**Proceedings of the 10th International ACM Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI '18), September 23–25, 2018, Toronto, Canada**

# An Investigation into Glance-free Operation of a Touchscreen With and Without Haptic Support in the Driving Simulator

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## ABSTRACT
In an empirical study conducted with 25 participants, touch interaction with and without haptic feedback on an 8-inch touchscreen with glance-free operation have been compared with each other. For this purpose, a main menu consisting of four control elements, each with a size of 86 mm x 51 mm, was selected from the touchscreen's existing menu structure. The comparison of with and without haptic support shows that the error rate without haptic feedback is significantly higher than with haptic feedback. This effect is shown in the driving task performed in the driving simulator. Three causes for the significantly higher error rate in conventional operation have been discovered. Furthermore, it was also discovered that the subjective operational stress with haptic support is significantly lower than without haptic support. There were no significant difference in driving lane deviation and efficiency.

## Author Keywords
Glance-free-interaction; haptic feedback; touchscreen; vehicle information systems;

## ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Touch screens and Haptic devices.

## INTRODUCTION
Touchscreens are becoming more and more popular as an input device for vehicle information systems, and forecasts show that the number of touchscreens in vehicles will rise constantly [31]. Instead of touchscreens, some vehicle models use rotary/push-button controllers as an input medium in combination with a touchpad and a separate display [2, 30]. Other vehicle models use two input options for the information system, a touchscreen in combination with a rotary/push-button controller [6] or with a touchpad [29]. The examination of the new premium class vehicle models shows that two touchscreens instead of just one are commonly used [3, 23]. The second touchscreen can be used to operate comfort functions. One vehicle model even give up the instrument cluster display and integrated its function into a single display with touchscreen functionality [38]. If this approach gains higher acceptance from the driver, then touchscreens will play a central role in future vehicle usage.

When various gestures and multi-finger interactions are used, touchscreens enable individual design options with regard to the flexibility of operation and the GUI (Graphical User Interface). The advantages of integrating the input and output interaction on a touchscreen can be seen from the comparative cost of using rotary/push-button controllers and touchpads with a separate display unit. With touchscreens, therefore, the costly and time-consuming process of interconnecting separate input and output components can be reduced. In addition, some studies [16, 24, 35] show that a touchscreen can be operated faster and with less distraction than with a rotary/push-button controller or even touchpad.

Interaction with a touchscreen should not impair driver attentiveness while driving the vehicle, as secondary activities can be highly distracting and thus lead to accidents [20]. The recommended maximum time for taking one's eyes off the road is 1.5 s [40]. For this reason, distraction-free operation of touchscreens should be made possible. This means guaranteeing effective, efficient, intuitive and glance-free operation without having an impact on vehicle guidance.

## RELATED WORK
An analysis of the current state of research reveals the following effects on effectiveness, efficiency, looking in the right direction, subjective operational stress and vehicle guidance when operating a touchscreen:

- Position of the touchscreen in the vehicle interior
- The design of the GUI
- Interaction method with the touchscreen
- Duration of interaction on the touchscreen
- Type of feedback with touchscreen interaction
- Ambient factors in vehicle guidance during touchscreen interaction



*AutomotiveUI '18,* September 23–25, 2018, Toronto, ON, Canada

ACM ISBN 978-1-4503-5946-7/18/09…$15.00
https://doi.org/10.1145/3239060.3239077

### Touchscreen Position

The studies conducted by Fuller et al. [13, 14] show that the ideal position of a touchscreen in the vehicle is directly beside, and at the same height as the steering wheel. A position beneath the steering wheel causes a longer operating duration of more than 10 seconds and longer glances of 4 seconds than a position at the same height as the steering wheel [13, 14]. However, in these studies, the different touchscreen positions do not show any significant difference in vehicle guidance [13, 14]. The study conducted by Hagiwara et al. [15] confirms that the duration of the glance is influenced by the touchscreen position, just like the studies conducted by Fuller et al. [13, 14].

