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Investigation of the Influence of Sensors for Automated Driving on the Perception of Exterior Design

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ABSTRACT

Automated driving requires a large number of sensors to detect the environment. Many of these sensors have to fulfil requirements regarding position and functional installation space, which creates a conflict of objectives between aesthetically appealing and functional integration into the design. In addition, the perception of the sensors by vehicle users and other road users could favour the recognition of an automated vehicle (AV). Numerous studies showed the importance of semantic aspects in a vehicle's exterior. Therefore, in this paper the preconditioning of the user in relation to the degree of integration and colouring of sensors on a concept AV in an eye-tracking study in investigated. It could be shown that the appearance of the sensors on the vehicle have an influence on perceived safety and, more importantly, vehicle appeal. This will provide designers and engineers with insights into the design of sensor clusters in the exterior design of future vehicles.

Keywords: Exterior design, Transportation design, Trust in automation, Sensor integration, Human-vehicle-interaction

OBJECTIVE AND SIGNIFICANCE

The introduction of vehicles with automated driving functions requires a comprehensive sensing of the environment by the vehicle and the interpretation of its influences on the driving task. Therefore actuators, sensors and control software play an important role in the realisation of safety and automation functions. In this paper, the focus is on sensors. They "replace" the senses of humans in highly automated vehicles. Many of these sensors have to fulfil requirements regarding position and functional installation space. This creates a conflict of objectives between aesthetically appealing integration into the design and functional integration into trim parts or an aerodynamic concept. Vehicle manufacturers and suppliers are increasingly showing concept vehicles for this purpose. The design-technology convergence fundamentally follows two strategies for the aesthetic integration of sensors into the exterior design. Fischer et al. (2021) derive an additive and an integrative strategy from known concepts and prototypes via a position analysis of the sensors. So far, it is unclear which strategy is favoured by the industry and designers. The investigation of effects on the perception of the population in traffic through the perception of sensors could support the selection of the strategy.

In real traffic, small, non-verbal nuances such as gestures, facial expressions or eye contact often determine the following behaviour and perception of the participants (Carmona et al., 2021). From SAE level 4 (SAE International, 01-2014) onwards, the person in the driver's seat no longer necessarily makes the decision about driving behaviour, so that this communication channel to the outside is no longer given. Numerous studies showed the fundamental importance of a vehicle's exterior, especially with regard to the various semantic aspects on human emotions and behaviour. In particular, distinctiveness and differentiation from other products, expression of function and features, fashion and trends, and branding influence the visual appearance of a product (Ranscombe et al., 2012). According to Mandel et al. (2015), the user of a vehicle absorbs various information about the vehicle through the visual perception of the exterior design before interacting with it. For example, the shape of the basic body and individual exterior elements convey specific information to the viewer, for example about seating or cargo volume. By comparing knowledge and experience with other vehicles, the first impression is formed and thus also an initial comfort assessment (Mandel et al., 2015). Knowledge of the exterior also supports the driver in performing the driving task, e.g., in estimating distances around the vehicle or all-round visibility (Mandel, 2019). Furthermore, it could be shown that the exterior design has an influence on the driving style of the user (cf. Reichelt et al., 2020) and the brand affiliation recognition (Fischer et al., 2020). Contours and surfaces influence the brand affiliation of vehicles. Thus, vehicle faces also have an influence on the emotions of the viewer (Fischer et al., 2020). The size of the vehicle can also influence the decision to cross a road when the car arrives (Dey et al., 2017). The influence of exterior design on users' emotions before using a vehicle is therefore described as visual preconditioning. Recent studies have examined the influence of so-called external HMIs (eHMI) on the perception of an AV. Although the studies usually focus on the communication itself, it could be shown that the presence of an eHMI already has a positive influence on the acceptance of the users (cf. Bazilinskyy et al., 2019; Burns et al., 2019; Joisten et al., 2021). Preconditioning can therefore also be observed here. Studies on the influence of more or less exposed sensors for automated driving on the perception of users or pedestrians are unknown.

