The Wheels are Turning: Content Rotation on Steering Wheel Displays

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ABSTRACT

The steering wheel is a promising space for the integration of displays since in the car there is very limited space for integrating interactive modalities for the driver that are close to the preferred field of view as well as in an easy to reach position. When the wheel is turned, the screen content could change its orientation to increase the readability and therefore reduce the distraction from the road. Thus, this paper describes three different content rotation behaviors for steering wheel displays. To investigate what effect these behaviors have on the driver in terms of visual distraction from the road we conducted a user study with eye tracking asking participants to read the current speed. We found no differences in terms of distraction and response time between the different rotation behaviors. Compared to a similar display in a dashboard position the visual distraction was reduced.

Author Keywords

Display; distraction; rotation; steering wheel.

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

Modern cars offer the drivers a high variety of functionality that requires corresponding input and output modalities. Recent research has identified the steering wheel in cars as a promising place to mount displays, allowing the driver to interact with in-car systems combining input and output without the need to move hands further away from the steering wheel [1]. There is a strong notion that placing interactive elements on the steering wheel is beneficial for the driver, supporting the drivers' in keeping their hands on the wheel [2]. Combining input and output elements on the wheel also allows more flexible car cockpit designs. It, for example, allows a change of the driver's position from the left to the right front seat, or to a central position, as already proposed by some car concepts of industry and research (see e.g. [8]) while still keeping all necessary controls close.

For future steering wheel displays, automotive interface designers can take inspirations from mobile devices. Modern smartphones, for example, support a change between screen orientation from portrait to landscape mode and back corresponding to the rotation of the device. Having the display on a steering wheel react to the wheel's movements has the potential to improve the drivers' situation, by increasing the readability of the display content and thus reducing the distraction from the road.

Nevertheless, there are open questions from a user interface perspective when implementing rotating content on steering displays in relation to the steering wheel momentum. Does it increase readability and therefore decrease distraction if the content is aligned with the user's perspective of the horizon, basing the orientation of content on gravity as mental model? Or is content better to perceive when it stays stable relative to the display edges, turning together with the surrounding element such as the steering wheel the display is mounted on? And which other display behaviors are possible that can improve the readability for the users? For that purpose we compare three different screen rotation behaviors of displays on the steering wheel with one in a dashboard position in dual task experiment with 20 users.

The goal of our research is, therefore, threefold. First, we want to find out which behavior of steering wheel display content rotation is beneficial for the user in terms of visual distraction and response time. Second, we aim at comparing the display on the steering wheel with the placement in a dashboard like position, looking again at distraction and response time. This provides information whether displays on the wheel are beneficial or problematic in first place, independent from a specific rotation behavior. Third, we want to gather participants' impressions on the different modalities after trying them out for a few minutes, to investigate if users would even accept certain modalities.

BACKGROUND

In general, there is a strong need for researching the division of attention between the primary driving task and the instrument panel in the vehicle [3] and to understand which design features of an information display are requiring more attention and thus causing distraction from the primary task. The rotation of display content, as part of an interaction design, has already been under investigation in other contexts than the automotive one. Researchers have, for example, evaluated different ways how to trigger the rotation content in tabletop displays [9].

When designing for the steering wheel it has to be considered, that all elements placed in this space are affected by the rotation of the wheel, a challenge which has already been identified by researchers. Pfeiffer and colleagues [6] described the design challenge related to placing displays on the steering wheel: 'When combining input via buttons and visualizations like a speed indicator together on a steering wheel the question arises which parts of the display should be turning around with the steering wheel.'

In our analysis of related efforts, we found that concepts for screen rotation behavior of steering wheel display content are a concern in industry. Lahiff [5] describes, in his patent, the use of a rotation sensor to adapt the orientation of steering wheel displays. Nevertheless, we are not aware of any work that covers the effect of different rotation behaviors on the users.