### Touchscreen GUI

In the GUI design, the size, color selection, and structure of the control elements can play a role in distracting the driver while driving. Rümelin et al. [34] compared two element sizes (60 mm x 78 mm and 30 mm x 30 mm) on a touchscreen in a driving simulator application. The findings of Rümelin et al. [34] show that the smaller control element causes twice as many input errors on the touchscreen as the larger control element. In addition, the larger control element reduces the time spent looking at the touchscreen by 300 ms compared to a smaller control element. With regard to the operating time, subjective operational stress, and vehicle guidance, the findings of Rümelin et al. [34] do not show any significant difference in the two selected control element sizes.

In comparison with the study from Rümelin et al. [35], Kim et al. [19] examined five different control element sizes (7.5 mm x 7.5 mm, 12.5 mm x 12.5 mm, 17.5 mm x 17.5 mm, 22.5 mm x 22.5 mm, and 27.5 mm x 27.5 mm) in their studies. The findings of Kim et al. [19] confirm the influence of the control element size on the effectiveness and duration of looking at the touchscreen control unit during usage in the driving simulator. In addition, Kim et al. [19] can show that the control element size influences the duration of operation, subjective operational stress, and vehicle guidance.

Eren et al. [10] used their study to determine the control element size. They investigated at which control element size a glance-free operation can be achieved during the driving.
Eren et al. [10] used four different control element sizes (20 mm x 20 mm, 60 mm x 60 mm, 100 mm x 100 mm, and 140 mm x 140 mm) and measured the length of time the experiment participants spent looking at the touchscreen. With a control element size of 140 mm x 140 mm, an average time of 0.5 seconds spent looking at the touchscreen was calculated. Approximately 44 percent of the measurement data revealed a glance-free touchscreen operation for a control element size of 140 mm x 140 mm. The studies conducted by Franz et al. [12] show that a similar color selection in combination with similar symbols for the control elements causes the participants to look at the touchscreen for an average of 6.8 seconds. This is a time that the participants needed in order to find the specified control element. The study conducted by Pitts et al. [32] shows that, when operating a touchscreen, the user spends 70% of the operating time looking at the touchscreen before user interaction starts. Pitts et al. [32] also shows that, due to the longer look duration, driver distraction in the form of driving lane deviation is increased compared with a driving task without touchscreen operation. However, both studies used the GUI design that consisted identical colors and symbols of the control elements, as can be seen in the Figure 1.

### Touchscreen Interaction Method

Interaction with a touchscreen can take the form of different input gestures. The most frequently used input gesture is the tap gesture, as used when operating a smartphone. The tap gesture is also called “direct touch” [11]. The tap gesture is marked by the two states “press” and “release” [26]. During the tap gesture, the touch duration of the “press” state on a touchscreen must be short so that it can be detected as a tap gesture [17].

As an alternative to the tap gesture, the swipe gestures [22], the multi-finger gesture [12], or a combination of both gestures [21, 37] can be used to input and select a function on the touchscreen. The advantage with the alternative gestures lies in the fact that, unlike the tap gesture, they can be used without looking at the touchscreen while driving the vehicle, and thus require a shorter look duration than the tap gesture [4]. The disadvantage is that the alternative gestures are more prone to error and also require a longer operating time than the tap gesture [12, 34].

### Touchscreen Interaction Task

With the touchscreen, different tasks such as selecting a music track, entering an address/telephone number, or enlarging the navigation view can be performed. Each one of these tasks requires a different length of time spent interacting with the touchscreen [33]. This results in different look durations as well as different effects on driving behavior [35]. Entering an address in the navigation menu can require the longest interaction time [7].

