Chaparro, M. M. Mills, C. G. Halcomb, Comparing the effects of text size and format on the readability of computer-displayed Times New Roman and Arial text. International Journal of Human-Computer Studies, 59, (2003) 823-835.

[11] D. Huang, P. P. Rau, Y. Liu, Effects of font size, display resolution and task type on reading Chinese fonts from mobile devices. International Journal of Industrial Ergonomics, 39, (2009) 81-89.

[12] M. L. Bernard, B. S. Chaparro, M. M. Mills, C. G. Halcomb, Examining children's reading performance and preference for different computer-displayed text. Behaviour and Information Technology, 21, (2002) 87-96.

[13] I. Darroch, J. Goodman, S. Brewster, P. Gray, The effect of age and font size on reading text on handheld computers. Lecture Notes in Computer Science, 3585, (2005) 253-266.

[14] H. Cai, P. Green, Range of character heights for vehicle displays as predicted by 22 equations. Proceedings of the SID Vehicle Display Symposium (2005)

[15] K. Fujikake, S. Hasegawa, M. Omori, H. Takada, M. Miyano, Readability of character size for car navigation systems. Human Interface and the Management of Information. Interacting in Information Environments. Lecture Notes in Computer Science, Vol. 4558/2007, (2007) 503-509.

[16] B. Reimer, B. Mehler, Y. Wang, A. Mehler, H. McAnulty, E. McKissick, J. F. Coughlin, S. Matteson, V. Levantovsky, D. Gould, N. Chahine, G. Greve, An exploratory study on the impact of typeface design in a text rich user interface on off-road glance behavior.

Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '12), Portsmouth, NH, USA (2012)

[17] D. Viita, A. Muir, Exploring comfortable and acceptable text sizes for in-vehicle displays. Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. ACM, (2013) 232-236.

[18] J. A. J. Roufs, M. C. Boschmann, Text quality metrics for visual display units: I. Methodological aspects. Displays, 18, (1997) 37-43.

[19] M. C. Boschmann, J. A. J. Roufs, Text quality metrics for visual display units: II. An experimental survey. Displays, 18, (1997) 45-64.

[20] ISO 9241, Ergonomic requirements for office work with display terminals (VDTs) Part 3: Visual display requirements (1992).

[21] P. Green, W. Levison, G. Paelke, C. Serafin, Suggested Human Factors Design Guidelines for Driver Information Systems. Technical Report UMTRI-93-21, (1993)

[22] M. L. Garcia, C. I. Caldera, The effect of color and typeface on the readability of on-line text. Computers & Industrial Engineering 31 (1–2), (1996) 519–524.

[23] M. C. Dyson, G. J. Kipping, The effects of line length and method of movement on patterns of reading from screens. Visible Language 32, (1998) 150–181.

[24] D. Boyarski, C. Neuwirth, J. Forlizzi, S. H. Regli, A study of fonts designed for screen display. CHI 98 Conference Proceedings, (1998) 87-94.

[25] J. M. Cattell, The time it takes to see and name objects. Mind, (1886) 63-65.

[26] G. M. Reicher, Perceptual recognition as a function of meaningfulness of stimulus material. Journal of Experimental Psychology 81 (2): (1969) 275–280.

[27] G. W. McConkie, K. Rayner, The span of the effective stimulus during a fixation in reading. Perception and Psychophysics, 17, (1975) 578-586.

[28] K. Rayner, The perceptual span and peripheral cues in reading. Cognitive Psychology, 7, (1975) 65-81.

[29] T. Mustonen, M. Olkkonen, J. Hakkinen, Examining mobile phone text legibility while walking. CHI 2004 Extended Abstracts on Human Factors in Computing Systems, (2004) 1243-1246.

