Age-specific contact analogue head-up displays: Will they be accepted by older drivers?

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Abstract

Due to the current changes in the population’s age distribution and senior citizens’ mobility needs, an increasing number of older people are taking an active part in road traffic. One strategy to prevent their driving performance from being impaired by age-related cognitive, sensory, or motor changes might be to support them through driver assistance systems, especially by using new technologies like contact analogue head-up displays (HUDs). Because there is empirical evidence of age-specific acceptance barriers concerning new driver assistance technologies, we assessed the acceptance of an age-specific contact analogue HUD in a driving simulator experiment with 65 older (> 65 years) and 52 younger (25 – 45 years) drivers. Overall, both age groups showed a very positive attitude towards the system. Older drivers’ significant higher scores on different acceptance determinants confirm the potential of age-specific contact analogue HUDs to assist this driver group.

Keywords: Older drivers; acceptance; driver assistance systems; contact analogue head-up displays; augmented reality.

Résumé

En raison de développement actuel de la répartition par âge de la population et les besoins de mobilité des personnes âgées, un nombre croissant de personnes âgées prennent une part active dans le trafic routier. Une stratégie pour prévenir leur performance de conduite par des restrictions cognitives liées à l’âge, sensorielle, ou des changements de moteur pourrait être aussi de les soutenir à travers le système d’assistance au conducteur, en particulier par l’utilisation de nouvelles technologies telles que les affichages contacts analogiques, connue sous le nom contact analogue head-up displays (HUD). Parce qu’il existe des preuves empiriques des obstacles d’acceptation par âge concernant les nouvelles technologies d’assistance au conducteur, nous avons évalué l’acceptation d’un contact analogue spécifique de l’âge HUD dans une expérience de simulateur de conduite pour 65 conducteurs âgés (> 65 ans) et 52 conducteurs jeunes (25 - 45 ans). Généralement, les deux groupes d’âge ont montré une attitude très positive envers le système. Les estimations plus élevés des conducteurs âgés sur les différents déterminants de l’acceptation confirment le potentiel de contact analogue HUD pour aider ce groupe de conducteurs.

Mots clés: les conducteurs âgés; acceptation; système d’assistance au conducteur; HUD; la réalité augmentée.

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Introduction

1.1. Assistance of older drivers by augmented reality (AR)

The aging society as part of demographic change faces transportation research with new challenges. Especially the fast growing proportion of older people (aged 65 and over) within the population (European Commission, 2009) in combination with their rising need for autonomous mobility up to old age (Schlag & Megel, 2002) leads to an increasing number of high-aged road users. This development needs to be taken into account, because the aging process includes several changes in perception, cognition and motor functions (see Kaiser & Oswald, 2000 for a review) that can have a negative impact on driving performance and thus on traffic safety (Bayam, Liebowitz, & Agresti, 2005).

Even though older drivers are not more likely to make driving mistakes than younger drivers overall, this age-related changes lead to increased difficulties with specific driving task and situations. Most problems occur in complex, dynamic environments (Buld, Hoffmann, & Krüger, 2006) which contain a lot of information that need to be processed and responded in a limited time (Schlag, 2001). According to Kubitzki and Janitzek (2009), the largest difficulties of older drivers concern complying with priority regulations at intersections, followed by turning manoeuvres at intersections. Priority errors were also identified as the main reason for older drivers’ accidents by Clarke, Ward, Bartle, and Truman (2010). Those age-specific driving problems require new strategies to assist older drivers and thus support their mobility needs, taking into account safety of all road users.

One strategy to meet this requirement is to develop age-specific driver assistance systems, which is also addresses by the OECD that says “particular attention needs to be given to evaluating new technologies to ensure that older people can use it comfortably” (OECD, 2001, p. 12). The large amount of already existing systems does not necessarily present a support for older drivers, because they are not oriented toward age-specific assistance needs. Therefore, an age-appropriate design of automotive technologies is expected to improve the safety and driving comfort of older drivers (Eby & Molnar, 2012). Emerging technologies provide new possibilities to meet this demand.