### Touchscreen Interaction Feedback

Interaction on the touchscreen can be supported by a specific type of feedback. The entry on the touchscreen can be auditory, tactile, or a combination of auditory and tactile. The studies conducted by Lee et al. [25] and Pitts et al. [32] show that, with haptic and auditory support when making entries on the touchscreen, the shortest operating time, look duration, and the lowest subjective operational stress are achieved compared to the scenario without support. In the study conducted by Lee et al. [25], the operating time with the combination of haptic and auditory support can be reduced from 15.4 seconds to 11.6 seconds on average, compared to the scenario without support.


**Figure 1. Selected touchscreen displays (left: Franz et al. [12], and right: Pitts et.al. [32]).**

The study conducted by Beruscha et al. [5] reveals in its findings that haptic support can facilitate glance-free interaction on the touchscreen. In the Beruscha experiment, three different input modalities were compared: without haptic support, with haptic support, and haptic support with the touchscreen visuals switched off. The task for the three interaction variants was to operate one of the four control elements while using a driving simulator. Haptic support with the touchscreen visuals switched off shows the shortest look duration (an average of 5 seconds), compared to without haptic support (an average of 12 seconds) and with haptic support (an average of 7 seconds) [5]. An evaluation of operational effectiveness shows that, in the variant with the touchscreen switched off, more operating errors occur. Statistically, however, they are not significantly different from the two other input variants [5].

### Touchscreen Interaction and Different Road Conditions

It is not just the design of the touchscreen itself that influences driver distraction; the driving conditions under which the touchscreen interaction takes place also exert an influence. One influencing factor is the vehicle speed, a second one is the condition of the road surface. In the study conducted by Li et al. [27], it was discovered that, when the speed is increased from 30 km/h to 80 km/h, twice as many input errors occur on the touchscreen. The study conducted by Kim et al. [19] revealed that, as the vehicle speed rises, the time spent operating the touchscreen increases. Ahmad et al. [1] examined the influence of the road surface's condition on touchscreen interaction in their study. In their study, they compared three different types of road surfaces conditions in touchscreen interaction. As the road surface level of perturbation increased, the number of incorrect operations on the touchscreen also increased [1].

## METHOD

An analysis of the studies presented above shows that selecting the right settings and functions on the touchscreen can support distraction-free operation while driving. There is even the potential to facilitate glance-free touchscreen operation. The findings of Eren et al. [10] and Beruscha et al. [5] show that glance-free operation on a touchscreen while driving can be facilitated with the selection of large control elements or haptic support. For the automotive application, the main goal of touchscreen development is to ensure glance-free operation on the touchscreen during vehicle guidance by means of large control elements in combination with haptic support.

This poses the question whether both "large control elements" and "haptic feedback" conditions are required in order to facilitate glance-free operation of the touchscreen. Or is it sufficient to facilitate glance-free operation of the touchscreen with only large control elements and no haptic feedback? For this reason, an experiment was designed to examine genuine glance-free operation depending on support with or without haptic feedback on a touchscreen in the driving simulator. The goal of the experiment was to determine the fitness for use in the form of the required effectiveness, subjective operational stress, and driving lane deviation. As during the touchscreen operation without glance interaction will produce longer operating time, the efficiency was not the main focus in this experiment.

The following working hypotheses were formed for this purpose:

***H1:*** Effectiveness is higher during glance-free operation with haptic support than without haptic support.

***H2:*** Efficiency is higher during glance-free operation with haptic support than without haptic support.

***H3:*** The subjective operational stress is lower during glance-free operation with haptic support than without haptic support.

***H4:*** Driving lane deviation is lower during glance-free operation with haptic support than without haptic support.

### Participants

The participant of this experiment was randomly chosen and comprised 17 males and 9 females. The average age was 38.8 years (SD = 16.7 years). All of the participants posed valid driver's licenses. The average annual driving distance for participants was 20 km per year (SD = 9 km per year). Only one participant was a left-handed user. 12 participants had experience with a touchscreen in the car. 6 participants had experience with haptic feedback from touch surfaces. 5 of them with a smartphone and 1 with the touchpad in the Mercedes C Class.

