HMI for anticipation of upcoming curvature in automated lateral control

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***Abstract*— Driving Automation Systems conduct the driving task to a partial or even full extent. HMI concepts that support the understanding and predictability of the system's behaviour may be beneficial for the safe and efficient use of such systems. We investigated HMI concepts indicating the predicted curvature of the road section in two consecutive studies. The research questions were: How do drivers perceive curvy roads? What do drivers expect from a visual HMI concept indicating the upcoming curvature during driving with automated lateral control?**

Using a Wizard-of-Oz set-up, two on-road studies were conducted on rural roads and highways in Germany. In the first study, N=24 drivers evaluated the curvature of the experienced road sections on a visual-numeric rating scale. The results showed a strong correlation between lateral acceleration in the curve and the curve ratings. A possible explanation might be that drivers take into account not only the visual perception of the curve geometry but also the perceived lateral acceleration.

A second study was conducted with the same Wizard-of-Oz vehicle setting. Another N=24 drivers evaluated different HMI concepts for automated vehicles that depict upcoming curvature. We used two experimental methods: First, the drivers influenced the curve images in the HMI display themselves using a mechanical slider. Second, the drivers experienced a dynamic display indicating upcoming curvature based on two different parameterisations. The display either used the radius of the curve ("geometry" concept), or it indicated curvature based on the lateral acceleration in the vertex of the curve ("acceleration" concept). Each condition was experienced twice with different driving speeds. The participants evaluated the appropriateness of each display for presenting the upcoming curvature. The results showed that drivers preferred the geometric concept and used the manual slider according to the geometric appearance of the curvature, independent of diving speed. We discuss the results in both studies based on the characteristics of the curves. Overall, the results of the study allow for conclusions on a human factors based parameterisation of a visual feedback system for automated lateral control.

Keywords—*curvature, automated driving, HMI, anticipation.*

I. Introduction

Based on the definition of the SAE [1], in Level 1 (L1) or Level 2 (L2) automation, the system takes over lateral or longitudinal control, or automates both, respectively. However, L1 and L2 automation require that the driver supervises the automated control. In case a system limit is reached or the system fails to interpret or react correctly in a situation, the driver has to take back control immediately [2]. To fulfil this task, it may be beneficial to provide relevant information on the system's performance level via the Human Machine Interface (HMI) to support the driver with the supervisory task [3]. For example, it has been shown repeatedly that drivers are able to compensate system failures of L2 automated driving functions when take-over requests are provided at system limits or malfunctions [3, 4, 5]. However, L2 automation may also require that the driver intervenes and overrides the automation without being requested to do so [6]. In these cases, it may be beneficial to provide the driver the possibility to identify in the HMI whether the L2 automation works reliably (see [7] for an overview).

In systems that take over lateral vehicle control, this could be achieved by presenting upcoming curvature detected by the L2 automation. This gives the driver the possibility to compare the system's situation analysis with the real environment. In case of a mismatch, the driver is then able to react appropriately by taking back the steering control.

Researchers have investigated different HMI concepts supporting drivers in the task of supervising the system. For example, van den Beukel et al. [3] presented an illumination concept to guide the driver's attention towards the direction of a potential hazard. Large et al. [8] followed a more general approach and used a "health bar" to indicate the automated vehicle's reliability level. A similar approach has been used by Helldin et al. [9]. Beller et al. [10] presented a visual icon showing a face with an uncertainty expression and hand gestures. Naujoks et al. [5] presented a visual HMI for L2 automation that contained separate reliability indicators for lateral and longitudinal vehicle control with three reliability levels (green: normal active state, yellow: uncertain state, red: system limit).

The presented HMI approaches are not specific to our use case at hand. To support the drivers effectively with supervising the lateral vehicle control of the L2 automation, it might be necessary to provide HMI elements that are specific to the lateral vehicle dynamics. Additionally, a drawback of the HMI concepts in previous studies is that they mostly build on the automated vehicles' situation analysis and assessment of its own driving capabilities. We expect that most challenging for drivers are those situations in which the automation misses to indicate failures or limits in its capabilities. Following this, the HMI concept investigated in the current studies aims at allowing the drivers to compare the automated vehicle's predicted path directly with the current driving situation and by that, evaluate the reliability of the system.

