Virtual eye height and display height influence visual distraction measures in simulated driving conditions

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Abstract: Glance behaviour towards in-vehicle visual displays is likely not only a result of the design of the display itself, but also influenced by other factors such as the position of the display and characteristics of the surrounding road scene. In the current study, it was hypothesized that both display position and simulator view will affect a driver's glance behaviour. A simulator study was conducted in which 25 participants drove in a highway scenario while performing three different tasks in a smartphone positioned at two different heights. Two different simulator views used: one corresponding to the view from the driver's seat of a truck and the other one corresponded to the view from the driver's seat of a car. A within-group design was used with simulator view, smartphone position, and task as factors.
Results showed that type of view and display position to some extent influenced glance behaviour as well as subjective ratings of driving performance. These results may have implications for eye glance measurement procedures as well as for guidelines relating to driver distraction, e.g. that simulated road scenes must correspond to the vehicle class that the device under test is intended for.

1. Introduction

Reducing visual distraction in vehicles is key in terms of safety [1,2] and many different factors may influence visual behaviour in relation to in-vehicle displays. Previous research has shown that for example font type can influence glance behaviour and response time and that optimising typefaces could mitigate interface demands to some extent [3]. Reducing visual distraction caused by in-vehicle devices, infotainment systems and similar could also be done by e.g. introducing voice interaction or sound feedback [4,5]. There are thus measures to improve existing in- vehicle interfaces from a distraction point of view.

However, there is reason to believe that glance behaviour towards in-vehicle visual displays is not only a result of the design of the display itself, but also influenced by other, contextual factors. The position of the display is one such factor potentially affecting how much one need to look at the display to perform certain tasks [6]. In the study by Fuller & Tsimhoni [6] it was found that a low display position led to longer total glance times and more glances compared to a high display position. They explained this by the fact that it might have been more difficult to see the information and operate the display controls when placed low, in turn requiring more glances. Another explanation was that glance times included the gaze movement from looking ahead to the display, which would then increase when the display was located further away from the "ahead" position. Fuller & Tsimhoni [6] did however not find any difference in average glance duration, which in some sense contradicts that explanation. In fact, one could speculate that drivers are more likely to glance longer at displays located *close* to the "ahead position" (i.e. a high display position) since they then have the road scene in their field of vision to greater extent [11,13]. In those cases, drivers may feel that they can react to any changes in the traffic ahead – e.g. looming stimuli – even while looking at the display. In contrast, if drivers have to look at a display in a low position they may feel less inclined to use longer glances since they do not have the road scene in their field of view in the same way.

In a similar vein, it is also reasonable to believe that glance behaviour can be affected by the characteristics of the surrounding road scene [7,8]. Route familiarity has for example been shown to affect visual sampling strategies when driving without secondary tasks [7]. In the study by Tivesten & Dozza [8], it was shown that drivers had a lower proportion of long off-road glances in complex driving contexts (such as when lead- or oncoming vehicles are present), compared to simpler scenarios, both in normal driving and while engaged in a visual-manual secondary task.

In-vehicle visual display guidelines provided by NHTSA [10] and AAM [11] provide recommendations on the lower limit of a display's downward viewing angle. These recommendations are in turn based on the JAMA guidelines [12] and the research underlying this criterion [13] investigated the viewing angle at which drivers, when looking at the display, were still able to perceive that they are approaching a preceding vehicle in time to avoid a rear-end collision [11]. The research performed in [13] also took into account that drivers can see further down the road when positioned higher above the road surface. Consequently, the guideline criteria [10-12] provide means for calculating the recommended position of the display based on the driver's eye point height.

Based on this, one may hypothesize that if the driver has a good view of the road and can anticipate what is going on in front of him/her with good margins, he/she might feel safer looking down more often and/or with longer glances as opposed to if the view is poor. In a heavy truck, the driver sits high above the road surface and has the possibility to assess the surrounding traffic in a different way compared to in a passenger car, where the driver is positioned much closer to the road surface and the dashboard obstructs the view to greater extent. If we consider previous reasoning, the differences in a driver's view between car and truck could potentially affect the strategy the driver adopts when using a visual interface. In other words, visual display tasks may afford different glance behaviours if the tasks are performed in a passenger car compared to if the same tasks are performed in a truck. The truck driver may look down longer or more often since he/she feels safer to do so because of the improved ability to predict upcoming traffic events compared to when driving in a car.

