Ng, A., Brewster, S. A., Beruscha, F. and Krautter, W. (2017) An Evaluation of Input Controls for In-Car Interactions. In: CHI '17: CHI Conference on Human Factors in Computing Systems, Denver, CO, USA, 6-11 May 2017, pp. 2845-2852. ISBN 9781450346559(doi:10.1145/3025453.3025736)

An Evaluation of Input Controls for In-Car Interactions

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ABSTRACT

The way drivers operate in-car systems is rapidly changing as traditional physical controls, such as buttons and dials, are being replaced by touchscreens and touch-sensing surfaces. This has the potential to increase driver distraction and error as controls may be harder to find and use. This paper presents an in-car, on the road driving study which examined three key types of input controls to investigate their effects: a physical dial, pressure-based input on a touch surface and touch input on a touchscreen. The physical dial and pressure-based input were also evaluated with and without haptic feedback. The study was conducted with users performing a list-based targeting task using the different controls while driving on public roads. Eye-gaze was recorded to measure distraction from the primary task of driving. The results showed that target accuracy was high across all input methods (greater than 94%). Pressure-based targeting was the slowest while directly tapping on the targets was the faster selection method. Pressure-based input also caused the largest number of glances towards to the touchscreen but the duration of each glance was shorter than directly touching the screen. Our study will enable designers to make more appropriate design choices for future in-car interactions.

Author Keywords

Pressure-based input; Touch input; Touchscreens; In-car interactions; Haptic feedback.

ACM Classification Keywords

H.5.2. User Interfaces [Input devices and strategies]

INTRODUCTION

In-car controls on centre consoles are undergoing major changes as traditional buttons, dials and switchgear are replaced by touchscreens and touch-sensing surfaces. The replacement of these physical components allows more aesthetically pleasing in-car interiors and the design of more flexible and dynamic user interfaces. New methods such as force input (commonly known as pressure-based input in related literature) are now available on mobile devices such as Apple's iPhones and MacBook Pros and are likely to transfer to in-car centre consoles in the future. However, the tactile sensations from pressing on physical buttons and grasping rotary dials are lost when inputting on smooth touchscreens and many in-car touch surfaces lack any form of haptic feedback. This is a safety concern as drivers are likely to spend more time looking at and interacting with the touchscreen and new touch surfaces than at the road ahead [4,12].

This paper presents a real world, on the road driving study which compared the input performance and visual attention required of three main input controls that are currently found or likely to feature in cars in the future: (1) touch input in the form of direct target selection or onscreen buttons, (2) physical dial and (3) pressure-based buttons on a touch-surface. Furthermore, we evaluated the rotary dial and pressure-based buttons with haptic feedback to see if vibrotactile cues were still effective in driving situations to improve targeting performance and reduce visual attention on the screen. Doing the test with drivers when driving means that we can collect the most robust and reliable results about the performance of the controls in real world conditions.

BACKGROUND

Related work has examined drivers' ratings for physical switches in cars and reported the importance of touch over auditory and visual cues to judge the quality of buttons and dials [2]. As touchscreen infotainment systems became popular in cars, researchers investigated in-car touch-based interactions [3,6,9,11,20,24]. Kern and Schmidt [10] discussed the increased number of input devices (e.g. touchscreens, physical buttons and dials) and output modalities (e.g. analog, digital and virtual speedometers) found in cars and safety concerns regarding driver distraction due to complex interactions with in-car systems. Therefore, studies such as Pitts *et al.* [17] explored the effectiveness of haptic feedback for in-car touchscreens and found that a combination of visual, audible and haptic feedback was subjectively preferred over visual feedback only. Richter *et al.* [19] showed that haptic feedback reduced input error rate and improved overall task completion time on a force-sensitive touchscreen device in their simulated driving study.

Recent studies on pressure-based input on centre consoles have become more common. Huber *et al.* [8] conducted a preliminary elicitation study which explored the mappings of different force-based gestures on a touchpad to common in-car commands. The results from their driving simulator study found that participants used two levels of force to differentiate between a tap and a press to interact with in-car applications.