In production vehicles, car manufactures have presented visual HMI concepts representing lateral vehicle dynamics. For example, the TESLA Model S uses a depiction of the road geometry in the main driver display indicating the upcoming curvature in relation to the ego vehicle [6]. It is, however, unclear if and how drivers make use of the presented information.

Besides the challenging question of an appropriate graphical design of a display, there is the question of how to present curvature information that can be intuitively understood and matches the drivers' mental model of how the automation works. Different approaches are conceivable. First, the visual display could show the upcoming curvature based on the geographic characteristics of the road. This implies that the HMI display reflects the actual curve angles. Second, a visual display could show the upcoming curvature based on lateral acceleration perceived when driving through the curve (which can be estimated by the radius and the driving speed). This means that depending on the expected driving speed, the same curve with the same radius would result in different visualisations in the display.

In order to determine which of the two concepts matches drivers' perception best, we conducted two on-road studies. We investigated how drivers rate upcoming curvature and what they expect from a visual HMI display that is designed to inform about the curvature detected by the sensor system of a L2 automated driving system. The first study focused on the drivers' perception of curvature without any HMI display. In the second study, we integrated the results of the first study in the HMI display and measured drivers' evaluations of different HMI concepts based on different parameterisations.

II. Study 1: Evauation of curvature

The first study focused on the participants' perception of curves and expectations on a possible display and did not use any HMI display. We investigated which curve characteristics influenced drivers perception of the curve and if feedback in a hypothetical HMI display was desired.

A. Methods

a) Participants

N=24 (13 female) participants took part in the study. Their mean age was 38.8 years (SD = 10.6). They were recruited from the WIVW (Würzburg Center for Traffic Sciences) GmbH driver panel and received a gratification for their participation.

b) Apparatus and materials

We built up a Wizard-of-Oz real vehicle setting. A right-hand drive Opel Insignia Sports Tourer was driven by a trained driver. Participants sat on the left passenger seat in order to assure their usual drivers' view of the road scene in Germany. The participants' view of the steering wheel and actions of the trained driver was obscured by using a hat with covers on the right side (Fig. 1). The hat was used in order to support the impression that the participants were driving in a L2 automated vehicle while the vehicle was actually under full manual control by the trained driver.

Fig. 1. Participant position in the right-hand drive vehicle wearing a hat obscuring the view to the driver.

The trained driver of the vehicle used the Adaptive Cruise Control (ACC) for realizing a previously defined speed profile. Other than that, no driver assistance or automation feature was used. The vehicle was equipped with Controller Area Network (CAN) recorders to record driving data.

For the subjective ratings of the curves, participants used a seven-point bipolar scale including three curvature levels for left and right curves and a middle category for straight sections (Fig. 2). The pictures used on the scale were abstract visualisations of the strength of curves and no detailed depictions of the real road. The scale also provided the option to select a curvy section category, in case a simple classification was not possible (e.g. when differently shaped curves followed each other in quick order).

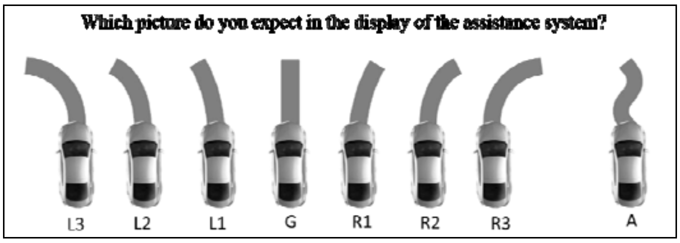

Fig. 2 Rating scale to evaluate the curvature. "L1-L3" indicated left curves, "R1-R3" indicated right curves, "G" indicated a straight section. "A" indicated a curvy section.

a) Instructions and procedure

Participants were instructed to rate defined scenarios in the test track. They were asked to imagine being drivers of a L2 automated vehicle, which needs to be supervised all the time. The cover story included that the experimenter, who actually drove the vehicle, was only present to supervise the L2 automated system.