In the current study, we test the following hypotheses based on the reasoning presented above:

H1. Truck road view (eye point high above road, low dashboard) leads to longer glances (in mean) and more long glances (>2s) towards a visual display than car road view (eye point low above road, high dashboard)

H2. Lower display position leads to shorter glances (in mean) and fewer long glances (>2s) towards a visual display compared to a high display position.

We also hypothesize that there are interaction effects between type of task and view and as well as between type of task and display position. We expect that for a simple task – e.g. pressing the same button repeatedly – eye glance measures and task duration will be less affected by the variation in view or display position compared to a more difficult task since simpler tasks may allow for partially performing the task without looking at the display. The hypotheses are tested in the simulator experiment presented in the remaining paragraphs.

The aim of this research is obviously to gain more insights into whether there are any differences in glancing behaviour towards visual displays in cars vs. in trucks. In direct relation to this, we would also like to highlight and possibly answer the question whether distraction guidelines for passenger cars are directly applicable to heavy trucks or not. The outcome could not only increase understanding of the visual distraction problem per se, but could also provide important input to guidelines and standards – e.g. how display criteria or evaluation procedures should be adapted to the heavy truck segment.

2. Methods

2.1. Experiment Design

A 2 x 2 x 3 x 2 within-group factorial design was used with virtual eye point height (car / truck), display height (low / high), task (easy/normal/difficult), and task repetition as independent variables. The order of conditions was balanced between participants in order to avoid order effects.

2.2. Participants

25 persons between 32-59 years old recruited from within the company took part in the experiment. Half of the participants held truck driver´s licenses and were in the analysis labelled “experienced”.

2.3. Apparatus, Equipment and Stimuli

A medium-sized fixed-base simulator was used in the experiment. The simulator consists of a truck dashboard, including steering wheel and all relevant controls, and a truck seat. Image is projected by means of a standard computer projector at approximately 2.5 m from the eye position and the horizontal field-of-view is approximately 30 degrees (which is consistent with [10]). Small loudspeakers placed in front of the dashboard reproduce simulated engine sound.

To measure glance behaviour, an Ergoneers Dikablis eye tracker together with Ergoneers DLab 3 data acquisition and analysis software was used [9]. This eye tracker device consists of a headpiece with two cameras, where one camera records the pupil movement and the second one faces forward.

Two different simulator views were created. The first one corresponded to the view from the driver's seat of a truck, where the viewpoint height was located 2.3 m above the road. The second one corresponded to the view from the driver's seat of a car, with a viewpoint 1.2m above ground. For the second viewpoint, a segment of the lower part of the view was also covered with a black rectangle covering 25% of the total image height, to simulate the effect of the car's dashboard.

The two display positions are shown in Fig. 1 below. The High position was located at an angle of about 20 degrees from the horizontal plane and the Low position was located at 45 degrees relative the horizontal plane. Relative the vertical plane, both positions were located at 27 degrees. The eye-to-phone distance was thus approximately the same for both positions (approx. 80cm). The angles were chosen based on the 2D display position criterion VC [10] (similar to criterion 1.4A in [12]). According to this criterion, the maximum downward display angle for vehicles where the driver eye point is less than or equal to 1700 millimeters above the ground is 30 degrees. For vehicles where the eye point is higher than 1700 mm, the maximum downward display angle should be calculated as:

$$\text{Angle (degrees)} = 0.01303 \times (\text{eye point height from the ground (mm)}) + 15.07 \quad (1)$$

Fig. 1. *The smartphone positions used in the experiment, High (left) and Low.*

In the current setup, the High position (20 degrees) is clearly within the acceptable range for both passenger car and truck view (which should be less than 30 degrees for the car view). The Low position (45 degrees) is clearly out of the range for the passenger car view and on the limit for what is acceptable for the truck view ($0.01303 \times 2300 + 15.07 = 45$ degrees).

2.4. Tasks

The participants performed three different tasks using the display, a Samsung I9001 Galaxy S Plus smartphone; 1) Tune radio, 2) Set the alarm clock, and 3) Find a truck dealer close to Barcelona using a specific truck dealer app. Screenshots from the three tasks are shown in Fig. 2.