One promising technical approach in this context is augmented reality (AR), which offers the projection of significant traffic information through the windscreen directly into the driver’s field of view via contact analogue head-up display (hereinafter referred to as augmented reality display, ARD). That gives the driver the visual impression that those information are part of the real car environment. This technology seems to have a high potential to assist especially older drivers (Färber, 2000), because it enables the compensation of several age-related declines in cognition, e.g. regarding selective and divided attention (Hahn, Wild-Wall, & Falkenstein, 2011), and perception, e.g. regarding range of accommodation (Cohen, 1994), speed of accommodation (Temme & Morris, 1989) or peripheral vision (Burg, 1968). Thus, presenting significant traffic information by superimposing the driver’s real view instead of providing an extra display could contribute not only to reduce the amount of glances away from the road ahead, like it is also done by conventional head-up displays (HUD), but also to facilitate switching attention between environment and displayed information. Additionally, this display structure allows for a very intuitive information design, which can be processed comparatively easily by the driver (Kim & Dey, 2009).

1.2. Acceptance of new technologies among older drivers

However, as promising innovative technologies like AR might be, older driver can only benefit from them if they are open-minded to use them. But there is empirical evidence of age-specific acceptance barriers concerning novel automotive technologies. Hence, older people show a lower willingness to use new in-vehicle information systems than younger people (Lerner, Singer, & Huey, 2008). One reason might be that the current older generation’s understanding of technique is strongly influenced by the mechanical and haptic character of the machines they grew up with. Thus, they have more reservations to use electronic systems with no or only restricted possibilities to influence their functionality (Jakobs, Lehn, & Ziefle, 2008). That assumption does not imply that older drivers refuse any kind of innovative driver assistance systems, but it places higher demands on the conceptualization and design of such systems in order to develop technologies that will be accepted and thus used by a fast growing group of drivers. Older peoples’ evaluation of technical devices depends strongly on their perceived usefulness (Jakobs et al., 2008). As Ziefle, Pappachan, Jakobs, Christen, and Wallentowitz (2007) could show based on the example of display size, this usefulness rating in turn is affected by design aspects. Musselwhite and Haddad (2007) stated older drivers to be willing to accept in-vehicle technologies that
help their driving. The subjects in this study assessed beside other systems a dashboard sign display to be useful for distinguishing between important and unimportant road signs. With the help of an ARD, such a system would be more user-friendly than displaying road sign-information in the dashboard, which again may cause a higher rate of acceptance (Musselwhite & Haddad, 2007) because it addressed ergonomic design needs of older people (Pauzie, 2003).

Considering these aspects, an ARD is expected to be well-accepted among older drivers, if designed according to their preferences. Because it is important to survey this assumption prior to a system’s development to guarantee the integration of users’ requirements in the design process, this issue is addressed in this paper.

1.3. Evaluation of an age-specific augmented reality-display (ARD)

To investigate the potential of the AR technology to assist older drivers from their own perspective, we composed an ARD whose content and design correspond to the assistant needs of the target group. Based on the findings on problematic driving situations, we choose urban intersections as use case for the system, because they contain the most difficult traffic conditions for older drivers. One beneficial function of an age-specific ARD in this context is to inform about the priority regulation of an upcoming intersection. This gives the driver the opportunity to perceive and process one important part of a complex traffic situation even before he reaches the situation itself, giving him more time to prepare for the traffic conditions ahead. Following the findings on age-related changes in perception and cognition, we decided to present the priority information within the driver’s direct field of view by projecting the respective traffic sign in the middle of the road right in front of the car, while it is moving towards an intersection (see fig. 1).

Fig. 1. Simulated augmented reality display in the driving scenario 150 m in front of an intersection where the driver has (a) the right of way or (b) to yield right of way.

Because intersections are comparatively difficult traffic situations for road users of all ages, a benefit from using such an ARD can be expected for younger drivers, too. But due to the negative image of automotive technology especially designed for older drivers (Färber, 2000), it is unclear if they would be willing to use such a system, at all. For this reason, the acceptance of an age-specific ARD amongst younger drivers was also investigated in this study to derive implications of the technology’s application possibilities.