Further, we instructed that the system might make detection failures or driving errors. Therefore, a visual display indicating the upcoming curves could support the participants in their task of supervising. The participants were asked to imagine a display in front of them where the usual instrument cluster would be positioned. The task during the drive was to express whenever they would use such a feedback display to verify that the system detected the curve correctly and to rate what image they would expect to be shown in the situation.

When approaching a curve, an acoustic signal (“gong”) indicated the start of a scenario. After this start gong, the participants pressed a button positioned at the passenger seat to indicate if and when they would look at the feedback display. After pressing the button, they were asked to indicate the strength of the curvature they would expect a system to display in the approach of the curve by using the rating scale depicted in Fig. 2. Drivers rated the curvature again after passing through the curve (indicated by another gong). The post-ratings were introduced in order to identify potential differences between ratings that were given when approaching the curve and ratings that were given after passing through the curve. The first evaluation of the curve only took place in case the participants had pressed the button during the approach. The post-rating of the curve took place after every scenario.

Fig. 3 visualises the procedure.

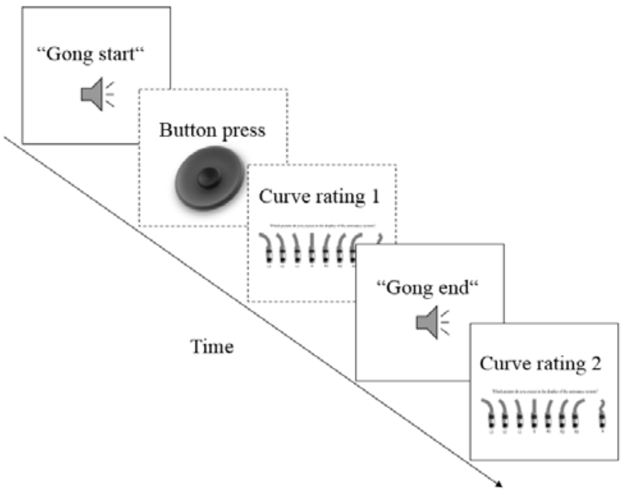

Fig. 3 Schematic depiction of the procedure of a single scenario. The dotted boxes indicate that these parts only occurred in case the drivers actually pressed the button.

Following the instructions, the procedure included a ten minute familiarisation drive. The main test drive took about one hour. Afterwards, the experimenter explained the cover story and the participants received their gratification.

b) Test course

The test course consisted of a rural and a motorway section. Motorway scenarios included entrances and exits. Overall, 29 curves with different radii and environmental conditions were included. The rural section always proceeded the motorway section. The separation into evaluation sections was GPS based; therefore the acoustic signals marking the start and the end of the sections were triggered via GPS position.

c) Study design

The two main research questions of the first study were:

- When would drivers like to verify if the L2 automation system detected a curve correctly?
- Which schematic HMI picture would drivers expect to be displayed by the system in the situations in which they would check the display, i.e. how do drivers perceive the curves?

For the analysis, we defined the vertex of the curves by visual inspection and extracted the lateral acceleration recorded in the vertex. As dependent variables we analysed the percentage of participants who pressed the button as well as the ratings on the 7-point rating scale (Fig. 2).

B. Results

a) Button presses

The button presses indicated the desire to receive feedback by an assistance display showing the curvature that the system has detected. Fig. 4 shows the percentage of participants pressing the button when approaching the scenarios separated for all 29 curves.

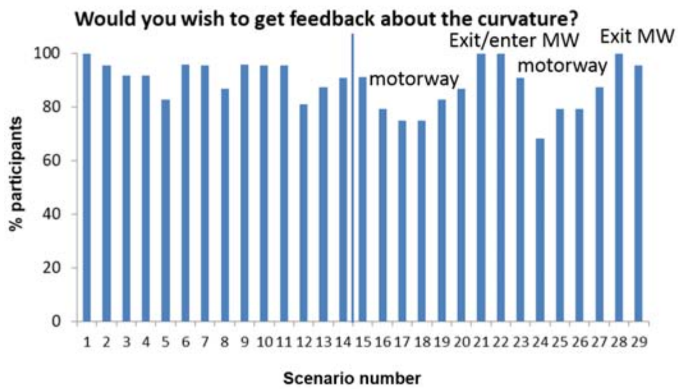

Fig. 4. Percentage of participants pressing the button when approaching each of the 29 curve scenarios. Scenarios 1-14 took place on the rural road, scenarios 15-29 were motorway scenarios.