Therefore, in this paper the preconditioning of the user in relation to sensor configurations for automated driving is considered. For this purpose, configurations differing in the degree of integration and colour are applied to a concept car and examined in an eye-tracking study with regard to their influence on the perception of passengers and other road users. The three main research questions considered were: 1. Do sensors on AVs have an influence on system trust, the perception of safety or the judgement of appeal? 2. Does the subgestalt (Seeger, 2005) of colour have an influence on system trust, the perception of safety and the judgement of appeal? 3. Does the degree of integration shown in the positioning of sensors on the AV have an influence on system trust, the perception of safety and the judgement of appeal? Answering those questions will provide designers and engineers with insights into the design of sensor clusters in the exterior design of future vehicles.

METHODS

For the assessment of the sensor concepts, an eye-tracking study with two separate parts was designed. This article presents the research on the perception of sensor technology, another article will go into more detail on connections with eHMI. In the study, the test persons were sequentially shown renderings in 3/4 front and 3/4 rear perspective of a concept car with different sensor configurations on the screen.

The vehicle exterior was developed in the RUMBA research project and corresponds to the expected body for a highly automated vehicle. Due to the high space requirements of the comfortably seated to reclining occupants, the result is a large wheelbase, a high vehicle roof and a van-like IC body with an integrated, rising front and a cubically terminated rear (Holder, 2016). The relevant sensor configurations are based on the previously mentioned study in which Fischer et al. (2021) derived integration strategies for sensors. The stimulus patterns differ specifically in the subgestalt of shape (position and degree of integration), shape and colour. The stimulus patterns are (c.f. Figure 1):

1. RMS1 (sensors invisible): Concept 1 deliberately shows no sensors to create a similarity to known vehicles. This maximally integrative design also serves as a baseline.
2. RMS2 (sensors visible, kept in car colour): Standard sensor configuration where the immediately adjacent vehicle colour is applied to the brackets and sensor trim to create a more harmonious image.
3. RMS3 (sensors visible in black areas): Sensors behind black glass or plastic trim. This, the most common type of design used in previous concepts, corresponds to the current state of development of the concept vehicle.
4. RMS4 (sensors visible, trim parts in a contrasting colour): Further variation of the partial design colour with the same sensor configuration.
5. RMS5 (sensors visible and deliberately shown exposed): The stimulus pattern follows the additive strategy (Fischer et al., 2021) of sensor integration and thus follows concepts such as the Waymo Jaguar (Waymo LLC, 2018) or Mercedes-Benz ESF 2019 (Mercedes Benz Group Media, 2019).

Inside a within-subject-design the test persons evaluated each of the stimulus patterns by means of a questionnaire with regard to their subjective impression in predefined use cases "*crossing the street as a pedestrian*" and "*getting into the vehicle and being driven home*". The use cases provide a fictitious context that the participants were asked to imagine for the evaluation. The questionnaire in this part of the study has a total of 12 items that are rated after each stimulus pattern on a six-point Likert scale (agree strongly = 6 to disagree strongly = 1). To evaluate trust in automation adjusted items from the TiA questionnaire according to Körber (2018) and items from Ekman (2020) are used. The selection was made according to whether the items are meaningful when looking at an external product design. The perception of safety was evaluated with items following Arndt (2010), Salonen (2018) and Bazilinskyy et al. (2019). The judgement of appeal was assessed according to Holder (2016) and additional self-developed items. The stimulus patterns were shown randomly to each test person to minimise sequence effects. The time for looking at the vehicle was limited to 20 seconds to take viewing times in real traffic into account. With a Tobii-eye-tracking system absolute dwell time, relative dwell time and fixation were recorded. Fixation was evaluated.

Figure 1: Stimulus patterns of future vehicle presented to test persons.

RESULTS

This section presents the results of the study on the perception of sensors on AVs. First, the participants collective is presented. This is followed by the interpretation of the eye-tracking data and statistical evaluation of the questionnaire.

Participants

Overall 36 participants – 15 female and 21 male – completed the study (cf. Figure 2). The participants' age spans from 18 to 65 years representing a young technically orientated sample around the University of Stuttgart.

After the main study the participants were asked about some psychographic characteristics (cf. Figure 3). Three questions aimed at the general trust of the participants towards automated systems. Most test persons are rather cautious about the subject. Moreover most participants are interested in vehicle design. When asked about their experience with automated vehicles, the participants answered that they had seen such vehicles before, but that they had very little experience with automated systems themselves.