In our previous study [15], we conducted two experiments to compare different pressure-based input techniques with a standard physical dial. Pressure-based input with touchscreen mobile devices has been broadly studied (e.g. [1,13,14,22,23,25]) but little is known about the effectiveness of pressure for in-car interactions. In our first experiment, *positional* and *rate-based* controls [25], two common pressure input techniques, were investigated along with pressure-based buttons using a driving simulator. Results showed that *positional* input performed the poorest in terms accuracy and was the slowest input method. Furthermore, *positional* control caused more lane deviation than the other input methods. Input with *rated-based* pressure control and pressure-based buttons were comparable to the physical dial. Target selections with haptic feedback further improved accuracy and selection time.

In our second experiment [15], the input techniques were evaluated inside a moving vehicle where participants, who sat in the front passenger seat, experienced real world driving noises, vibrations and forces to see if haptic feedback was still perceivable and how the input techniques performed compared to the simulator study. Accuracy was high (> 98%) but selection times were slower when compared to the first experiment. One limitation of the second experiment was that users were not driving the vehicle so a true representation of how well the pressure input methods perform in actual driving situations cannot be clearly measured. Furthermore, it is unclear how visually distracting or how much attention is required to operate these input methods. Therefore, we extended our previous experiments by getting users to drive and interact with the input controls at the same time.

STUDY

A study was conducted to compare the input performance and visual distraction during driving of four interaction methods using a list-based targeting task on a touchscreen. There were two touchscreen input methods: selecting the targets in the list directly ($Touch_{Direct}$) and using onscreen buttons ($Touch_{Buttons}$), a standard physical dial (*Dial*) and pressure-based buttons ($Pressure_{Buttons}$) using force sensors mounted onto a case below the touchscreen. List-based target selection tasks are used to compare input techniques [13,25] and are commonly found in touchscreen applications, such as lists of songs, street names or points of interest.

Task

We used the same list-based targeting task as our previous study [15] to allow a comparison of the results. There were ten targets in the list numbered '1' to '10' from top to bottom. A standard start position labelled '.' was placed at the top so that some form of cursor movement had to be performed for all input controls, except for $Touch_{Direct}$. The current target to select was highlighted in red and a blue cursor marked the current position in the list, except for $Touch_{Direct}$. By default, the cursor was placed on the '.' labelled item at the start of each target selection. There was no looping when the cursor reached either end of the list. Each target in the list measured 133 x 16mm and the interface used for each input control is shown in Figure 1. A beep was played to indicate the start of each trial and the participants were asked to select the target as quickly and accurately as possible but it was emphasised that it was essential to drive the vehicle as safely as possible and keep within the speed limits. The task ran on a Microsoft Surface 2 which has a 10.6" (1920 x 1080 pixel, ~208 ppi) touchscreen. The tablet was positioned in portrait orientation to replicate large touchscreens found in cars, such as the 2016 Volvo XC90.

For $Pressure_{Buttons}$, two force sensors from Peratech (www.peratech.com) were mounted onto a 3D printed case, which was placed below the touchscreen to simulate an in-car touch-surface (see Figure 2). The two sensors allowed bi-directional movement and applying greater than 3N on the left or right sensors moved the cursor down and up the list respectively. Users had to lift off the sensor and apply pressure again for the cursor to move. The 3N cut-off meant that light touches caused by car movements did not trigger interaction. To select a target, users had to apply greater than 2N on both sensors at the same time. This method was deemed to be least difficult to perform after testing other common selection mechanisms such as Dwell and Quick Release [1,18,25].

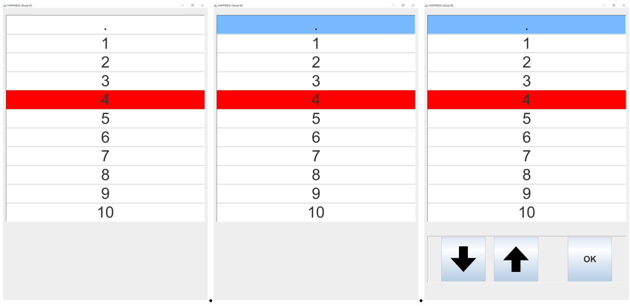

Figure 1. The list-based interface for $Touch_{Direct}$ (left), $Pressure_{Buttons}$ and *Dial* (middle) and $Touch_{Buttons}$ (right).