In most scenarios, the majority of drivers indicated the desire to receive information on the upcoming curvature from the assistance display. Curves number 16-20 and 24-27 represented wide motorway curves. For these curves, slightly less drivers pressed the button to indicate their desire for information in the display.

b) Strength of the curvature

We analysed the consistency between the curve ratings before and after passing through the curve. Fig. 5 shows the curve ratings on a scale from 0 to 3, whereby ratings for left and right curves were merged into a single-polar scale. Selections of the category “curvy section” were excluded from this analysis. The graph shows that the ratings before and after passing through the curve are mostly consistent. The two exceptions were curves 4 and 14. Both scenarios included curves on a rural road with bad visibility, which might be responsible for the change in the rating category after experiencing the full scenario.

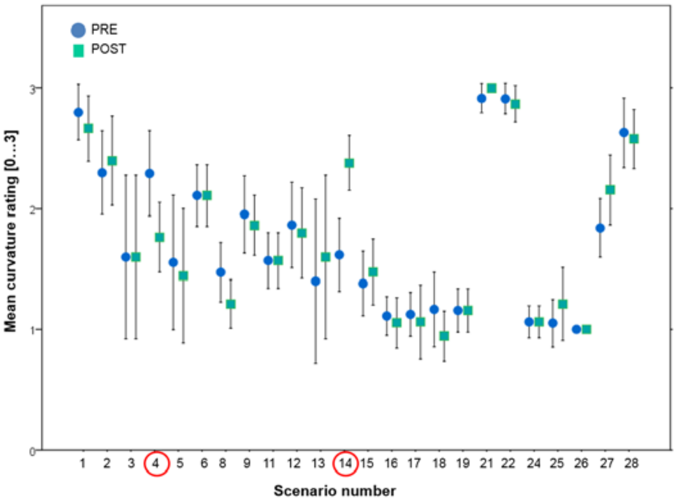

Fig. 5 Curvature ratings before (pre) and after (post) passing through the curve. The red circles indicate the two curves in which the pre- and the post-ratings of the curvature differed. Scenario 29 was excluded from this graph as this section was defined as curvy sections by almost all of the drivers.

Additionally, we analysed the correlation between the lateral acceleration in the vertex of the curves and the strength of the curve that drivers expected in the display. Because of the high accordance between pre- and post-ratings, the analysis only included the post ratings of the curvature. Fig. 6 shows the correlation between lateral acceleration and perceived strength of the curve mapped to the single-polar scale from 0 to 3. The graph depicts a strong positive correlation (r=.805) between lateral acceleration and subjective curve ratings.

C. Conclusions and discussion

Study 1 showed that when being driven by a L2 system, only in a small percentage of curves drivers did not want to receive feedback about the upcoming curvature. The possibility for a feedback display that supports the supervision of the L2 system was well accepted. There was a tendency that less drivers would want to get information from an assistance display in very broad motorway curves. It can be assumed that these curves were so wide that some drivers did not even perceive them as curves and therefore would not expect any indication in the assistance display.

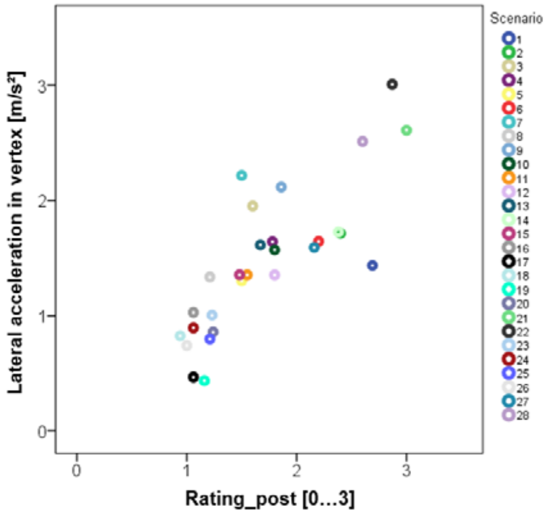

Fig. 6 Correlation between lateral acceleration in the turning point and subjective evaluation of the strength of the curve at the end of each scenario. Scenario 29 was excluded from this graph as this section was defined as curvy sections by almost all of the drivers.