In two final open questions, the test persons were asked about positive and negative conspicuous features of the vehicles. In the context of the sensors, the

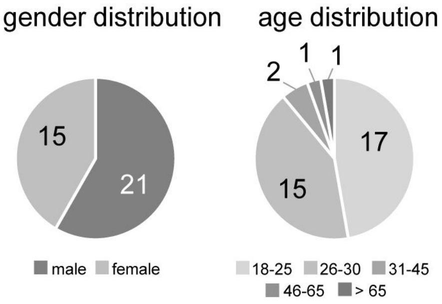

Figure 2: Age and gender distribution of participants sample.

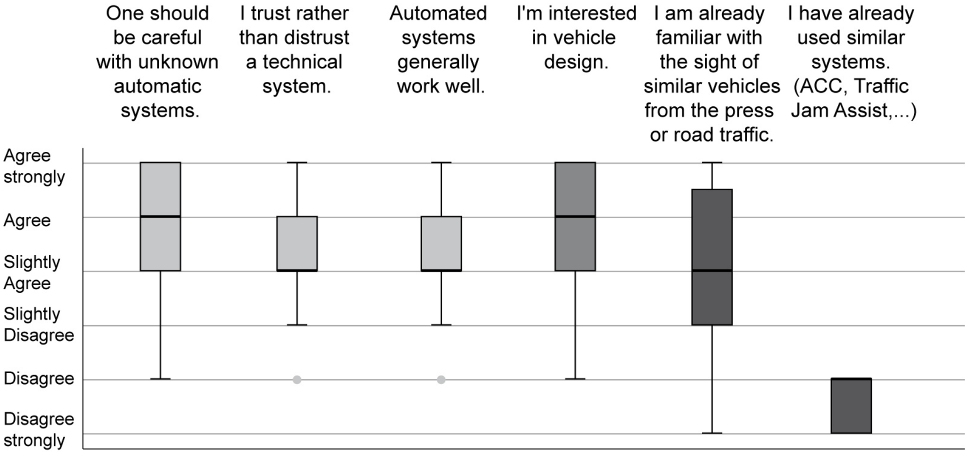

Figure 3: Survey results towards psychographic characteristics of the participants.

orange colour in particular was mentioned positively as an additional safety feature (14 mentions). In addition, the sensors instead of the outside mirrors were mentioned positively. Other positive mentions related to the shape of the headlights. The protruding components in particular were described as negative (10 mentions) and especially the roof rack (6 mentions). The transition between the door and the side window as well as the orange colour scheme were also criticised (5 mentions each).

EVALUATION

The evaluation of the eye-tracking data had a high error rate. Of the 36 test persons, only 19 data sets could be used to create the heat maps (c.f. Figure 4).

The evaluation of the heat maps shows typical gaze clusters at headlights, rims, window line and the known position of the driver's seat across all images, but especially at RMS1. This is fundamentally consistent with an eye-tracking study of the vehicle body, which shows gaze concentrations in the front oblique view in the area of the windows, mirrors and headlights, and in the rear oblique view in the area of the tail lights and side windows (c.f. (Holder, 2016)). Despite this, the gaze concentrations of the front sensors are clear and especially the gaze concentrations in the oblique front view in

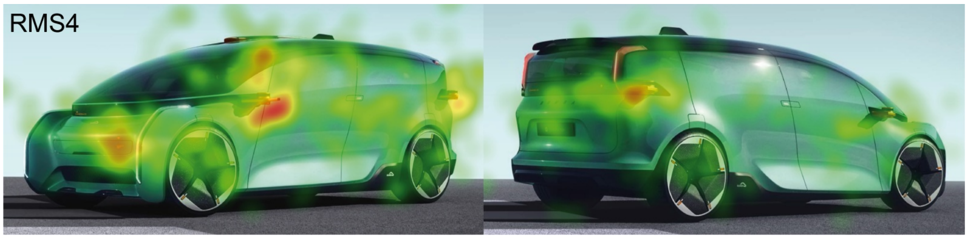

Figure 4: Example for areas of interest from the eye-tracking data presented via heat maps.

the area of the rear sensors deviates from comparable results (Holder, 2016) and shows that the unusual and exposed shape of the sensors was perceived by the subjects. The figures for RMS2 - 5 clearly show that the test persons also noticed the sensors. In particular, the sensors on the 'corners' of the vehicles were fixed. The roof rack (RMS5) also attracted attention. In general, it is noticeable that the front perspective was looked at much more intensively than the rear representations of the vehicles.