One possible disadvantage of an ARD could be a higher difficulty for the driver to ignore the displayed information if he wishes or needs to, because it is presented in his direct field of view instead of a separate display. This can be problematic in complex traffic situations (like intersections), where supplementary information are more likely to be demanding rather than supporting (Falkenstein & Poschadel, 2008), which should lead to a reduced acceptance. This particularly applies to older drivers because of their difficulties with multitasking situations and divided attention (Färber, 2000). Taking this into account, we composed two alternative ARDs with different display durations. In this case, display duration determined whether the ARD remained activated until the driver started to cross the intersection, providing additional information in the complex intersection situation itself, or if it was deactivated half way between the point of activation and the intersection itself. We investigated the impact of display duration as an example of information design on the acceptance of the ARD in both age groups.

Taking into account all these factors, the objective of this paper is to present older drivers’ acceptance data concerning two design variants of an age-specific ARD in comparison to younger drivers’ acceptance data.
2. Method

2.1. Experimental design

Participants experienced the age-specific ARD during a driving simulator experiment using a 2x3-between-subject-design. To investigate age-specific effects of drivers’ acceptance, the experiment was conducted with older (65-80 years) and younger (25-45 years) drivers. Participants of both age groups were distributed to three groups with different ARD conditions (experimental group 1: short ARD duration, experimental group 2: long ARD duration, control group: no ARD).

2.2. Participants

One hundred and twenty participants took part in the experiment. All of them had successfully completed a separate training session before, which was conducted to familiarize them with the driving simulator and to reduce the occurrence of simulator sickness. However, three of them could not complete the experiment because of minor simulator sickness symptoms, leading to a final sample of 117 persons in total. Sixty-five of them (three female, 62 male) belonged to the older group with a mean age of 70.5 years (SD = 4.9) and a mean driving experience of 48.9 years (SD = 6.8). The 52 participants in the younger group (21 female, 31 male) had a mean age of 29.2 years (SD = 5.3) and a mean driving experience of 11.0 years (SD = 5.2). Table 1 shows the distribution of the sample to the different experimental conditions.

Table 1. Size and mean age of the experimental subgroups

<table>
<thead>
<tr>
<th>ARD condition</th>
<th>Younger drivers</th>
<th>Older drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>$M_{age}$</td>
</tr>
<tr>
<td>No ARD (control group)</td>
<td>18</td>
<td>28.7</td>
</tr>
<tr>
<td>ARD_short (experimental group 1)</td>
<td>15</td>
<td>28.7</td>
</tr>
<tr>
<td>ARD_long (experimental group 2)</td>
<td>19</td>
<td>30.0</td>
</tr>
<tr>
<td>Total</td>
<td>52</td>
<td>29.2</td>
</tr>
</tbody>
</table>

2.3. Apparatus and driving scenario

All drives were performed in a fixed-base driving simulator consisting of an Audi shell with a fully equipped interior and an automatic gearbox. A 180° field of view was realized by projecting the driving scenarios on three 2.5-meter screens with the help of three LCD-projectors with a resolution of 1650 x 1050 pixels.

We created the driving scenarios using the SILAB simulation software. For the test drive, a rural track with a total length of about 8950 m was simulated, including 13 intersections which differed in priority regulation, course of the lanes and traffic density. Among other regular elements, each intersection contained a direction sign, helping the participants to follow their instructions to drive towards the city of Chemnitz.

For the two experimental groups, we additionally simulated the ARD which informed the driver about the priority regulation of each upcoming intersection by projecting the respective traffic sign contact analogue on the road in front of the car (see fig. 1). The ARD was activated 150 m in front of every intersection. In experimental group 2 (long ARD duration), the ARD was presented until the beginning of the intersection, while in experimental group 1 (short ARD duration) it was deactivated 75 m in front of the intersection.