Nevertheless, we carefully interpret the positive attitude towards the display in the light of the possibility that drivers might in general evaluate displays and isolated visual information as positive in the experimental setting. Additionally, the participants might have felt compelled to give a rating after the gong indicated the start of a scenario.

More interestingly, it is possible that drivers judged curvature according to the experienced lateral acceleration. Due to the observation that the pre- and post-ratings did not differ (for curves with normal visibility conditions), it might even be that drivers judge the curvature according to the expected lateral acceleration when approaching the curve. Hence, in addition to the visual appearance of the curve geometry, drivers could integrate the driving speed in their perception and rating of the curves. A conclusion might be that an assistance display should depict curvature based on lateral acceleration. However, the data in study 1 did not allow to investigate separately the relation of driver judgments with lateral acceleration or radius, i.e. the geometry of the curve. Without this distinction, we cannot finally conclude on the underlying concept for the participants’ evaluation of curvature.

III. Study 2: Evaluation of dynamic display concepts

To examine the assumption on the logic of the curvature display, a second on-road study was conducted. A dynamic predictive curvature display was installed in the Wizard-Of-Oz setting. Two methodological approaches were used for the evaluation of the display. First, a mechanical slider set up allowed drivers to control the images of curves on an assistance display according to their own perception of the curvature. Second, we presented two different dynamic concepts for a curvature display, which were continuously evaluated by the participants during the drives. One used geometry based parameters, i.e. the display represented the radius of the upcoming curve. The alternative concept used the strength of the lateral acceleration in the vertex of the upcoming curve for the representations in the display.

A. Methods

a) Participants

24 participants (12 female) took part in the study. Their mean age was 40.5 years (SD=12.9). They were recruited from the WIVW GmbH driver panel and received a gratification for their participation.

b) Apparatus and materials

The test vehicle in the second study was the same as in the first study. Again, a trained driver followed the pre-defined driving profile by means of the ACC system and the view of the participants was obscured using the special hat described in study one (see Fig. 1). Additional to the set up in the first study, we installed a 7“ TFT LCD display in front of the participants at the left passenger seat that showed the predictive curvature feedback. The animations consisted of 13 different pictures for each curve direction (i.e. left and right) assuring a dynamic appearance when transitioning between positions (Fig. 7).

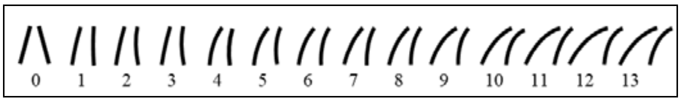

Fig. 7 Schematic depiction of the assistant display indicating the anticipated curve bending to the right. Picture “0” represented a straight section. The sharpest curve in the track was matched to picture “13” in the respective direction. The same stimulus material was mirrored to the left for left curves.

For the drives in which the participants manually controlled the display (see study design), we developed a slider set up (Fig. 8). The participants positioned the set up on their legs. For moving the curve display to the right or left they moved the slider along a predefined path in horizontal direction. Moving the slider away from the middle position increased the bending of the curvature shown in the display (i.e. increased the number of the image depicted when referring to Fig. 7).

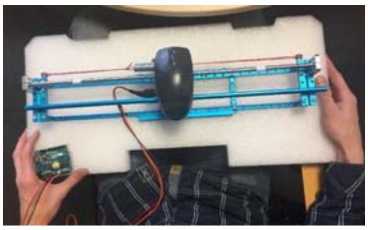

Fig. 8 Slider setup for dynamically controlling the curve depiction in the display. Participants moved the slider along the blue frame. The middle position was haptically emphasised by a resistor.