### Apparatus

To perform the experiment, a touchscreen with a graphic user interface was used. The touchscreen can be operated either with or without haptic feedback. Without haptic feedback, the touchscreen is operated by means of a tap gesture, just like a smartphone. The haptic feedback is provided, just like in Beruscha et al. [5] and Zhou et al. [41], by means of pressure-sensitive detection. Four actuators (voice coil) were used to perform the experiment. To detect pressure on the touchscreen surface, four addition voice coil were used; they had been integrated into the actuators in order to save space in the touchscreen. When the finger pressure was changed, the integrated coils measured a proportional change in voltage. The influence of finger pressure on the touchscreen surface was measured every 5 ms.

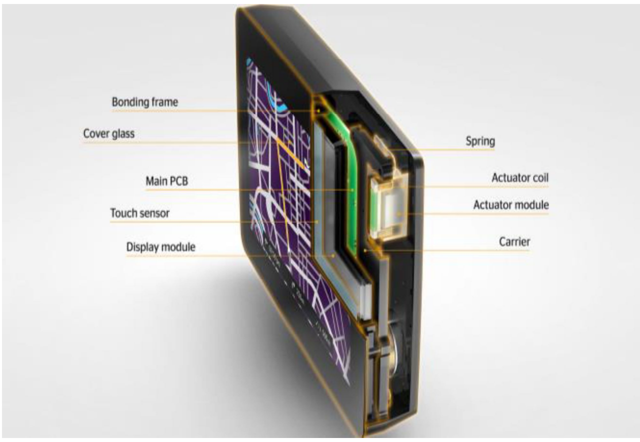


**Figure 2. Haptic touchscreen and an explanation of the internal design.**

The haptic feedback is activated once the force threshold of 3.5 N has been exceeded and then triggers a 3 ms semi-sinusoidal pulse with 0.14 mm pulse amplitude. This way we can replicate the haptic feedback of a pressing a mechanical button. Afterwards the mechanical button release feedback will be replicated once the force threshold is no longer reached. In addition, the haptic feedback generate auditory noise, which was occurred by the touchscreen panel movement. It is obvious, that the auditory noise become louder with the increasing of the haptic amplitude and duration. Therefore, the 3-ms-semi-sinusoidal pulse with 0.14mm amplitude was preferred to conduct the experiment. Figure 2 shows the 8-inch touchscreen with its internal design.

In this experiment, a main menu with 4 control elements "Navigation", "Entertainment", "Climate" and "Communication" was selected from the existing graphic user interface of the 8-inch touchscreen. Each control element is 86 mm x 51 mm in size. In order to imitate the mechanical edges between the control elements, the same haptic feedback as for the press and release feature was used when the user moved the finger from one control element to the next. This can offer guidance and encourage glance-free interaction. The selected menu is shown in Figure 3.

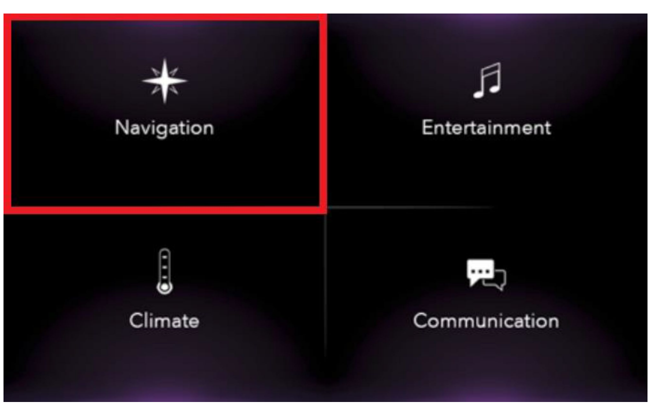


**Figure 3. GUI with a sample control element (with a red edge) to be selected in each case.**

In light of the findings of Colley et al. [8], it is advisable to provide an additional bezel as the mechanical feel aid on the touchscreen. For this purpose, a white template was attached (Figure 4a) on the outer black area of the touchscreen (Figure 2). This area is not touch-sensitive. In combination with the selected operating menu and the white template, every control element can be operated glance-free via the edges in the corners. The goal here was to balance out the disadvantages in glance-free operation without haptic feedback by means of this support.