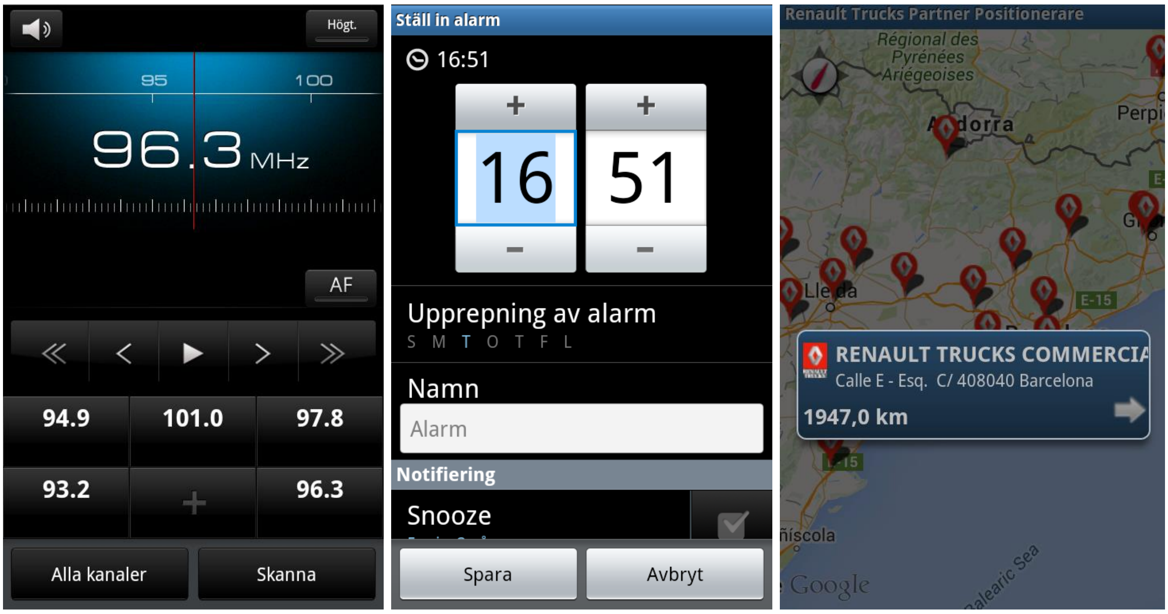

Fig. 2. *Screenshots from the three apps used for task 1-3: Tune radio (left), Set alarm (middle), Find truck dealer (right).*

Task 1, *radio tuning*, consisted of tapping the screen at a single location a number of times until a specific radio frequency had been reached. Task 2, *set alarm*, required tapping the screen a different locations and entering numbers from a virtual keypad. Finally, Task 3 – *find truck dealer* - involved several pinch and swipe operations in order to navigate a map (from Gothenburg, Sweden to Barcelona, Spain) to find a specific location as well as some tapping to select target. The number of different operations required to complete each task are shown in Table 1. From a visual-manual workload perspective, Task 1 was intended to be the easiest one while Task 3 was intended to be the most difficult one.

Table 1. Tasks described in terms of operations required for completion

Task	Number of taps (excl. digit entry)	Number of digit entries?	Number of pinch zoom (approx.)	Number of swipes (approx.)	Total interactions
1) Tune radio	31	0	0	0	31
2) Set alarm	7	4	0	0	11
3) Find truck dealer	4	0	4	4	12

2.5. Procedure

Participants arrived individually to the simulator lab. They were first introduced to the study, the simulator and the eye tracking equipment to be used. The participants were also instructed that the test could be stopped at any time and for any reason (e.g. if feeling motion sick or other type of discomfort). Then, the tasks to be performed during the test were demonstrated and the participants learned how to perform each task. The eye tracker was then calibrated after which a five-minute test-drive was carried out to make the test persons comfortable with the simulator.

The actual test then started. Before each task, participants again practiced the task before the task was recorded. If the task was not completed without errors, they were asked to perform the task once more. After each successful trial, participants were asked to rate their driving performance during the task, on a scale 1-10 where 1= very bad ("I drove in a very unsafe manner") to 10= very good ("I drove in a very safe manner"). Each task was performed twice, but not in succession (the order of all conditions was counterbalanced to avoid order effects). After all tasks had been completed and the participants had stepped out of the simulator, some follow-up questions were asked regarding if they experienced any differences in performing the tasks for the different conditions, and if any of the conditions were easier than others. Participants were then debriefed and thanked for their participation.