TURNING DISPLAY MODALITIES

We selected three different display behaviors where we saw potential for the future application on steering wheels. All approaches are based on the assumption that the steering wheel is round, but the display is not centered on the steering wheel. The display can not be centered on the wheel, since the center of the steering wheel is a predetermined breaking point for the airbag system. Displays on the wheel therefore will not be placed in a central position, until display technology allows the combination of a display and an airbag (e.g. displays, that break controlled without splintering when the airbag is released).

As display content, we focused on displaying information about the current speed of the vehicle. Apart from warning and information messages (e.g., turn signal status), the speedometer is the only information, which has to be visible to the driver at all times (according to the road traffic act of Germany and Austria).

In order to have a comparison to established placements of displays, we included a dashboard condition (C0) by placing a display in a dashboard like position. This was done to gather information if there was an effect of the display moving and being closer to the participants (on the steering wheel) compared to a standard dashboard. As shown in Figure 1 we studied three display behaviors, aside from the dashboard condition:

C1 NoTurn: There is no reaction of the display content to a movement of the steering wheel, the shown number does not change its orientation relative to the display. This modality is the result of mounting a display on a steering wheel without responding to the certain context. An advantage of NoTurn can be that the users actively rotate the steering wheel and thus can assume the displays rotation, allowing them to adjust to the tilted content. Additionally, the content is stable in relation to the edges of the display (parallel) and the steering wheel rim. NoTurn also requires the lowest technological effort and the best way of utilizing the screen real real estate.

C2 FerrisWheel: When the steering wheel is turned, the content also turns around its center so that it is always horizontally aligned with the environment. Since the center of the content does not equal the center of the wheel rotation, the metaphor of a gondola on a ferris wheel can be used, which keeps its orientation while spinning around the center of a wheel. The idea behind the FerrisWheel display behavior is that by maintaining the horizontal orientation of the number, it will be more readable for the driver.

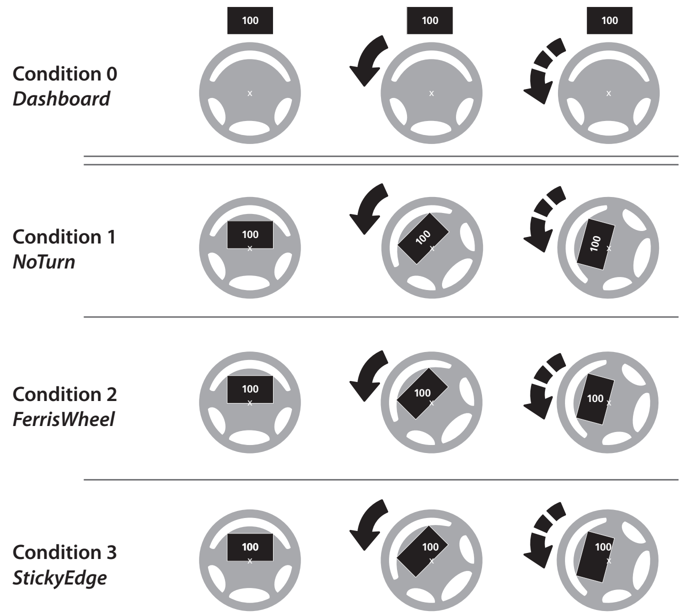

Figure 1. Three modalities supported by our prototype and dashboard condition.

C3 StickyEdge The StickyEdge modality uses the metaphor of a window through the steering wheel. When the steering wheel is slightly turned, the content stays virtually on the same place. This means, that while the display moves, the display content shifts on the display, so that it stays on the same position from the drivers perspective. When the steering wheel is turned further, the content will hit the edge of the display, were it will stick and continue moving with the display, maintaining its horizontal alignment. When the steering wheel is turned back, the content stays on the edge of the display until it reaches it's position central on the wheel. There it gets detached from the display edge. The StickyEdge approach works, when only single elements on the display are supposed to rotate. The StickyEdge modality can be beneficial for the drive especially during small movements of the steering wheel, which occur most often. In these cases the content stays in the same location for the driver.