### Experimental Setup

In the experimental setup (Figure 4a/b), a vehicle mockup with a driver's seat, a steering wheel, and the touchscreen in the center console were used. The touchscreen was positioned at the same height as the steering wheel (Figure 4a) in keeping with the findings of Fuller et al. [13]. OpenDS [28] was used as driving simulator software by means of a projector. For the simulated drive, a rural road track with traffic ahead and oncoming traffic was selected in order to replicate a situation that, according to accident statistics [36], accounts for the majority of fatal accidents in Germany.

A further goal was to take into consideration the influence of a critical road surface in the form of an S-bend, in keeping with the examination conducted by Ahmad et al. [1] and Kim et al. [19]. The vehicle speed for this rural road track was a constant 70 km/h. This is the maximum speed limit of the selected simulated road. By having this constant speed, the driver needs to only to steer and interact with the touchscreen. The simulation takes around 45 seconds. The rural road consisted of a straight track at the start and end of the driving tasks, and an S-bend in the middle.

To analyze glance-free operation, a white color curtain was placed beside the driver, to ensure that the participant could not look at the touchscreen. This can be seen in figure 4c. In order to inform the driver, which control elements they had to select, these elements have been displayed on the simulator screen, positioned at the top left edge.

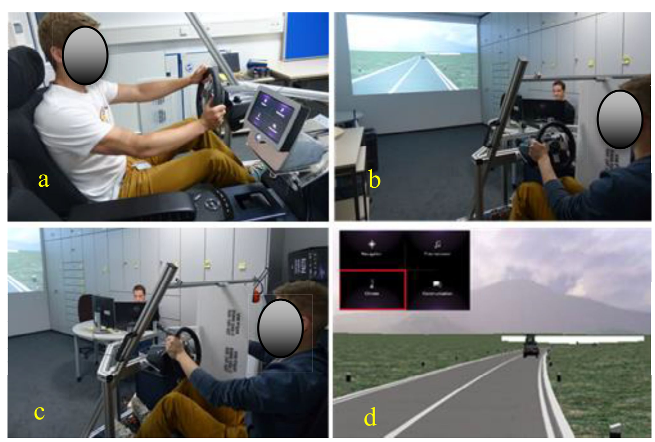


**Figure 4. Setup of the driving simulator (a: view of vehicle mockup; b: view of whole setup; c: view of curtain between participant and the touchscreen; d: display of the control task while driving at the same time).**

Once the control element is selected, it will be marked with the red color border. After two seconds, the control element will not be displayed anymore. This is necessary in order to keep the 1.5 seconds maximum look duration [40]. The illustration of this can be seen at the figure 4d. Another reason to choose this time period was in order to simulate a single glance-free interactive procedure with a maximum visual orientation along a real route. A further goal here was also to eliminate the influence of distraction caused by looking at the control menu, just as Franz et al. [12] and Pitts et al. [32] stated. The experiment was performed with an experiment leader and an assistant.

The experiment leader gave the instruction to the participant during the experiment. The experiment leader also noted the result of glance-free operation on the touchscreen, and gave the assistant a sign in advance to stop the time measurement. The time measurement was automatically started by the OpenDS program after the specified control task was hidden. The assistant had to stop the time measurement when instructed by the experiment leader.