9 Biographies

Elizabeth Crundall

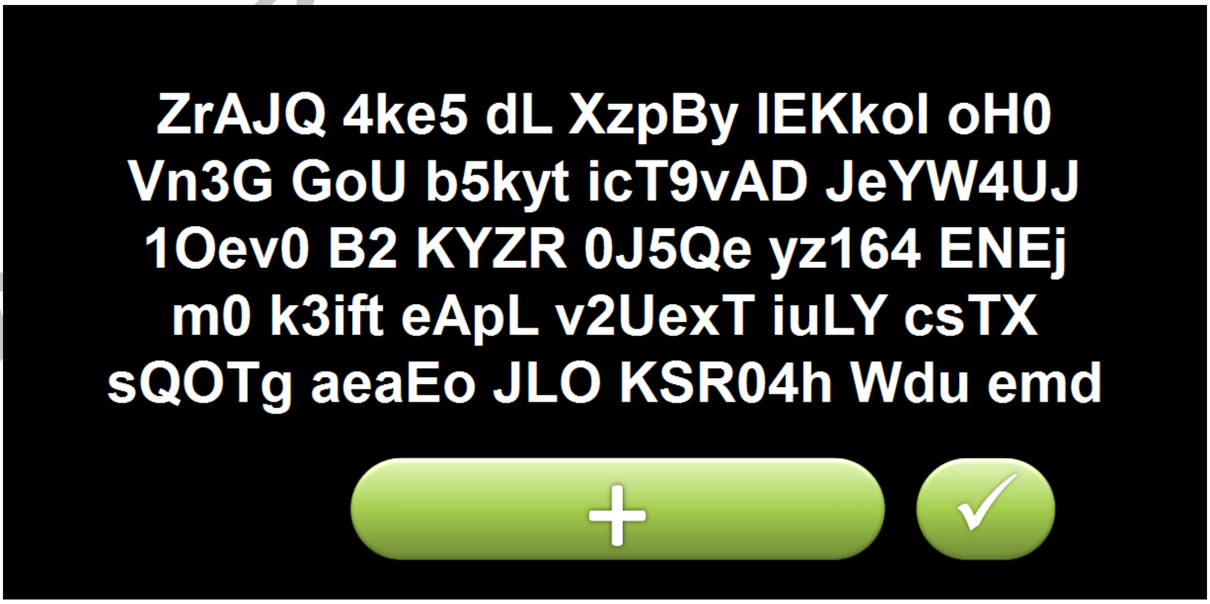
Dr Lizzie Crundall is a Human Factors research consultant with over 15 years' experience in experimental design and statistical analysis, specialising in eye-tracking and simulation methodologies. She started her career at the University of Nottingham, where she gained a PhD in Psychology then worked as a postdoctoral researcher, studying the effects of expertise on eye movements during music sight-reading. She continued her post-doctoral studies at the University of Sheffield, investigating interference and visual working memory. After a period working in industry as an eye-tracking specialist for research technology supplier, Lizzie returned to academia as a postdoctoral researcher in the Human Factors Research Group within the Faculty of Engineering at the University of Nottingham. Her most recent projects include an investigation of skill-based differences in motorcyclist behaviour, hazard perception, road sign design, and the effects of HMI attributes on driver distraction. Lizzie is currently involved in projects with the automotive industry.

David R Large

Dr David R. Large is a Research Fellow with the Human Factors Research Group at the University of Nottingham. Since gaining his PhD in 2013, David has been involved with a number of industry and EU funded projects concerning the design of novel in-vehicle interfaces for both road and rail transport. David is also interested in the development and application of simulation to support both this and other HF research more generally. Previously, David has spent almost ten years working within the manufacturing industry.