For the second part of the study, the display dynamically visualised the predictive curvature feedback of the simulated L2 system without the participants input. The vehicle we used was a prototype vehicle in which the actual functionality of the predictive display was not available. Therefore, we triggered the start of the curve animations by GPS positions. Different pre-defined animations were displayed for the different curves in the track and different driving speeds. Curves below 200 m radius were defined as using picture 13 as a maximum. A straight section was defined with a curve radius of larger than 2000 m. We estimated the radii based on GPS data recoded by an external GPS device, because the vehicle was not equipped with map or sensor data providing a real feature functionality. Based on this, we interpolated between the maximum and the minimum radius and mapped the 1-13 pictures to the curve animations equidistantly. The same procedure was repeated for the lateral acceleration set up, which was calculated based on the estimated radius and the expected driving speed. The maximum lateral acceleration that could occur in the test track was defined as using picture 13 in the display.

For the evaluation of display concepts, we used the acceptance scale of [12], which allows analysing the dimensions “usefulness” and “satisfaction”. For the situation specific evaluation we used a 16-point verbal-numeric scale from 0 (not at all) to 15 (very strong; Fig. 9).

Gar nicht	Sehr wenig			Wenig			Mittel			Stark			Sehr stark		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Fig. 9 Verbal-numeric scale for the situation specific evaluation of suitability of the display. Verbal categories were “not at all”, “very little”, “little”, “medium”, “strong”, and “very strong”.

c) Instructions and procedure

The participants were instructed that their task in the study was to rate the road curvature and to evaluate what they expect from a L2 system indicating the upcoming curvature on a display. Again, the cover story included that the vehicle was capable of L2 driving and the experimenter was there to initiate and supervise the functionality.

The experiment was conducted in two blocks. After arriving at the start position of the test track, the experimenter explained the usage of the slider. The participants experimented with using the slider and the related curvature visualisations in the display during a short familiarisation drive. Then the first experimental block started, in which we instructed to use the slider continuously according to their impression of the road curvature ahead.

Subsequently, the second block contained the drives with automatic dynamic curvature display. As preparation for the second block, the experimenter explained that different concepts for the depiction of the upcoming curvature were tested and that the task was to evaluate the appropriateness of the different concepts.

Overall, each participant drove through the test track six times. According to the study design, each experimental condition (slider, geometry concept, acceleration concept) was conducted twice with two different driving speeds (slow vs. fast). The drives were separated by short interviews on a parking lot. The procedure took around 3 hours.

d) Test course

A new test track was selected that fulfilled the following criteria: Reasonable length (six repetitions per participant needed to be feasible), possibility to turn and return to the start, and including a variety of different curve radii. A 21.4 km long section of A70/A71 near Würzburg, Germany matched the criteria. It consisted of 15 curves. Six exit/entrance ramps to the highway ensured curves with small radii. The classification of curves into narrow, medium and wide curves was based on the radius.

e) Study design

Two different methods were used to evaluate the concept of the dynamic curve display. First, the participants used the slider to control the curvature depicted on the display. Second, two different concepts were presented to the drivers and they evaluated the appropriateness of the respective HMI. In the geometric concept ("geo), the curve bending shown in the display represented the radius of the curve, independent of driving speed. In the acceleration concept ("acc) the bending shown in the display represented the maximum lateral acceleration experienced when driving through the curve, i.e. the display depended on curve radius and driving speed. The three conditions (slider, "geo" and "acc") were each conducted twice with different driving speeds (slow vs. fast) in order to investigate the relation between curve radius and driving speed in the participants' perception.

Table 1 shows the descriptive parameters for each curve and the maximum HMI image (according to Fig. 7) shown in the display. The experiment consisted of two blocks. The first block always included the two slider drives. The second block consisted of the four runs, whereby the fast and the slow run using the same display concept ("geo" vs. "acc") were conducted after each other. The order of the concepts and the order of the slow vs. fast run was permuted between participants.