The following boxplots show the statistical evaluation of the questionnaire with regard to the subjective perception of the different vehicles and the resulting evaluation of trust, perception of safety in the assumed situations and appeal of the vehicle.

Figure 5 shows that there is a certain level of trust in the vehicles. The ratings are positive, but a repeated measures ANOVA and Huynh Field correction (HF) shows no significant differences between the stimulus patterns (Question 1: F(3.644, 8.756) = 2.616, p = 0.045, partial η^2 = 0.070) and (Question 2: F(2.411, 43.989) = 1.918, p = 0.111, partial η^2 = 0.052)). However, the comparison in pairs shows a slight tendency between RMS1 and RMS5. The vehicle with the roof rack seems to be a little more trusting.

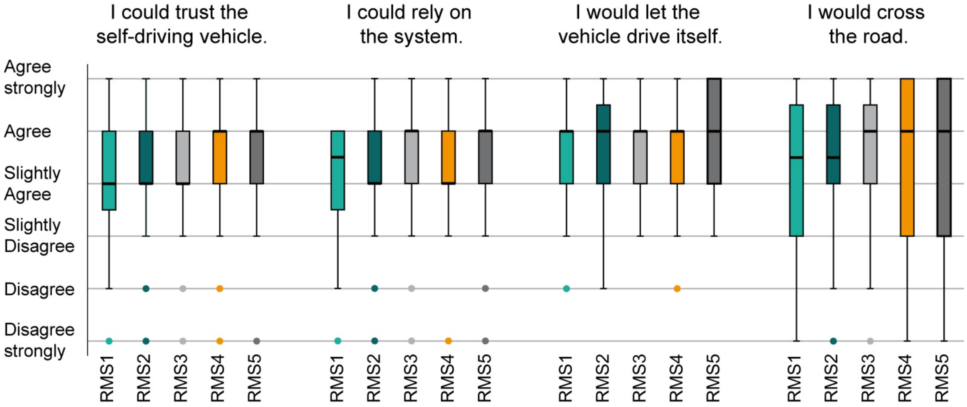

Figure 5: Survey results towards trust in automation as box plots.

Figure 6 shows the results of the assessments of the perception of safety. An analysis of variance with repeated measures and HF correction (sphericity assumed: Mauchly-W(2) = 0.591, p = 0.041, HF = 0.905) shows a significant difference between the vehicles regarding the *perceived safety standards*

(F(8.967, 70.233) = 4.468, p = 0.003, partial η^2 = 0.113). A Bonferroni-corrected comparison in pairs show that RMS1 without sensory equipment was rated significantly lower than RMS5 with a roof rack (M_{Diff} = – 0.694, p = 0.009, 95% CI[−1.265, −0.124]). No difference can be seen with regard to the other stimulus patterns. The effect size f according to Cohen (2013) is f = 0.379 and corresponds to a medium effect.

The ANOVA with repeated measures and HF correction (sphericity assumed: Mauchly-W(2) = 0.510, p = 0.008, HF = 0.846) also shows that a difference in ratings exists between stimulus patterns when *interacting with vehicles* (F(7.856, 66.944) = 4.107, p = 0.006, partial η^2 = 0.105). Bonferroni-corrected comparison in pairs show that RMS3 and RMS5 were rated significantly safer compared to the vehicle without sensors (RMS1_3: M_{Diff} = 0.583, p = 0.002, 95%-CI[.163, 1.003] and RMS1_5: M_{Diff} = 0.528, p = 0.040, 95%-CI[0.015, 1.041]). Between RMS1 and RMS4 a slight tendency can be observed. The effect size f according to Cohen (2013) is f = 0.362 and corresponds to a medium effect.

The evaluation of question three with an analysis of variance with repeated measures and HF correction (sphericity assumed: Mauchly-W(2) = 0.699, p = 0.219) shows differences in ratings regarding *the management of critical traffic situations* between vehicles (F(10.311, 55.289) = 6.527, p < 0.001, partial η^2 = 0.157). Bonferroni-corrected comparison in pairs show that RMS5 makes a significantly better impression regarding the management of traffic situations than RMS1, RMS2 and RMS3 (RMS1_5: M_{Diff} = 0.722, p = 0.001, 95%-CI[0.251, 1.194] and RMS2_5: M_{Diff} = 0.389, p = 0.044, 95%-CI[0.006, 0.772] and RMS3_5: M_{Diff} = 0.500, p = 0.003, 95%-CI[0.132, 0.868]). The effect size f according to Cohen (2013) is f = 0.379 and corresponds to a large effect. The evaluation of the risk of being involved in an accident with the vehicle was generally assessed as low.