Gary Burnett

Dr Gary Burnett has been investigating Human Factors issues since 1992, specialising on the human-related design issues for in-vehicle computing and communication systems, such as navigation, adaptive cruise control, vision enhancement, collision avoidance. His research has been funded by a range of organisations, including the UK Engineering research council (EPSRC), the UK Department of Transport and Highways Agency and the European Union. Most recently, he has worked closely on a range of projects concerning novel in-vehicle interfaces in collaboration with several vehicle manufacturers. He is an author for over 100 articles in peer-reviewed venues and is the general chair for the 2015 conference on Automotive User-Interfaces (Auto-UI).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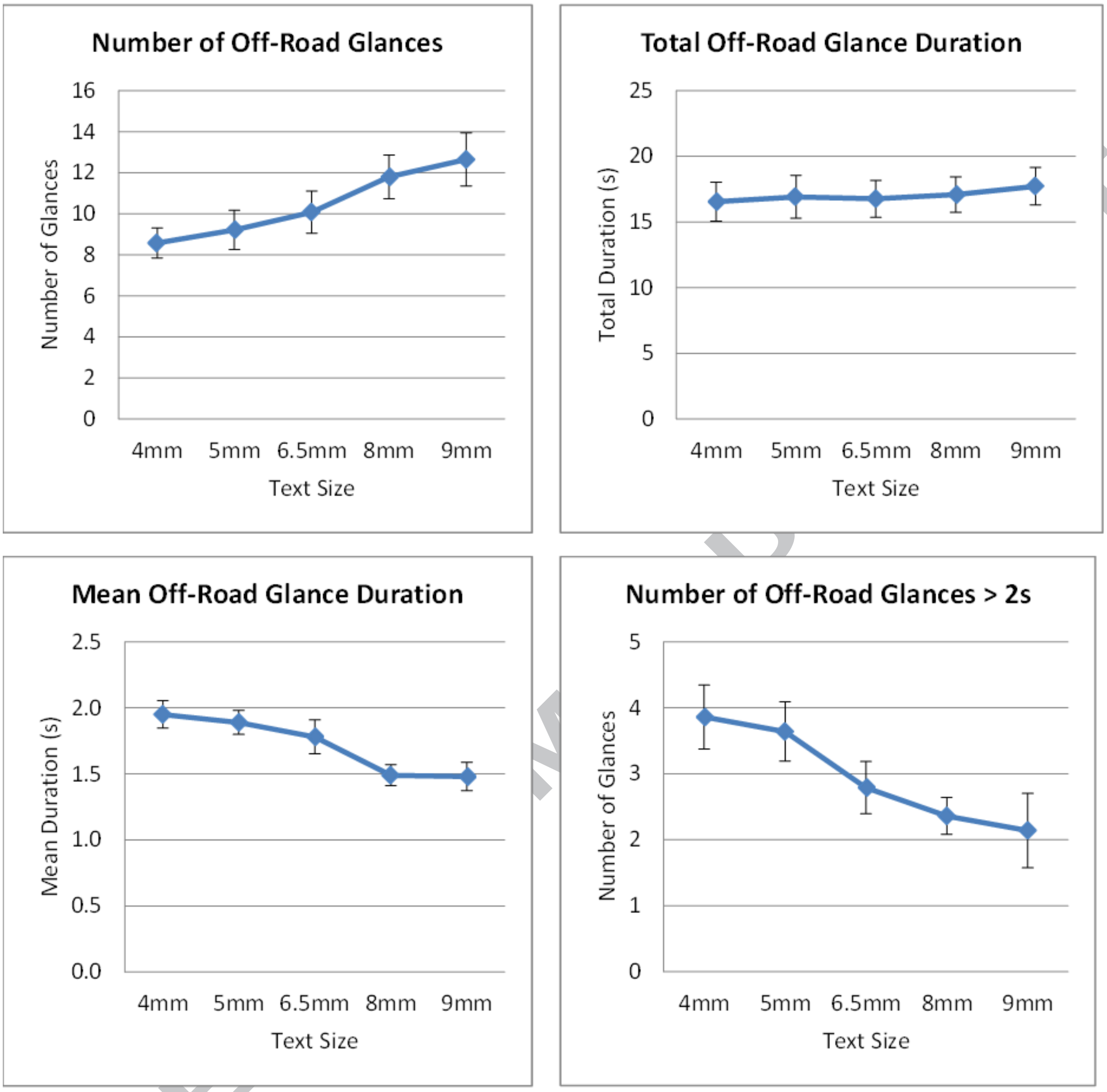
Number of Off-Road Glances
Number of Glances
16
14
12
10
8
6
4
2
0
4mm
5mm
6.5mm
8mm
9mm
Text Size
Total Off-Road Glance Duration
Total Duration (s)
25
20
15
10
5
0
4mm
5mm
6.5mm
8mm
9mm
Text Size
Mean Off-Road Glance Duration
Mean Duration (s)
2.5
2.0
1.5
1.0
0.5
0.0
4mm
5mm
6.5mm
8mm
9mm
Text Size
Number of Off-Road Glances > 2s
Number of Glances
5
4
3
2
1
0
4mm
5mm
6.5mm
8mm
9mm
Text Size

Table 1. Task times (in seconds) for each text size

	4mm	5mm	6.5mm	8mm	9mm
Mean (secs)	23.52	22.43	25.76	25.41	26.43
Standard Error	3.15	2.72	3.51	3.46	3.40

Table 2. Simulator data (means and standard errors) for each text size

		Baseline	4mm	5mm	6.5mm	8mm	9mm
Speed (mph)	*Mean*	64.2	66.6	64.3	63.3	63.9	63.9
	Std.Err	0.5	1.5	1.0	0.7	0.4	0.8
Speed Variation (mph)	*Mean*	2.9	2.2	1.9	2.2	2.5	2.2
	Std.Err	0.5	0.6	0.6	0.6	0.5	0.3
Lane Position (ft)	*Mean*	-33.8	-33.6	-33.5	-33.7	-33.9	-34.0
	Std.Err	0.2	0.2	0.3	0.2	0.2	0.2

Lane Variation (ft)	*Mean*	0.6	0.6	0.5	0.6	0.6	0.6
	Std.Err	0.2	0.1	0.1	0.1	0.1	0.1

Table 3. Median ratings for suitability of text size while driving (1 = too small; 3 =just right; 5 = too big)

	25th Percentile	Median	75th Percentile	N
4mm	1	1	1	10
5mm	1	1.5	2	10
6.5mm	1.75	2	2.25	10
8mm	3	3	3.25	10
9mm	3	3	4	10

Research Highlights

- A driving simulator study investigated different text sizes on an in-car display
- Larger text encouraged high numbers of relatively short glances
- Smaller text led to a lower number of longer glances
- Recommendations are made in line with NHTSA guidance on driver distraction
- Displays in vehicles should avoid text sizes of 6.5mm or smaller