We analysed the maximum curve image that resulted from the slider position as dependent variable in the slider drives. In the drives with automatic dynamic display, drivers evaluated the display after each curve section by answering the question "How suitable was the HMI for the recent section?" Additionally, overall evaluations were given after each run (by using the acceptance scale of [12]) and after experiencing all concepts.

Table 1. Parameters describing each curve in the test track and related HMI images used in the display. Narrow curves: 1-2, 8-10 and 15; middle curves: 4-5, 13; wide curves: 3, 6-7, 11-12, 14.

		Driving Speed per run		*Lateral acceleration per run at curve vertex*		*Maximum HMI image per concept*		
Curve	*Radius [m]*	*Fast run [km/h]*	*Slow run [km/h]*	*Fast run [m/s²]*	*Slow run [m/s²]*	*Geo*	*Acc fast*	*Acc slow*
1	27	50	40	-6,4	-4,1	13	13	11
2	32	50	40	5,4	3,5	13	13	9
3	1613	130	90	-0,7	-0,6	4	2	1
4	383	90	80	1,5	1,2	12	4	3
5	138	100	80	-5	-3,2	13	13	9
6	776	130	90	1,5	0,7	9	4	2
7	857	130	90	-1,4	-0,7	9	3	1
8	30	50	40	5,8	3,7	13	13	10
9	53	50	40	-3,3	-2,1	13	9	5
10	38	50	40	4,6	2,9	13	12	8
11	863	13	90	1,4	0,7	9	3	1
12	749	130	90	-1,6	-0,8	9	4	2
13	98	80	70	4,5	3,5	13	13	9
14	1567	130	90	0,8	0,4	4	2	1
15	28	50	40	6,2	4	13	13	11

B. Results

a) Slider drives

In the slider drives, we investigated the slider position by means of the maximum curve image appearing in the display triggered by the participants moving the slider. We conducted a 2x3 repeated measurements ANOVA with the factors driving speed (fast vs. slow) and curve type (wide vs. moderate vs. narrow). One participant could not be included in the analysis due to a data logging problem. There was a significant influence of curve type on the image that the participants used, $F(2,21)=99.68$, $p=.001$, $\eta^2=.905$. No other effect was significant (all $p>.267$). This showed that drivers moved the slider further away from the middle position in curves with narrow or moderate radii. In wide curves, the maximum selected picture was on average picture eight. In narrow curves, the maximum selected picture was on average picture twelve. The participants did not differentiate between drives with higher or lower speed.

b) HMI Concept comparison

For a meaningful interpretation of differences between the two concepts it was essential that drivers noticed differences between the concepts. In the direct comparison, 22 of 24 drivers agreed to have noticed differences between the two basic concepts, even though the exact nature of the differences was difficult to describe for them.

Fig. 10 shows the number of participants preferring one of the HMI concepts in a forced choice question after experiencing both concepts. Most drivers preferred the "geo" concept. The rating is based on N=23 participants, because one participant did not notice any difference between the concepts and therefore did not answer the question.

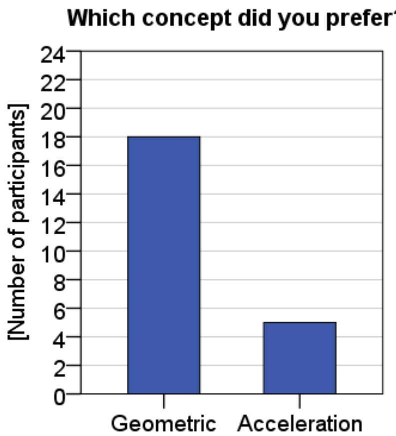

Fig. 10. Number of participants preferring each or the other HMI concept in a forced choice rating after experiencing both concepts.

Fig. 11 shows the results for the sub-scales usefulness and satisfaction extracted from the acceptance questionnaire. The graph relates to the ratings that participants gave right after experiencing each of the concepts. There was a significant difference between the two general concepts: The "geo" concept was rated as more useful than the "acc" concept, $t = 2.45$, $df = 23$, $p=.022$. There was no significant difference in the satisfying rating ($p > .05$).