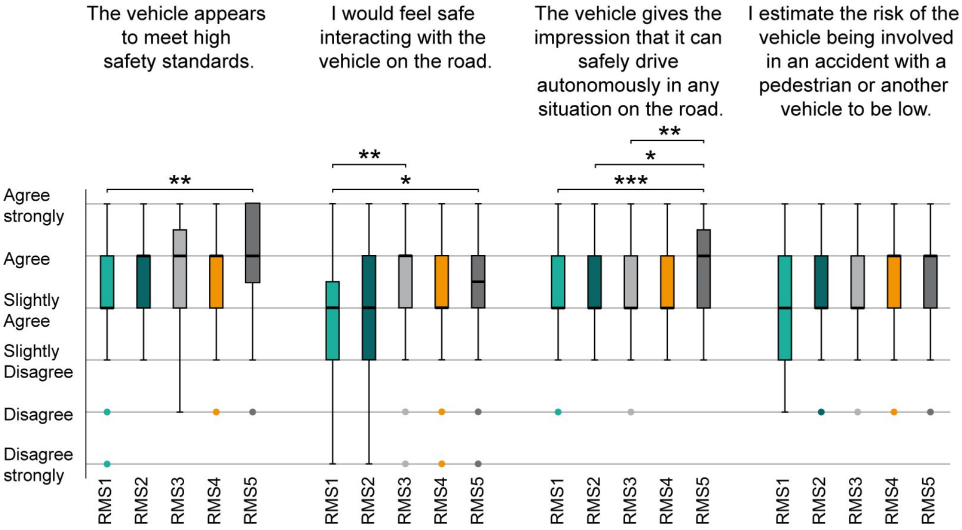

Figure 6: Survey results towards perception of safety as box plots with significances.

As expected, the subjects' evaluation of appeal varied greatly (c. f. Figure 7). An repeated measures ANOVA with HF correction (sphericity assumed: Mauchly-W(2) = 0.644, p = 0.100) shows that subjects tend to like a vehicle without sensors better (F(16.756, 145.644) = 4.027, p = 0.004, partial $\eta^2 = 0.103$). Bonferroni-corrected comparison in pairs show that RMS1 is rated significantly better than RMS5 (M = 3.333, SD = 1.171) ($M_{\text{Diff}} = 0.944$, p = 0.012, 95% CI[0.144, 1.745]). A slight tendency can also be observed between RMS2 and RMS5. The effect size f according to Cohen (2013) is f = 0.360 and corresponds to a medium effect.

The vehicle without sensors is also evaluated as *being more coherent* (ANOVA with repeated measures and HF correction: (sphericity assumed: Mauchly-W(2) = 0.573, p = 0.029, HF = 888) F(24.189, 130.211) = 6.502, $p < 0.001$, partial $\eta^2 = 0.157$). Bonferroni-corrected comparison in pairs show that RMS1 scored significantly better than RMS2, RMS4 and RMS5 (RMS1_2: $M_{\text{Diff}} = 0.472$, p = 0.048, 95%-CI[0.002, 0.942] and RMS1_4: $M_{\text{Diff}} = 0.833$, p = 0.014, 95%-CI[0.112, 1.554] and RMS1_5: $M_{\text{Diff}} = 1.083$, p = 0.003, 95%-CI[0.270, 1.896]). The effect size f according to Cohen (2013) is f = 0.470 and corresponds to a large effect.

Questions two and three are aimed at the perception of the degree of integration of the sensor system in the vehicle. As expected, ANOVA with repeated measures and HF correction for both questions clearly shows that there are differences between the stimulus patterns related to the sensor design.

(ANOVA question 2 (sphericity assumed: Mauchly-W(2) = 0.737, p = 0.335): F(70.689, 139.711) = 17.709, $p < 0.001$, partial $\eta^2 = 0.336$ and ANOVA question 3: F(13.089, 160.911) = 2.847, p = 0.026, partial $\eta^2 = 0.075$). Bonferroni-corrected comparison in pairs for question two show strongly significant ($p < 0.001$) differences in the ratings of the vehicles with sensors RMS2 to 5 compared to the vehicle without sensors displayed as RMS1 *appearing to be made of one piece*.