### Procedure

After the participant arrived at the experimental laboratory, a written explanation of the experiment process, with a declaration of anonymity, was handed out. Before starting the experiment, the participant completed a questionnaire for the purposes of gathering demographic data and their level of experience with vehicle input devices. Afterwards, two baseline journeys took place in the driving simulator without any use of the touchscreen. After each baseline journey, the participant were asked about their subjective experience of the journey using an RSME scale [39]. The RSME scale runs from 0 to 150, with 0 meaning “absolutely no effort” and 150 meaning “extreme effort”. Once the baseline journey is done, the participant will conduct the experiments, which are divided into three steps:

1. Introduction with glance.
2. Glance-free interaction without driving (learning).
3. Glance-free interaction with driving.

Each of the steps has to be conducted using two different interaction modes (with and without haptic feedback), whereas each of the interaction mode will be done twice. The participant with odd numbers started the experiment without haptic feedback and vice versa. After finishing each interaction mode, the participant have been asked about their subjective experience using an RSME scale [39]. At the end of the experiments, the participants were asked the following questions:

- Which is your preferred interaction mode (with or without haptic)?
- Do you prefer to have a touchscreen with haptic feedback in your vehicle?
- How satisfy are you with the implemented haptic feedback profile?

### Design

The interaction modes has been defined an independent variable. The effectiveness, efficiency, subjective effort and lane deviation have been defined as dependent variables. To determine the dependent variables, both interaction mode has been determined for all 26 participants. These will results in 52 data sets for each interaction mode. In total there are 104 data sets to be evaluated.

### Result

Unfortunately, only 25 participants took part in the interaction comparison while driving, as one participant was not able to operate the driving simulator. This meant that there were only 100 data sets of measurement instead of 104. In this experiment a $\chi^2$ test was used for statistically determining effectiveness, thus to identify the ratio of successful inputs to operating errors. The RM-ANOVA test is preferred to t-test for evaluating the efficiency and lane deviation. One of the main reason is that the dataset were not too close to normal distribution, whereas the t-test required a 100% normal distribution of the datasets. A Wilcoxon-signed-rank test was used for statistically evaluating ordinally scaled data for subjective effort.