2.4. Assessment of drivers’ acceptance

Drivers’ acceptance in terms of attitudes towards the age-specific ARD was assessed via Van der Laan acceptance scale (Van der Laan, Heino, & De Waard, 1997), which consists of nine bipolar five-point rating-scale items. The scale was presented after the test drive to both experimental groups and the control group as well to get a comparison between drivers’ evaluations of the ARD with versus without system experience. Members of the control group were introduced to the ARD in the acceptance questionnaire by explaining its functionality in written and showing figure 1.

To obtain additional information on different determinants of drivers’ acceptance beyond attitudes, we also applied our own German adaption of the Unified Theory of Acceptance and Use of Technology (UTAUT) questionnaire by Venkatesh, Morris, Davis, and Davis (2003). This instrument was established to assess the
expected use behaviour regarding a new technology considering the *behavioural intention to use the system* and facilitating conditions. The behavioural intention itself is affected by three direct determinants (*performance expectancy, effort expectancy, social influence*) and three indirect determinants (*attitude toward using the technology, self-efficacy, anxiety*), according to Venkatesh et al. (2003). Altogether, the questionnaire consists of 31 seven-point agreement-scale items. Because it mainly addresses information systems in a working context, we adjusted the wording of the items to the driving context during the translation process, if necessary. The UTAUT questionnaire was only applied to the two experimental groups.

2.5. Procedure

Initially, all suitors took part in a separate driving simulator-training. In this context, demographic data were collected via questionnaire. Everyone who did not show any simulator sickness symptoms during or after this training session was invited to the experiment.

At the beginning of the experimental session, participants signed an informed consent form. After a ten-minute familiarization drive, participants completed the test drive with either the help of the short ARD (experimental group 1), the long ARD (experimental group 2) or without any ARD at all (control group). Afterwards, they filled in the acceptance questionnaire in either a short (for the control group) or long version (for the two experimental groups). Overall, the experimental session took about 90 minutes. Participants received 30 € for their attendance.

3. Results

3.1. Van der Laan acceptance scale

According to an analysis of its factorial structure, we aggregated the nine items of the Van der Laan acceptance scale to one dimension, which showed a high reliability (Cronbach’s α = .93). Thus, scores for this dimension were computed for each experimental subgroup. Figure 2 shows the mean values of the Van der Laan acceptance scale in all three ARD conditions, separated by age group.

![Figure 2: Van der Laan acceptance scores compared between three augmented reality display (ARD) conditions and two age groups. Higher values indicate a better drivers’ evaluation.](image)

Generally, driver’s evaluation of the age-specific ARD achieved positive values in all ARD conditions and age groups. Concerning age differences of driver’s acceptance, figure 2 reveals that all ARD conditions were rated slightly higher by older than by younger drivers. This age effect was significant according to the results of a two-factorial (age, ARD condition) ANOVA, $F(1, 107) = 4.04, p = .047, \eta^2_p = .04$. 
Even though a visual comparison of the three ARD-groups shows that the two experimental conditions with actual system experience produced slightly higher values than the control condition in both age groups and the short duration ARD received better evaluations than the long duration ARD by older drivers, a two-factorial ANOVA did not produce any significant differences between the three ARD conditions, $F(2, 107) = 1.26, p = .289$, $\eta^2_p = .02$, as well as no significant interactions between ARD condition and drivers’ age, $F(2, 107) = .60, p = .552$, $\eta^2_p = .01$.

3.2. UTAUT questionnaire

All but one subscales of the UTAUT questionnaire showed sufficiently high reliability values (Cronbach’s $\alpha$ differed between .69 and .93). Reliability of the facilitating conditions scale was too low (Cronbach’s $\alpha = .34$), but could be improved substantial (Cronbach’s $\alpha = .50$) by excluding one of the four associated items. The excluded item was the only one with a negative wording throughout the questionnaire, probably leading to vagueness in answering it on an agreement-scale. Figure 3 shows the mean scores of all eight subscales in both experimental groups, separated by age group.