TECHNICAL SETUP

In the user study we used VDrift (http://vdrift.net/) since it allowed us access to the current speed data. We selected a track that best represented a real road, not a race track, to allow a realistic steering behavior. To study the different display behaviors we built a prototype. As displays, we used two Samsung Galaxy S2 smartphones and developed an android app, which displayed the current speed and moved the numbers accordingly to the condition. One smartphone was mounted on the steering wheel, the other one on a dashboard like position.

Figure 2. Study setup with smartphones on steering wheel and dashboard position, eye tracker and driving simulator projection.

EVALUATION

In order to investigate the different modalities, we set up a user experiment. In this experiment, we wanted to find out in which condition users would take longer to read the actual speed and therefore be more distracted from the road.

Method

We used a within subject design, meaning that each participant used all four modalities in randomized order to avoid an assumed carry over effect. For each condition, we chose the following procedure. Each participant drove on the same track in our simulator. Every 10 - 20 seconds (random) a speed limit sign (between 30 to 130 kilometers per hour) appeared on the road as a trigger. The participants' task was to control their current speed and read it out loud every time a sign appeared. The present researcher logged the moment in which the participants were done reading the current speed. Using eye tracking technology (http://www.smarteye.se), we recorded participants' eye movements which allowed us to measure the time their eyes were placed on the display (and off the road) when they checked their speed.

We focussed our analysis on two measures, following an approach similar to [3]. First, we measured the total time that participants' eyes were focussed on the display while conducting the task of reading the speed. We understand this as "visual cost" that come with displays in vehicles [7]. To calculate the visual cost, we analyzed the eye position between the trigger and the moment the speed was read out completely. Second, we aimed at analyzing the response time for each repetition as indicator for mental load. We defined response time as duration between the trigger (speed sign) and the moment that participants finished read the current speed out loud.

Each participant drove on the track until 20 speed signs had been shown and the task of reading out the speed had been conducted 20 times. After conducting the driving task with all four secondary task conditions, we asked participants to rank the conditions depending on their preference to also gather the subjective impressions of users.

Participants

For our user experiment, we recruited 20 participants (10 male, 10 female) with a mean age of 31 years (SD: 6.4). We asked them for their yearly milage and found that they drove 8731 kilometers per year on average (SD: 11630), ranging from 0 to 50000 kilometers per year. From our sample, we had to exclude two participants from the eye tracking analysis due to a insufficient quality of the tracking data.

RESULTS

To operationalize our data, we calculated the mean value of the gaze duration during all 20 speed readings (tasks) per condition. This lead to one combined value for each participant for each condition. Since our sample size was $n<30$, we conducted a Shapiro-Wilk test to check for normal distribution and did not find statistically significant results ($D>0.927$, $p>0.05$). As we can assume normal distribution in our data, we conducted a repeated measurement ANOVA comparing each steering wheel condition against the dashboard condition. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2(5) = 31.40$, $p<0.001$). Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\epsilon = 0.463$). A repeated measures ANOVA revealed a significant medium effect of the display condition on the average gaze time ($F(1.39, 23.49) = 6.05$, $p = 0.014$, $r = 0.45$).

In a next step we conducted a post-hoc test using a Bonferoni correction which only revealed a significant difference between C0 and C3 (C0: M 0.59s, C3: M 0.44s, p= 0.045). No other significant differences were found, neither between a steering wheel display condition and the dashboard condition, nor between the steering wheel display conditions. However, as the mean difference between the steering wheel conditions were rather small (C1-C2 = -0.005s, C1-C3 = 0.002s, C2-C3 = 0.007s) we decided to compare the dashboard condition C0 against the averaged gaze times for the steering wheel conditions C1-C3. We, again, computed a repeated measures ANOVA and found a statistically significant difference with a medium effect size between the averaged total gaze time for all steering wheel conditions (C1, C2, C3) compared to the dashboard condition (C0) ($F(1, 17) = 7.48$, $p = 0.014$, $r = 0.55$). On average, participants spent significantly more time with their eyes on the dashboard (M 0.59s, SD 0.32s) than on the steering wheel display (M 0.44s, SD 0.17s). For our research goals this means that no difference was found between C1-3, but compared to the dashboard display, the steering wheel conditions caused less visual distraction from the road.