A Griffin PowerMate controller (griffintechnology.com/us/powermate) was used for the *Dial* condition. The cursor moved down and up the list by turning the dial clockwise and anticlockwise respectively. The dial was pushed in to select targets. To select the targets with $Touch_{Direct}$, participants simply tapped on the highlighted target area on the touchscreen. For $Touch_{Buttons}$, onscreen buttons were placed below the list of targets. There were 'UP' and 'DOWN' buttons to move the cursor through the list and an 'OK' button to select the target. The 'OK' button was placed away from the arrow buttons to avoid accidental selection. Each button measured 25 x 25mm.

Figure 2. The force sensors and dial were placed on top of 3D printed cases (top). The touchscreen and hardware setup inside the car (bottom).

Haptic Feedback

In our previous lab study [15], we evaluated $Pressure_{Buttons}$ and *Dial* with and without haptic feedback and found that selection times were significantly quicker with tactile cues and were subjectively preferred. Furthermore, related work has reported the benefits of providing haptic feedback with in-car controls (e.g. [5,7,16,17,19,21]). We wanted to see if haptic feedback would still be effective for input in real world driving situations. One Adafruit medium surface transducer (www.adafruit.com/product/1785) was placed inside each printed case to give vibrotactile feedback on the movement of the cursor (50ms, 200hz sine wave) and the selection of a target (300ms, 300hz sine wave). The two touch input conditions were not evaluated with haptic feedback because finger contact on the touchscreen was so short, tactile feedback could not be felt.

Experimental Design

Twenty-six participants (15 males), aged between 26 – 58 (mean = 42.7, SD = 10.9) with a full driving license took part in the study. Twenty-two participants were right-handed, two left-handed and the remaining two were ambidextrous.

The participants drove a manual Mercedes-Benz GLA. The touchscreen tablet, sensors and components were securely mounted onto the centre console without obstructing the drivers' ability to change gear (see Figure 2 and 3). A GoPro Hero3 camera was mounted on the inside windscreen to record eye movements. The driving route consisted of town roads (50 km/h), dual carriageways (100 km/h) and highways (120 km/h). The distance of one loop of the route was approximately 56 km. The participants were given a training session to familiarise them with each input control before any driving started. An experimenter sat in the front passenger seat at all times to overview the experiment and ensure safety (see Figure 3).

Figure 3. A participant performing the list-based targeting task while driving. Visual attention is taken away from the roads during input. An experimenter sat beside the user to ensure safety.

A within-subjects design was used for the study. The Independent Variables were **Input Method** (four levels: $Pressure_{Buttons}$, *Dial*, $Touch_{Direct}$ and $Touch_{Buttons}$) and **Type of Feedback** (two levels: with and without haptic feedback for $Pressure_{Buttons}$ and *Dial* only). Hence, there was a total of six conditions as haptic feedback was not examined for the two touchscreen input methods. The Dependent Variables were target accuracy (%), selection time (ms), glance count towards the touchscreen (the number of times the participants looked at the touchscreen during input) and the duration per glance (the amount of time spent for each eye-gaze on the screen, ms). A trial was selected accurately if the highlighted target in the list was acquired. Selection time was the duration from the target being displayed onscreen until the selection of the target. The experimental hypotheses were based on the findings from our related lab study [15] (H1 and H2) and from observations from pilot tests (H3 and H4):

H1: Target selections with $Pressure_{Buttons}$ will take significantly longer than the other input methods;

H2: Haptic feedback will significantly improve accuracy and selection time for $Pressure_{Buttons}$ and *Dial*;

H3: $\mathit{Touch}_{\mathit{Direct}}$ will have significantly lower eye-gaze count than the other input methods;

H4: $\mathit{Pressure}_{\mathit{Buttons}}$ and $\mathit{Touch}_{\mathit{Buttons}}$ will have significantly longer duration per eye-gaze than *Dial* and $\mathit{Touch}_{\mathit{Direct}}$.