![Figure 3. Subscale scores of the UTAUT questionnaire compared between three augmented reality-display (ARD) conditions and two age groups. I = direct determinants of system usage, II = direct determinants of the behavioural intention to use the system, III = indirect determinants of the behavioural intention to use the system. Values of the anxiety scale were inverted so that higher values indicate a better drivers’ evaluation on every scale.](image)

As can be seen in figure 3, both experimental as well as both age groups produced high ratings on the behavioural intention to use scale and the facilitating conditions scale, which are both directly linked to actual system usage, according to the model. Interestingly, older drivers reported a higher intention to use the ARD, even though they rated the facilitating conditions slightly lower than younger drivers. These general high ratings on those two scales correspond with for the most part positive values on the direct and indirect determinants of the behavioural intention to use the ARD in both experimental and age groups. Mean values for performance expectancy, social influence and attitude towards using technology were higher for older drivers in both ARD conditions. Mean values for effort expectancy, self-efficacy and anxiety showed a contrarian tendency concerning drivers’ age. Relating to ARD duration, driver’s evaluations of both age groups show almost no differences. Mean values of all but two (social influence, self-efficacy) scales are merely slightly higher for the short ARD duration in both age groups.
A two-factorial (age, ARD condition) MANOVA with the eight UTAUT subscales as dependent variables verified a highly significant age effect in the drivers’ evaluation of the ARD, Pillai’s trace criterion = .36, $F$ (8, 66) = 4.69, $p < .001$, $\eta^2_p = .36$. Correspondent post-hoc-tests (see table 2) confirmed the described age effects regarding the behavioural intention to use the ARD and facilitating conditions to be midsized and significant. Also the higher ratings of older drivers on performance expectancy and attitude toward using the system as well as their lower ratings on self-efficacy appeared to be significant. There were no significant age affects found for the remaining three scales, indicating a likewise positive ARD evaluation of older and younger drivers on these aspects.

The described preference tendencies towards the short duration-ARD appeared not to be significant according to the results of the two-factorial MANOVA, Pillai’s trace criterion = .06, $F$ (8, 66) = .56, $p = .810$, $\eta^2_p = .06$. There was also no significant interaction between drivers’ age and ARD duration, Pillai’s trace criterion = .02, $F$ (8, 66) = .18, $p = .993$, $\eta^2_p = .02$.

<table>
<thead>
<tr>
<th>UTAUT scale</th>
<th>Younger drivers</th>
<th>Older drivers</th>
<th>$F$</th>
<th>$df$</th>
<th>$p$</th>
<th>$\eta^2_p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Behavioral intention to use the system</td>
<td>4.87</td>
<td>5.66</td>
<td>5.000</td>
<td>1</td>
<td>.028</td>
<td>.064</td>
</tr>
<tr>
<td>Facilitating conditions</td>
<td>5.80</td>
<td>5.31</td>
<td>7.003</td>
<td>1</td>
<td>.010</td>
<td>.088</td>
</tr>
<tr>
<td>Anxiety</td>
<td>5.34</td>
<td>5.28</td>
<td>.271</td>
<td>1</td>
<td>.604</td>
<td>.004</td>
</tr>
<tr>
<td>Self-efficacy</td>
<td>4.64</td>
<td>3.93</td>
<td>4.944</td>
<td>1</td>
<td>.029</td>
<td>.063</td>
</tr>
<tr>
<td>Attitude toward using technology</td>
<td>4.45</td>
<td>5.26</td>
<td>6.751</td>
<td>1</td>
<td>.011</td>
<td>.085</td>
</tr>
<tr>
<td>Social influence</td>
<td>3.85</td>
<td>4.26</td>
<td>2.397</td>
<td>1</td>
<td>.126</td>
<td>.032</td>
</tr>
<tr>
<td>Effort expectancy</td>
<td>6.37</td>
<td>6.11</td>
<td>2.153</td>
<td>1</td>
<td>.147</td>
<td>.029</td>
</tr>
<tr>
<td>Performance expectancy</td>
<td>4.51</td>
<td>5.59</td>
<td>11.863</td>
<td>1</td>
<td>.001</td>
<td>.140</td>
</tr>
</tbody>
</table>

Note. Mean values of the anxiety scale were inverted, so that higher values indicate a better drivers’ evaluation on every scale.