Second, we analyzed whether the display modalities (C1-C3) had an effect on the response time (time between trigger and reading out the speed). A repeated measures ANOVA did not reveal a statistically significant effect of the condition on the response time ($F(3, 51) = 1.68$, $p = 0.18$). This shows that we could not find any differences between the response time over the conditions.

Finally, we analyzed how participants ranked the conditions after using all of them. We found a clear preference towards the dashboard condition (see table 1). It was ranked 1st by 13 participants. Condition 1 (NoTurn) got the lowest ranking; never ranking first but 10 ratings for 4th place. The NoTurn condition can, therefore, be considered as being least liked by

Table 1. Frequency of ranking (1-4) of the conditions by the participants (n=20)

	1st	2nd	3rd	4th
C0: Dashboard	13	4	1	2
C1: NoTurn	0	6	4	10
C2: FerrisWheel	3	6	10	1
C3: StickyEdge	4	4	5	7

the participants. Condition 2 (Ferris Wheel) was ranked averagely, most participants placed it either in 2nd or 3rd rank. Condition 3 (StickyEdge) on the contrary was rated more diverse, with some participant preferring it and others ranking it lower. In summary, the most established and well known solution (display in a dashboard position) was preferred by most participants.

DISCUSSION

Contrary to our expectations, our results did not reveal differences in terms of visual cost between the display rotation behaviors (NoTurn, StickyEdge, FerrisWheel). This goes in accordance with [4], who found that a rotation of words below 60 degrees does not have an influence on the legibility of words. We assume that due to the low amount of digits that had to be read (max. 3) and a naturalistic steering behavior, which rarely exceeds a steering wheel movement of 60 degrees, all conditions provided a comparable legibility.

Noteworthy are the differences between the steering wheel (C1-3) and the dashboard conditions (C0). Users to dedicated more visual attention to the dashboard than to the steering wheel display. To investigate this difference, we looked deeper into the eye tracking log and found supporting data. Since a Shapiro-Wilk test revealed of the gaze frequency data is not normally distributed ($D > 0.668$, $p < 0.05$) we conducted non-parametric procedures. Pairwise Wilcoxon Tests showed that users looked significantly more often on the dashboard display than on any other steering wheel display condition (C0 vs. C1: $z = -2.72$, $p = 0.006$, $r = -0.64$, Mean Rank C0: 5.75 C1: 10.57 ; C0 vs. C2: $z = -2.79$, $p = 0.005$, $r = -0.66$, Mean Rank C0: 7, C2: 8.71; C0 vs. C3: $z = -2.678$, $p = 0.007$, $r = -0.63$, Mean Rank C0: 8 C3: 9.8).

CONCLUSION

Our work showed different rotation behaviors of content on steering wheel displays. Although these modalities differed strongly in their design, we could not find an effect on the visual cost and the response time when using them in a driving simulator experiment. Other than expected, a display mounted in a dashboard position caused more visual distraction from the road, while the overall response time stayed stable. Based on our results we can state that placing displays on the steering wheel for driving relevant information was not found to negatively affect the user in terms of distraction and task load compared to an established dashboard position.

As our data shows, we found mainly medium and large size effects. A bigger sample size (around 36 participants) might have revealed also smaller effects. The discovered effects are highly relevant for the car context, were already small improvements in terms of visual distraction can reduce safety critical situations. This argues also for further investigation of the issue with larger samples, to discover smaller effects.

A strong motivation for further investigating content rotation behaviors on steering wheel displays comes from the differences in users' personal opinions. Although most users liked the dashboard display (it is also the most common), the preferences regarding the steering wheel modalities were quite diverse, with a tendency towards adapting the screen content based on the rotation of the wheel (C2, C3).

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