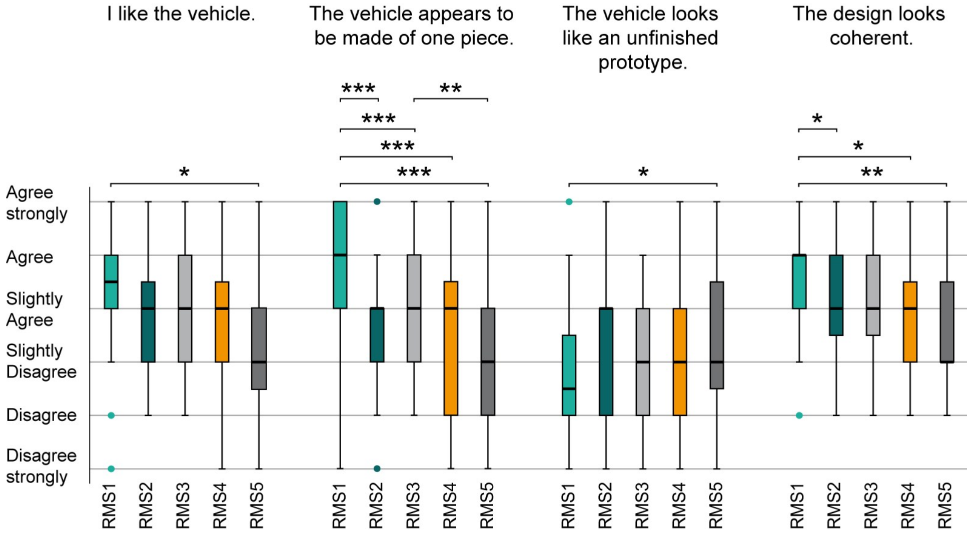

Figure 7: Survey results towards appeal as box plots with significances.

In addition, RMS3 and RMS5 show a significant difference. It can be concluded from this that the more highlighted the sensor configuration, the less pleasing the vehicle appears. The effect size f according to Cohen (2013) is $f = .379$ and corresponds to a large effect. Question three focuses on how *close to series production* the vehicle appears and shows that the degree of integration can, however, be assessed as rather high overall. On average, none of the vehicles was rated as an unfinished prototype. A Bonferroni-corrected comparison in pairs shows that RMS1 is considered less of a prototype than RMS5 ($M_{Diff} = -0.667$, $p = 0.011$, 95%-CI[0.−1.227, −0.107]. The effect size f according to Cohen (2013) is $f = 0.296$ and corresponds to a medium effect.

Finally, a Chi^2 test was conducted to answer the research questions of whether the degree of integration or the colour of the sensors correlate with the evaluation of trust, safety perception and appeal.

The degree of sensor integration is represented by the three stimulus patterns RMS1, RMS3 and RMS5. It has no significant influence on the ratings of the questions regarding trust in the vehicle (question 1: $\chi^2(10) = 7.728$, $p = 0.655$ and question 2: $\chi^2(10) = 5.683$, $p = 0.841$). No correlation with the degree of sensor integration could be determined for the evaluation of the feeling of safety either (question 1: $\chi^2(10) = 9.432$, $p = 0.492$; question 2: $\chi^2(10) = 5.877$, $p = 0.825$; question 3: $\chi^2(8) = 12.614$, $p = 0.841$; question 4: $\chi^2(8) = 4.048$, $p = 0.853$). The significances of the stimulus patterns among each other could therefore not be confirmed. It is not possible to draw conclusions from the evaluation of the feeling of safety alone to the degree integration of the sensors with this study.

As already shown in the evaluation of the questions about appeal, a significant correlation between the degree of integration of the sensors and the appeal could be found (question 1: $\chi^2(10) = 19.180$, $p = 0.038$; question 2: $\chi^2(10) = 43.291$, $p < 0.001$; question 3: $\chi^2(10) = 12.429$, $p = 0.257$; question 4: $\chi^2(8) = 19.744$, $p = 0.011$). A general correlation between appeal and the degree of integration of the sensors could thus be demonstrated. The more extensive and conspicuous the sensors, the less the subjects liked the vehicle.