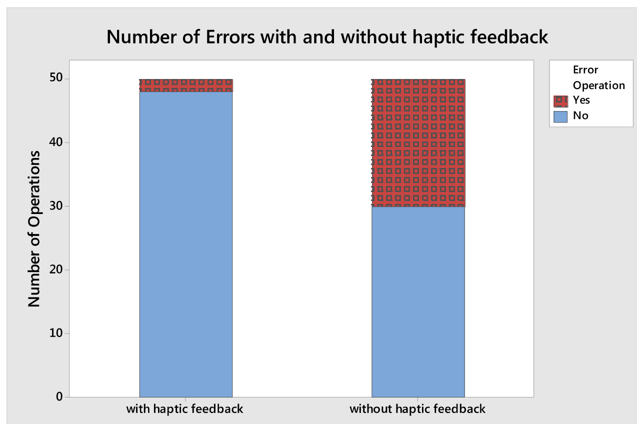


**Figure 5.Effect on operating effectiveness of operation with and without haptic feedback.**

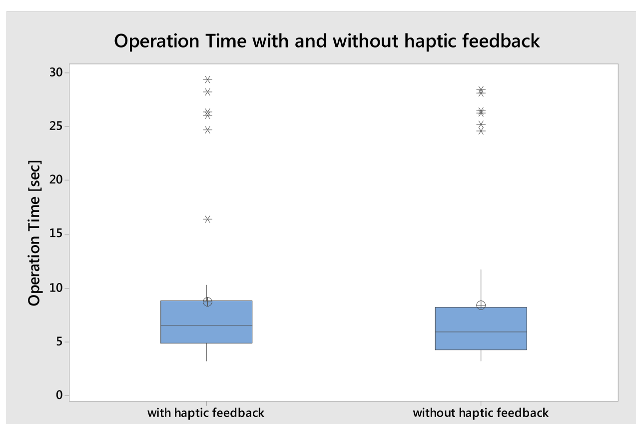


**Figure 6. Effect on operating efficiency of operation with and without haptic.**

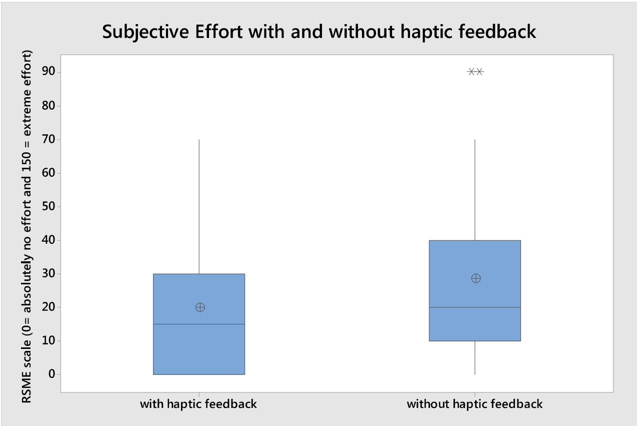


**Figure 7. Effect on subjective effort of operation with and without haptic.**

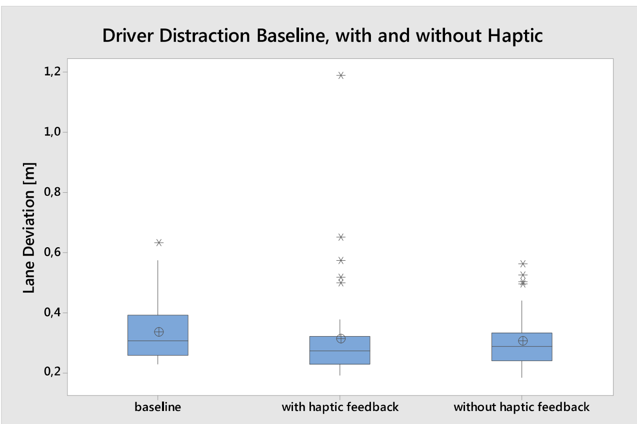


**Figure 8. Effect on lane deviation of operation with and without haptic feedback.**

The glance-free operation with haptic feedback shows only two input errors have been made. In contrast to this, significantly higher input error, 20 errors, can be observed once the haptic feedback functionality was deactivated ($\chi^2$ [1, N = 100] = 18.881, p < .001). Thus, hypothesis H1 can be accepted. These results are graphically presented in figure 5.

The analysis of the operation time showed no significant differences between both interaction modes (F[1, 99] = 1.045, p = 0.309). Consequently, hypothesis H2 was discarded. With haptic feedback the participants needed in average 8.64 seconds and without haptic feedback 8.42 seconds to interact with the touchscreen. Figure 6 shows the operating times for the versions with and without haptic feedback.

Subjective effort can likewise be reduced significantly with haptic feedback (z = -2.7867, p = 0.005, r = 0.39). Consequently, hypothesis H3 is accepted. With haptic feedback the participants rated the subjective effort in average 20 and without haptic feedback 28. Figure 7 shows the subjective effort for the versions with and without haptic feedback.

The evaluation of lane deviation shows that the presence or absence of haptic feedback has no significant effect on lane deviation (F[1, 99] = 1.826, p = 0.179). Consequently, hypothesis H4 was discarded. The average lane deviation for this experiment was 0.3 meters for all three condition. Figure 8 shows lane deviation for the versions with and without haptic feedback.

## DISCUSSION

The results show that glance-free operating on a touchscreen with the haptic feedback leads to significantly fewer operating errors than without the haptic feedback. Therefore, with the chosen experimental setup, it can be shown that the haptic feedback enables robust touchscreen operation without the driver having to look away from the road. This result was initially not expected, since the experimental setup allows already the user to perform glance-free operation without haptic feedback with low input errors.