RESULTS

Each of the ten targets was selected twice, therefore a total of 3120 trials (*26 participants x 6 conditions x 20 selections*) was recorded for the targeting task. Two sets of video recordings (P1 and P2) were corrupted and therefore were removed from the final data analysis. The data for target accuracy, selection time, glance count and duration per glance were all not normally distributed. Because the design of the study was unbalanced, two separate non-parametric tests were conducted. Firstly, Friedman tests were conducted to compare the four input methods without haptic feedback. Secondly, Aligned Rank Transform [26] was applied before conducting a two-factor (Type of Feedback and Input Method) repeated-measures ANOVA to compare the effectiveness of haptic feedback between $\mathit{Pressure}_{\mathit{Buttons}}$ and *Dial*.

Target Accuracy

The mean accuracy for each condition is shown in Figure 4. The results from conducting the Freidman test showed a significant difference for Input Technique, $\chi2(3) = 12.64$, $p < 0.05$. However, *post hoc* Wilcoxon signed-rank tests showed no significant differences between any pairs.

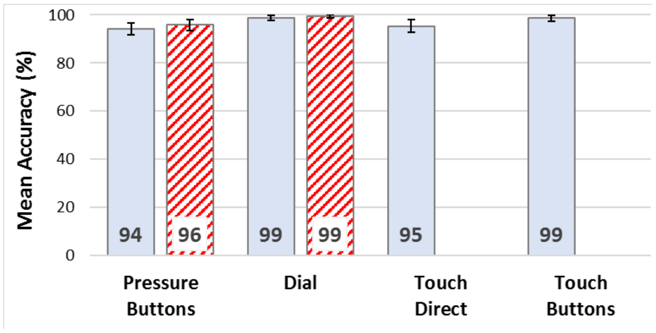

Figure 4. The mean target accuracy (%) for each condition. Solid and striped bars represent controls without and with haptic feedback respectively. Error bars denote CI (95%).

The ANOVA on $\mathit{Pressure}_{\mathit{Buttons}}$ and *Dial* showed a significant effect for Input Technique, $F(1, 75) = 25.14$, $p < 0.05$. *Dial* was more accurate than $\mathit{Pressure}_{\mathit{Buttons}}$. A significant main effect was found for Type of Feedback, $F(1, 75) = 5.66$, $p < 0.05$. Haptic feedback improved target accuracy, a mean difference of 4% over no tactile feedback. The interaction between the factors was not significant, $F(1, 25) = 3.2$, $p > 0.05$.

Selection Time

The mean selection time for each condition is shown in Figure 5. The Freidman test for selection time showed a significant difference for Input Technique, $\chi2(3) = 55.25$, $p < 0.05$. Wilcoxon signed-rank tests showed that $\mathit{Touch}_{\mathit{Direct}}$ was quicker than all the other input methods. The other pairwise comparisons were not significant.

The ANOVA on $\mathit{Pressure}_{\mathit{Buttons}}$ and *Dial* showed a significant main effect for Input Technique, $F(1, 75) = 41.27$, $p < 0.05$. Input using the dial was quicker than the pressure-based buttons. The main effect for Type of Feedback was not significant, $F(1, 75) = 2.96$, $p > 0.05$. The interaction between the factors was not significant, $F(1, 75) = 0.57$, $p > 0.05$.

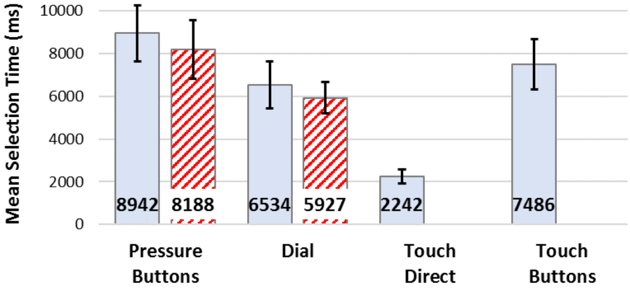

Figure 5. The mean selection time (ms) for each condition. Solid and striped bars represent controls without and with haptic feedback respectively. Error bars denote CI (95%).

Glance Count & Duration

The mean number of glances at the touchscreen and duration per glance for each condition are shown in Figure 6 and Figure 7 respectively. The Friedman test for glance count showed a significant difference for Input Technique, $\chi2(3) = 60.59$, $p < 0.05$. *Post hoc* Wilcoxon signed-rank tests showed that all pairwise comparisons were significant except between $\mathit{Touch}_{\mathit{Buttons}}$ and *Dial*.