3. Results

Before statistical analysis of eye glance metrics could take place, post processing and glance metrics calculations had to be performed in the DLab software. First, the video recordings of pupil movements were manually corrected in cases where automatic pupil detection failed. Moreover, two Areas of Interest (AOIs) were defined; one covering both smartphone positions and one covering the forward roadway. These were then used in the calculation of relevant eye glance metrics - mean glance duration, total glance time, number of glances over 2s, and number of glances - per participant and condition. In addition, task duration was also recorded for each condition.

Eye glance metrics and task time were then submitted to separate 2x2x3x2 (Viewpoint x Display Position x Task x Repetition) - repeated measures Analyses of Variance (ANOVAs) with experience (truck license vs car license) as a between-groups factor.

3.1. Effects of task on glance measures and task duration

While the tasks used in the experiment are not the main focus of the current paper, we here separately report the effects of task on glance measures and task duration to verify whether or not they actually can be classified as being visually-manually simple or difficult (as per the task description in section 2.4).

A main effect of Task on Mean Glance Duration (MGD) was found: $F(1.51, 27.15) = 9.04$ ($p = .002$) (Greenhouse-Geisser corrected). Post-hoc tests, using Bonferroni's method to adjust for multiple comparisons showed that mainly Task 3 (Find truck dealer) caused this effect, and gave statistically significantly longer MGD than task 1 ($M = 1.66$ vs. $M = 1.39$, $p < .001$) and marginally significantly longer MGD than task 2 ($M = 1.54$, $p = .06$).

Moreover, a main effect of Task on Total Glance Time (TGT) was found: $F(2, 36) = 60.10$ ($p < .001$) (Sphericity assumed). Post-hoc tests showed that it was Task 1 (radio tuning) which caused this effect and resulted in significantly lower TGT than Task 2 and 3 ($M = 8.14$ vs. $M = 12.52$ and $M = 12.34$ respectively, $p < .001$).

There was also an effect of Task on Number of Glances longer than 2s (NoG2) $F(2, 36) = 15.22$ ($p < 0.001$), Sphericity assumed. Post-hoc tests showed that Task 1 (Tune radio) gave significantly fewer NoG2's than Task 2 and 3 ($M = 1.04$ vs $M = 1.70$ and $M = 1.89$ respectively, $p < .001$ and $p = 0.001$); however, there was no statistically significant difference between Task 2 and 3.

Furthermore, there was a main effect of Task on Number of Glances (NoG): $F(2, 36) = 24.31$ ($p < .001$) (Sphericity assumed). Post-hoc tests (Bonferroni corrected) indicated that Task 1 gave significantly lower NoG than Task 2 and 3 ($M = 6.76$ vs. $M = 10.14$ and $M = 9.12$, both $p < .001$). The difference between Task 2 and 3 was marginally significant ($p = 0.063$).

Finally, a main effect of Task on duration was found $F(2, 36) = 37.05$, $p < .000$ (Sphericity assumed). Bonferroni-adjusted post-hoc tests showed that Task 1 resulted in statistically significantly shorter duration than Task 2 and 3 ($M = 13.92$ vs. $M = 20.16$ and 18.87 respectively, both $p < .001$). The difference between Task 2 and 3 was not statistically significant ($p = .165$).

One can thus conclude that the tasks resulted in different glance measures and task duration, although Task 1 stands out as being the least difficult one and the other two are less different from each other.

3.2. Effects of View and Phone Position on eye glance metrics

A main effect of View on NoG2 was found, $F(1, 18) = 4.59$, $p = .046$. Truck view gave statistically significantly more NoG2's than the Car view ($M = 1.64$ vs. $M = 1.45$). Thus, H1 was partially corroborated.

Moreover, an interaction effect between View and Phone Position on MGD was found; *F*(1, 18) = 6.52, (*p* = .02), suggesting that lowering the phone in car view increased MGD, while lowering the phone in truck view decreased MGD (see Fig. 4 below). H2 could thus be seen as corroborated for the truck view conditions but not for the car view conditions.