Through observation of the experiment performed, three main reasons were identified for the significantly higher error rate during tap gestures without haptic feedback. Due to a lack of hand-eye coordination, the participants were frequently too slow to interact with the control elements on the touchscreen. Which mean that any attempted input was not detected by the system. Furthermore, the participants also frequently selected the wrong option on the touchscreen, even though they had been able to find the correct control element beforehand. The participants unintentionally confirmed a selection through brief contact with the touchscreen while orientating themselves, which can lead to higher error rate.

The results for the operating times show no significant difference between the two interaction modes (with and without haptic feedback). The results with driving show dispersion in the operating times for both interaction modes, which was mainly due to the chosen road track. If the participants had not finished operating the touchscreen without looking before they reached the S-bend track, they wouldn’t continue operating the touchscreen.

Once they passed the S-bend track, they continued operating the touchscreen. Therefore, the chosen method for measuring the operation time was not suitable. A more accurate measure method for operating time might lead to more significantly differences between the two interaction modes, for instance using a camera.

The evaluation of the data for subjective effort shows that significantly less effort was perceived in glance-free operating with haptic feedback. Based on the participant’s feedbacks, the haptic feedback provides orientation and confirms their actions. This could explain the lower subjective effort when the touchscreen is operated with haptic feedback.

The lane deviation analysis shows that there is no significant difference between the two interaction modes. A comparison between the baseline journey and the journeys with both interaction modes shows no significant differences. The results for lane deviation show dispersion, similarly to the data for operating times. The biggest lane deviations were identified in the area of the S-bend track. This dispersion is linked to the chosen road track and the set speed of 70 km/h.

The analysis of the feedback from participants shows, that all participants preferred the haptic feedback interaction. Also all participants prefer the presence of touchscreen with haptic feedback in the vehicle. The main reasons are the higher safety feeling and the better orientation for finding the control menu. Most of the participants were already comfortable with the chosen haptic feedback intensity and the resulting auditory feedback. Only five participants felt the haptic feedback intensity was too strong and preferred a smoother haptic feedback. Several of the participants proposed to have different haptic feedback type between edge feedback and the feedback from a selected control element.

## CONCLUSION

The conducted experiment illustrates that with haptic feedback in combination with large control elements, it is possible to enable drivers to perform glance-free operation on the vehicle touchscreen. By contrast, conventional touchscreen operation without haptic feedback does not ensure that drivers can perform the glance-free operation. This can be confirmed from the statistical result of driver distraction in the form of subjective effort. In terms of efficiency and lane deviation, there is no significant difference between the two interaction modes. The feedback from the participants shows, that they prefer a touchscreen with haptic feedback for a vehicle application.

Additionally, there are several potentials to optimize the experiment setup, on account of the fixed screen used to block the driver vision, thus to replicate the glance-free operation. This affected operating time in that it hindered the natural hand and arm movements involved in interacting with the touchscreen. Using a curtain with a slit could presumably cut the time taken to move during glance-free operation and would correspond to interaction involving looking at the screen.

In a follow-up experiment, it would also make sense to record the times for complete interactions using a video camera, in order to determine the operating time broken down into individual stages. Furthermore, it would then be possible to record the extent to which input via tap gestures was slower and to compare this with the experiment by Colley [9]. Colley [9] established that the contact time involved in a tap gesture can last between 70 ms and 400 ms.

It would be interesting to add a voice feedback feature to the haptic feedback. Voice feedback could be enabled by means of a gesture interaction based on the work of Kane et al. [18]. In their analysis, Kane et al. [18] developed a form of two-finger interaction enabling blind people to use smartphones.

To further underscore the necessity of haptic feedback in vehicle applications, it would be useful to pick up on the analyses conducted by Ahmad et al. [1]. The results presented do not consider the influence of road surface conditions as the experiment with tap gestures does, conducted by Ahmad et al. [1]. It would be interesting to find out whether it is possible to operate a touchscreen, when the road surface changes, with and without haptic feedback.

## ACKNOWLEDGMENTS

We would like to thank our colleagues from the model shop and the haptic laboratory for their assistance.

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