The ANOVA on $\mathit{Pressure}_{\mathit{Buttons}}$ and *Dial* for glance count showed a significant main effect for Input Technique, $F(1, 69) = 89.82$, $p < 0.05$. The number of glances at the touchscreen was lower for *Dial* than $\mathit{Pressure}_{\mathit{Buttons}}$. A significant main effect was observed for Type of Feedback, $F(1, 69) = 28.01$, $p < 0.05$. Input with vibrotactile feedback caused a lower number of glances than without. The interaction between the factors was significant, $F(1, 69) = 14.5$, $p < 0.05$, but not required to support or reject the hypotheses.

The Friedman test for duration per eye-gaze showed a significant difference for Input Technique, $\chi2(3) = 21.35$, $p < 0.05$. *Post hoc* Wilcoxon signed-rank tests showed that all pairwise comparisons were significant except between $\mathit{Touch}_{\mathit{Buttons}}$ and *Dial*.

The ANOVA on $\mathit{Pressure}_{\mathit{Buttons}}$ and *Dial* for eye-gaze duration showed a significant main effect for Input Technique, $F(1, 69) = 6.65$, $p < 0.05$. The duration per glance at the touchscreen was longer for $\mathit{Pressure}_{\mathit{Buttons}}$ than *Dial*. A significant main effect was observed for Type of Feedback, $F(1, 69) = 5.86$, $p < 0.05$. Input with haptic feedback reduce the duration per glance, a small mean difference of

58.5ms. The interaction between the factors was not significant, $F(1, 69) = 0.00$, $p > 0.05$.

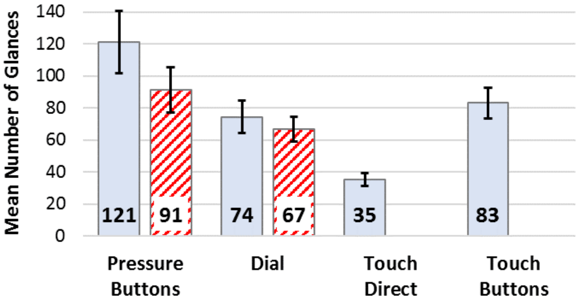

Figure 6. The mean number of glances at the touchscreen for each condition. Solid and striped bars represent controls without and with haptic feedback respectively. Error bars denote CI (95%).

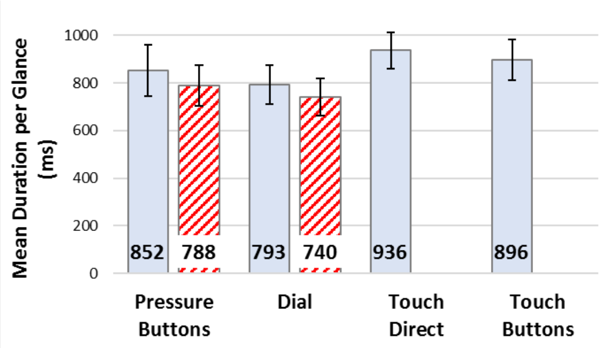

Figure 7. The mean duration (ms) per glance at the touchscreen for each condition. Solid and striped bars represent controls without and with haptic feedback respectively. Error bars denote CI (95%).

DISCUSSION

The results for accuracy showed that input with the dial while driving was more accurate than using the pressure-based buttons. Accuracy for the dial was near identical to our in-car non-driving study [15], with a difference of 1%. However, driving had a bigger effect on the accuracy of pressure-based buttons, a decline of 6% when compared to just sitting inside a moving vehicle where users achieved 100% accuracy. Target accuracy with and without haptic feedback for the dial was the same while the number of correct selections improved by 2% for pressure-based buttons when vibrotactile cues were used.

It is worth noting that in general, accuracy across all input techniques was high (>90%) regardless of haptic feedback. We chose relatively large targets to utilise the available touchscreen which meant they were easier to hit. Furthermore, it allowed a direct comparison to our previous studies to observe changes in performance in different experimental driving setups. Real world list-based interfaces and applications are likely to require scrolling through a larger set of elements [11] which we plan to evaluate in the future.