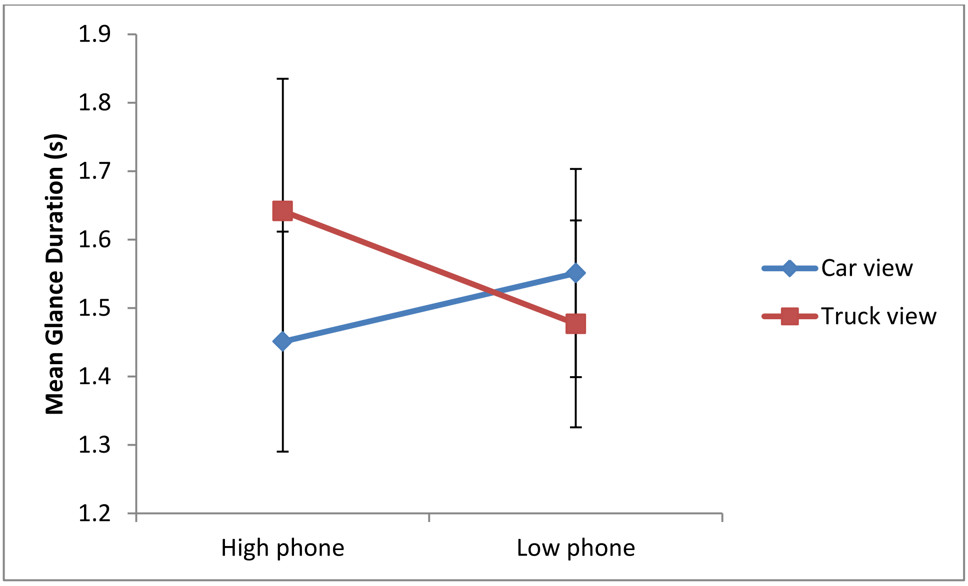

Fig. 4. *Interaction effect between View and Phone Position, MGD. Whiskers show standard error.*

Although there were no significant interaction effects between Task and View or Task and Phone position on any of the glance metrics, there was an interaction effect between Phone position and task on duration *F*(2, 36) = 5.35, *p*= .009 (Sphericity assumed). As shown in Fig. 5, this suggested that the more complicated tasks 2 and 3 where more affected by the phone position than the easier task 1; the more difficult tasks took longer time to complete in the Low phone conditions while the easy task did not. Thus, our hypothesis regarding task interaction effects was partially corroborated.

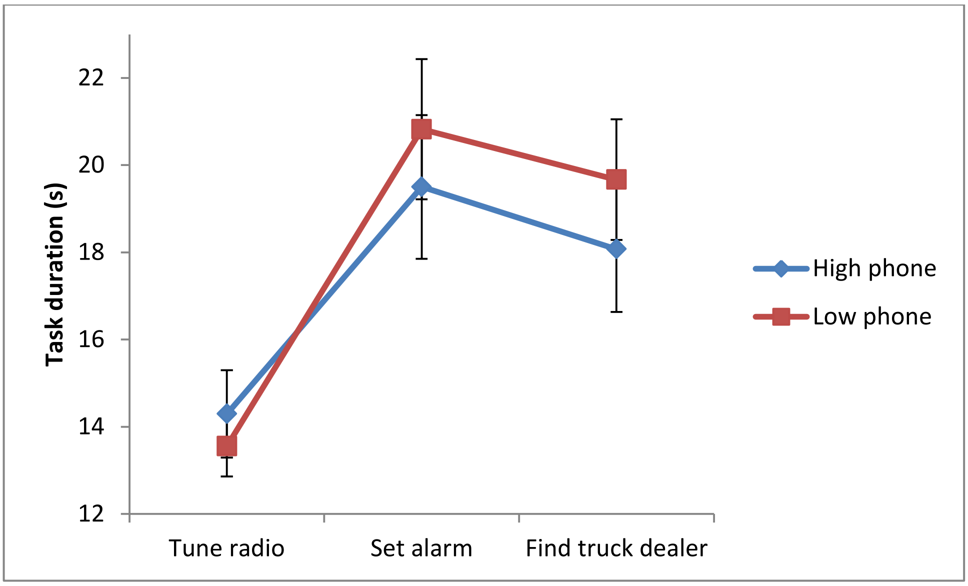

Fig. 5. *Interaction effect between Task and Phone Position on task duration. Whiskers show standard error.*

Outside the scope of the hypotheses, an interaction effect between View and Task on TGT was also observed; *F*(1.42, 25.49) = 6.48 (*p* = 0.010), Greenhouse-Geisser corrected. The interaction effect is shown in Fig. 3 and suggests that the Radio Tune task gave longer TGT in Truck View compared to Car View, and the Find Truck Dealer task gave shorter TGT in the Truck View compared to the Car View, while the Set Alarm task seemed to be unaffected by view.