4. Discussion and conclusions

Aim of this study was to assess the acceptance of an ARD as an example of emerging driver assistance technologies among older drivers, who could benefit from those technologies. To maximise this potential benefit, content and design of the examined ARD were adapted to the specific requirements of the target group. Besides, this system could assist younger drivers as well in a main hazard spot, namely intersections, thus their acceptance was also assessed in this study.

In summary, the evaluation of the ARD was very positive, both among older drivers, who tend to be cautious about new technologies (Lerner et al., 2008), and younger drivers, even though there was a risk of a negative system image, because it was specifically designed for older drivers. This could be shown on the basis of drivers’ consistently positive acceptance ratings indicated by de Van der Laan acceptance scale independent of actual system experience and duration of ARD activation. This general impression was confirmed by the drivers’ ratings on the UTAUT scales which were in a large part very high as well.

Older drivers’ attitudes towards the age-specific were slightly higher than younger drivers’ once, indicated by a significant age effect regarding the Van der Laan acceptance ratings. This impression was strengthened by the results of the UTAUT questionnaire (see table 2). Especially older drivers’ higher attitude towards using the system turned out to be significant. A further significant age effect was produced by drivers’ performance expectancy, indicating that older drivers believe more strongly that their driving performance will benefit from using the ARD.

Consistent with the age effects produced by its determinants, the behavioural intention to use the system, which is one of the questionnaire’s two scales directly linked to actual system usage (Venkatesh et al., 2003), appeared to be significantly higher for older than younger drivers as well. Those results approve that the age-specific ARD matched the assistance requirements of its target group. With their high ratings, older drivers confirmed the supposed benefit of the AR technology from their subjective perspective. Their higher behavioural intention to
use the system is even more meaningful considering their significant lower rating on the second direct determinant of actual system usage, facilitating conditions. As this scale deals with external conditions other than the system itself that could support its usage, this result emphasizes the fit between the ARD and the target group, since older drivers are more open-minded to use the system than younger drivers even though they feel less facilitated by their environment in doing so.

Interestingly, older drivers only showed a significant lower rating than younger drivers regarding that determinant of the behavioural intention to use the system that includes not only the evaluation of the ARD’s characteristics, but also of their own competences in using it, namely self-efficacy. Thus, answering this scale could be affected by their insecurity concerning complex traffic situations in urban environment, as those are experienced as difficult by older drivers (Kaiser & Oswald, 2000).

Concerning the different ARD conditions, the study could not reveal any significant differences or interactions with drivers’ age. The comparison of the Van der Laan acceptance scale ratings of the two experimental groups that tested the ARD in the driving simulator and the control group that was introduced to the system only via written explanation showed that the actual system experience had no effect on drivers’ attitude. Members of both age groups evaluated the system concept itself in a positive manner. This was not significantly reduced or increased by experiencing its function on the simulated test track.

The comparison of the two different ARD durations revealed no significant effects, as well, indicated by Van der Laan acceptance scale and UTAUT questionnaire. This is comprehensible, as none of the two ARD versions was throughout poorly designed. It was only presumed that the short duration would fit older drivers’ assistance requirements slightly better, because it provides additional information solely in advance of an intersection, but not in this complex situation itself. This assumption was confirmed by the results at least rudimentary, since all drivers’ ratings were slightly higher for the short ARD duration. It is conceivable that the comparison between a well and a poor designed ARD would produce significant differences in acceptance. Thus, the orientation of the system development towards older drivers’ needs regarding not only ARD content, but also design aspects is recommended.

Summing up, the general apprehension of older drivers not using a beneficial driver assistance system because of their reservations about new technologies could not be confirmed in the case of a target group-specific system design. Additionally, this study shows the chance that such a system will not be refused by other drivers who could also (albeit to a lesser degree) benefit from its usage. Existing acceptance differences between different age groups could potentially be balanced by an adaptive ARD design allowing for the adjustment of its functionality to individual user differences. Of course, assessing users’ acceptance is not sufficient to evaluate a system, but since it is a necessary condition of actual system usage, a substantial potential of age-specific ARD to assist older (and younger) drivers to improve their driving performance and sustain their independent mobility can be assumed based on this study.

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References