The influence of colour on the subjects' ratings was examined with the stimulus patterns RMS2, RMS3 and RMS4. These only differ in the colour design of the sensors, but not in the degree of sensor integration. Here, too, it was shown that the colour had no significant influence on the trust shown towards the vehicle (question 1: $\chi^2(10) = 2.389$, $p = 0.992$ and question 2: $\chi^2(10) = 5.439$, $p = 0.860$). Furthermore, no correlation could be found between colour and perceived safety ratings (question 1: $\chi^2(8) = 5.489$, $p = 0.704$; question 2: $\chi^2(10) = 2.849$, $p = 0.985$; question 3: $\chi^2(8) = 3.590$, $p = 0.892$; question 4: $\chi^2(8) = 3.840$, $p = 0.871$). The Chi^2 test also showed no significant correlation between the ratings of appeal and colour design (question 1: $\chi^2(10) = 5.900$, $p = 0.824$; question 4: $\chi^2(8) = 3.768$, $p = 0.877$). For the orange colour, which is often highlighted as positive in the open questions, no correlation to trust, perception of safety or appeal could be proven here.

DISCUSSION

Overall, the statistical evaluation of the questionnaire shows differences in the ratings for safety perception and appeal between the stimulus patterns, but no firm conclusions can be drawn about the degree of integration of the sensors or the colour design. Only the expected, more negative evaluation of appeal of vehicles with additive sensor technology could be clearly shown. The visible sensory system does not seem to be a salient feature for the stimulus patterns shown. High ratings (Agree strongly = 6) are rarely achieved.

With regard to the significance of the results, however, the low immersion underlying the study setting should be viewed critically. Despite a very high level of detail, the vehicles show some characteristics of a concept car, e.g., very large rims. This polarisation of the design might have led to an inconclusiveness in the evaluations. The vehicle should therefore be designed more realistically. The chosen observation time tends to be too long in the context of real traffic. However, a short preliminary test with shorter and longer viewing times showed that below 20 seconds it is hardly possible to make an assessment about the unfamiliar design. In order to improve immersion, a dynamic presentation of the stimulus patterns, ideally with real vehicles or virtual reality at a real crossing, would be helpful. In addition, the sample, which is rather young here, should be enlarged and adjusted to a higher age average. For the interpretation of the gaze concentrations, it must be taken into account that areas of the vehicle can be perceived and evaluated through the peripheral vision of humans without these being demonstrably focused (cf. Reid et al., 2013; Holder, 2016). The interpretation of the heat maps is therefore difficult.

CONCLUSION AND OUTLOOK

This paper presents an eye-tracking study to investigate the influence of visible sensors on trust in AVs, safety perception and appeal of AVs. Five stimulus patterns differ specifically in the subgestalt of shape (position and degree of integration), shape and colour. Areas of interest were derived from the eye-tracking data via heat maps. They confirmed that the test persons notice the sensors even with a short viewing time. The statistical evaluation of the results has shown that the sensors have a minor influence on trust in the vehicle but have an influence on the perception of safety of the users. In particular, for the configuration without visible sensors and additively integrated sensors, significant differences emerged. As expected, there was a high degree of dispersion in the opinion towards appeal of the design on the users. It has been shown that a low level of integration of the sensors in the vehicle body has a significant negative influence on the vehicle's appeal. Therefore research question one can be largely confirmed. An influence of the colour of the sensory system could not be statistically proven and therefore cannot be answered positively. The influence of the degree of integration of sensors was possible for the appeal of the automated vehicles. It can be deduced that a high degree of integration of sensors is to be preferred. The more accurate understanding of the perception of the degree of integration of sensors into the exterior design can support the work of designers by giving them the freedom to realise more innovative designs in their design proposals compared to previous vehicles.

It remains to be clarified, whether visible sensors can increase the trust and safety in dynamic traffic. Particularly interesting could be the view out of one's own vehicle and thereby possibly compensate for a negative appeal. System trust and safety perception therefore could be investigated in an extended virtual reality test design with a variety of other relevant use cases such as: "oncoming AV at right-before-left intersection". Also the influence of time and the associated habituation factor must be considered. Furthermore, it should be investigated whether there are interactions with eHMI and sensors on AVs. Extending the investigations to much larger vehicles, especially trucks or robotic vehicles according to SAE Level 5 (SAE International, 01-2014) without passengers could also show interesting results.

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