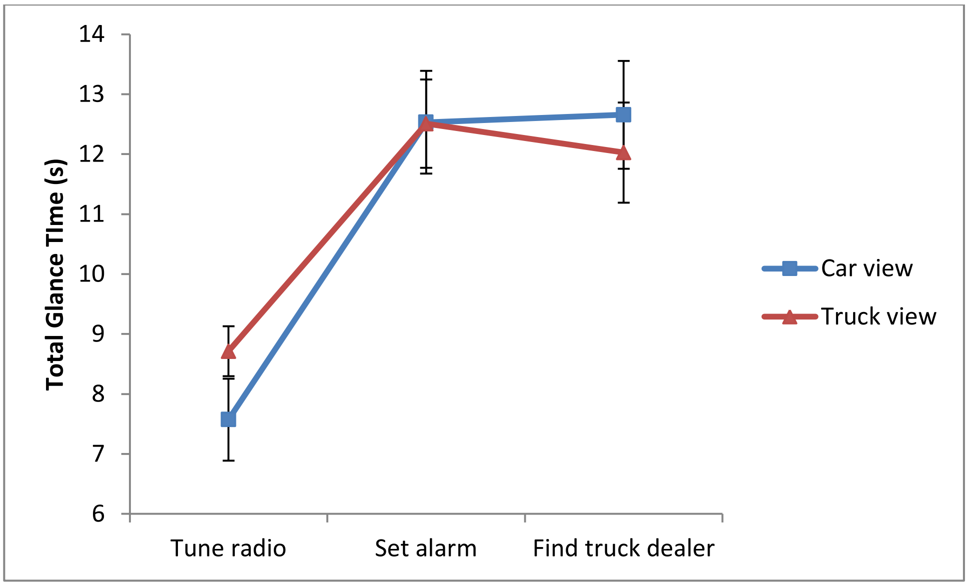

Fig. 3. *Interaction effect between View and Task on TGT. Whiskers show standard error.*

Finally, there was a main effect of Experience on TGT $F(1, 18) = 5.05$, $p = .037$. The experienced group (those who held truck driver licenses) had statistically significantly shorter TGT than the inexperienced group $M = 9.62$, $SE = 0.87$ vs. $M = 12.38$, $SE= 0.87$).

3.3. Subjective Metrics

Participant's self-assessment of their driving performance (on a scale 1-10 where 1= very bad to 10= very good) for each condition was submitted to a 2x2x3x2 (Viewpoint x Display Position x Task x Repetition) ANOVA.

First of all, there was an effect of Phone position on Subjective Driving Performance (SDP): $F(1, 22) = 4.40$, $p = 0.048$. The high phone position rendered higher Subjective Driving Performance than the low one ($M = 6.20$ vs. $M = 5.94$). Moreover, there was also an effect of Task on SDP: $F(1.37, 30.02) = 9.219$, $p = .002$ (Greenhouse-Geisser-corrected). As indicated by post-hoc tests, Task 1 (radio tuning) resulted in higher SDP scores than Task 2 and 3: $M = 6.41$ vs. $M = 6.03$ and $M = 5.77$, $p = .039$ and $p = .009$ respectively. The difference between Task 2 and 3 was not statistically significant ($p = .06$). There was also an interaction effect between View and Task on SDP: $F(2, 44) = 3.28$, $p = .047$ (sphericity assumed). This effect is visualized in Figure 6, and suggests that SDP decreases more with increasing task difficulty in the Car view condition compared to the Truck view condition.