Pressure-based buttons were slower than the dial and directly tapping on the targets in the list but not when using the onscreen buttons, therefore, hypothesis H1 cannot be fully supported. Our previous in-car study [15] found that the dial took approximately 3.4s (for both with and without haptic feedback) and pressure-based buttons took 5.2s (no feedback) and 4.9s (with haptic feedback). In comparison, the results from the driving study presented in this paper showed that driving increased selection time considerably. Pressure input without haptic feedback required almost 9s to select a target, compared to 2.2s for direct touch selection, both techniques having similar accuracy. The difference in selection times with and without haptic feedback for the dial and pressure-based buttons input were not statistically significant, therefore, hypothesis H2 cannot be fully supported.

We predicted that direct touch input would be the quickest technique and used it as the baseline measure to compare against the other input controls. Pressure-based buttons had a similar accuracy to direct touch input but selection time took almost four times longer and was the slowest method overall. Our implementation of pressure input to replicate physical buttons may benefit from further refinement to reduce incorrect selections and improve input speed. A continuous pressure input such as rate-based control (i.e. the user's finger does not need to lift off the sensor for the cursor to move) is likely to reduce selection time as shown in our previous study [15]. The mapping between the input pressure range and the speed of the cursor will need careful design to avoid constantly overshooting the target. Furthermore, our selection mechanism of having to use two fingers on both sensors might have been awkward to perform while driving and hence slowed down input. A more effective selection method is likely to improve targeting speed.

Pressure input caused the largest number of glances at the touchscreen of all the input methods, therefore, hypothesis H3 is supported. Tapping on the targets directly resulted in the fewest glances, perhaps due to the other three input techniques requiring multiple actions to select a target. In particular, pressure-based and onscreen buttons required more time to aim at the sensors and onscreen widgets, perhaps due to the smaller targeting area of the sensors and the onscreen buttons. Furthermore, the loss of mechanical feedback when finding the flat pressure sensors and onscreen buttons is likely to have caused the drivers to look for the controls more often. However, visual distraction can be reduced with haptic feedback as our results showed that glance count at the touchscreen declined when haptic feedback was present, illustrating the importance of providing tactile cues for in-car user interfaces.

While directly tapping on the targets required the smallest number of glances at the touchscreen, the duration per glance for direct touch was longer than the other three input methods. Therefore, hypothesis H4 is rejected. It is interesting that there was a trade-off between longer but less frequent glances for the touch conditions and shorter but more frequent glances for pressure input and the physical dial. Perhaps this was due to the lack of haptic feedback for the touch conditions and that the users spent more time looking to aim precisely at the touchscreen for direct touch since an inaccurate selection cannot be corrected. An input technique or in-car application that caused long fixations on the touchscreen or input surface is likely to be more problematic than one which requires shorter bursts of attention, which would allow the driver to switch focus between looking ahead on the road and input more often.

CONCLUSIONS

A study was conducted to evaluate three different input methods to interact with a centre console touchscreen in real world driving situations. The findings showed that directly selecting targets in an abstract list-based interface was the quickest technique. Input using a physical dial and onscreen buttons took longer than direct touch but resulted in near perfect accuracy. Designers will need to consider what is more important, target speed or accuracy, when mapping physical and touch-based input controls to infotainment applications and tasks.

Pressure-based buttons caused more glances at the touchscreen than touch input and the dial, therefore needs improvements before it can be recommended as a safe alternative to physical controls for in-car interfaces. A different implementation such as rate-based pressure control might be more useful to improve selection time in driving situations. Pressure input provides an extra input dimension and could supplement touch interactions if these problems can be overcome. In the future, we plan to integrate pressure input on touchscreens to design new interaction techniques that will hopefully improve input performance and require minimal visual attention while driving.

Driving studies on public roads provide designers and researchers with the most realistic setting to test the limitations of new input techniques and applications. It is difficult to simulate the noise, movements and vibrations of a moving vehicle, which could have a major impact on usability and driver distraction, with a cost-effective in-lab setup. In-car touchscreens and touch-surfaces are rapidly replacing physical controls, allowing the development of novel interaction techniques and applications with complex functions. Our results show that engineers will need to test the effectiveness and safety of their designs in real world driving scenarios to ensure they get a full picture of their usability.

ACKNOWLEDGEMENTS

This research is funded by the Horizon 2020 HAPPINESS project (Grant agreement no. 645145).

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