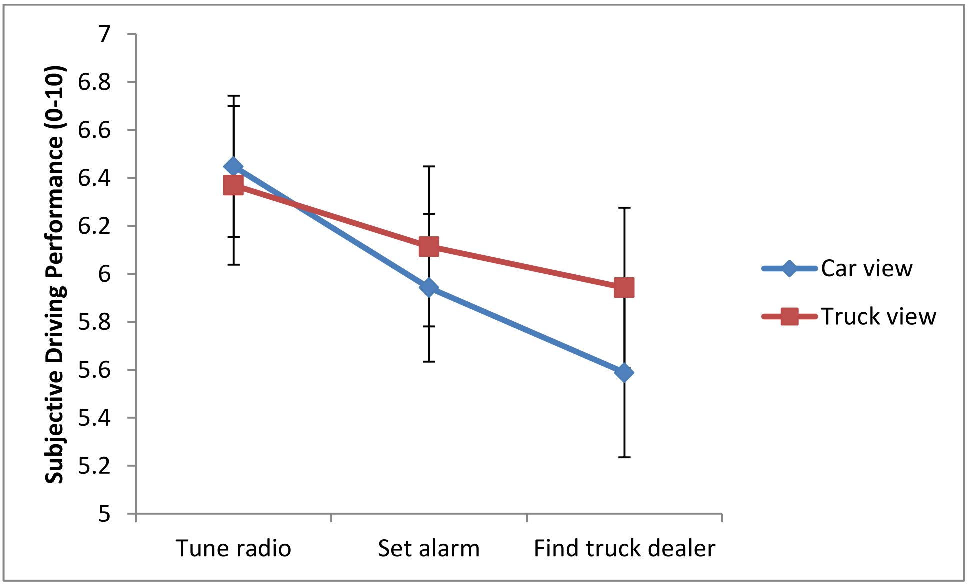

Fig 6. *Interaction between task and view on subjective driving performance. Whiskers show standard error.*

3.3.1 General impression & preferences: A majority (8 out of 11 in the experienced group and 7 out of 12 in the inexperienced group) of the participants thought that it was easier to drive and perform the tasks in the truck view conditions. The remaining participants did not have an opinion or thought there was no difference. Participants who thought the truck view was easier to drive with, thought it gave them better view over the traffic and a few also thought it was easier to keep the distance to other vehicles with this view. Thirteen participants thought that the high phone position was better than the low position, and four had a clear opinion of the lower position being the best one. The remaining nine participants had no clear opinion, but some noted that the lower felt more ergonomic and was easier to reach.

4. Discussion

The current study gave partial support to the initial hypotheses that type of road view and display position can influence the glance behaviour, and we have also shown that the subjective experience can be affected by these factors. Perhaps most interesting was the finding that the number of long (>2s) glances was higher in the truck view conditions compared to the car view conditions, which relates well to the findings by Tivesten & Dozza [8]. This could have been an effect of the participants feeling more comfortable with throwing longer glances on the phone in the truck view, also considering their self-reported sensation of having a better view of the surrounding traffic in this condition. Given the quite simple manipulation of view in the current simulator setup, one could expect that the difference must be bigger in real situations (especially also since the current simulator was rather basic with its 30 degree horizontal field-of-view). However, most importantly this result has serious implications for the specification of guidelines (such as NHTSA's, AAM's or JAMA's distraction guidelines [10-12]) that postulate glance measurement pass/fail criteria for in-vehicle interfaces. A very strict definition of the simulator scene and setup needs to be defined for the criteria to be valid and comparable, unless the tests are to be conducted in real conditions. Moreover, the results might suggest that pass/fail glance criteria used for passenger cars are not directly applicable to heavy trucks.

Hypothesis 2, which predicted that lower display position would lead to shorter glances, was not fully corroborated. However, the results suggested the presence of an interaction effect between view and display position from which one could assume that display position does have an effect on mean glance length but that the effect is dependent on how much of the forward roadway is within the driver's peripheral view when looking at the display.

As the current study indicated, not only the simulator view but also participants' experience could have an effect on glance behaviour; those with experience from driving trucks had shorter total glance time compared to participants with only car driving experience. This finding further indicates that guidelines carefully need to specify participants' driving experience including their specific experience with the vehicle class under study.

So far, we have only discussed the potential influences on glance measures per se, but not their related safety effects. While such an investigation would be out of the scope of this paper, one could speculate that although the truck view may give rise to more, longer glances than a car view, these glances may not be as safety critical since the truck driver anyway has a better overview of the traffic ahead. While this cannot be shown by the current study, it would be an interesting topic for a future exploration.

In sum, we have shown that, when measuring visual distraction from in-vehicle displays, the simulator view shown as well as the display position can affect glance measures. Thus, it is of great importance to keep this view and the setup constant when comparing the distraction from e.g. different display concepts. In addition, guidelines should carefully describe the type of simulator view to display during distraction testing of devices. Future studies could further explore whether similar effects also exist in real driving conditions and whether the relationship between glance measures and safety is different for vehicles of different classes.

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