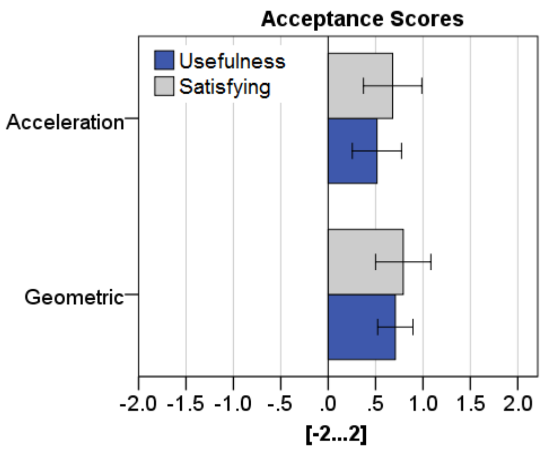

Fig. 11. Usefulness and satisfying sub-scales of the acceptance scale for the "geo" and "acc" HMI concepts. The graph shows means with 95% confidence intervals.

For the analysis of the situation specific evaluations of suitability of the display after each curve scenario in the track, we conducted a repeated measurements ANOVA with the factors concept ("geo" vs. "acc"), driving speed (fast vs. slow) and curve type (wide vs. moderate vs. narrow). The dependent variable was the suitability rating on the verbal-numeric scale. There were significant main effects for the factors concept, $F(1,23)=15.94$, $p=.001$, $\eta^2=.409$, and curve type, $F(2,22) = 8.12$, $p=.002$, $\eta^2=.425$, and significant interaction effects for the interactions concept*speed, $F(1,23)=10.42.$, $p=.004$, $\eta^2=.312$, and concept*curve type, $F(2,22)=3.56$, $p=.046$, $\eta^2=.244$. No other effect was significant (all $p>.057$). This shows that drivers evaluated the "geo" concept as more suitable, which is most evident in the slow driving condition and situations with wide curves. Fig. 12 visualises the described effects.

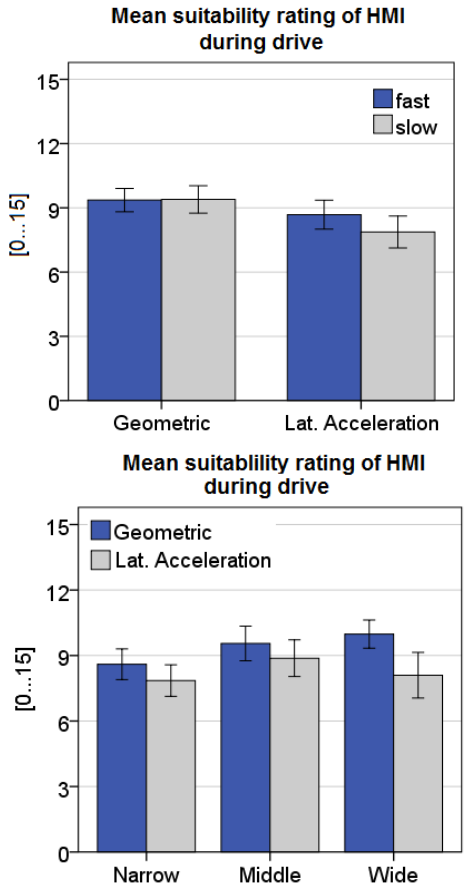

Fig. 12. Suitability ratings given during the drive for the two HMI concepts differentiated for the fast and the slow driving condition (top) and the three types of curves (bottom). The graph shows means with 95% confidence intervals.

a) Comparison of slider and system drives

To learn more about the drivers' perception of the evolution of the dynamic situation, we plotted and explored profiles of the curvature produced by the drivers against those shown by the HMI concepts for selected curves.

Fig. 13 shows the plots for a narrow curve (top) and a wide curve (bottom). As specified, in narrow curves the “acc” concept and the “geo” concept did not differ much in the depiction of the curve in the display. When driving slowly through the narrow curve, the maximum shown image in the display is lower in the “acc” concept compared to the “geo” concept and to the “acc” concept fast run. The profile also shows that the maximum picture selected by the participants by using the slider matches the “geo” concept and the “acc” fast concept.

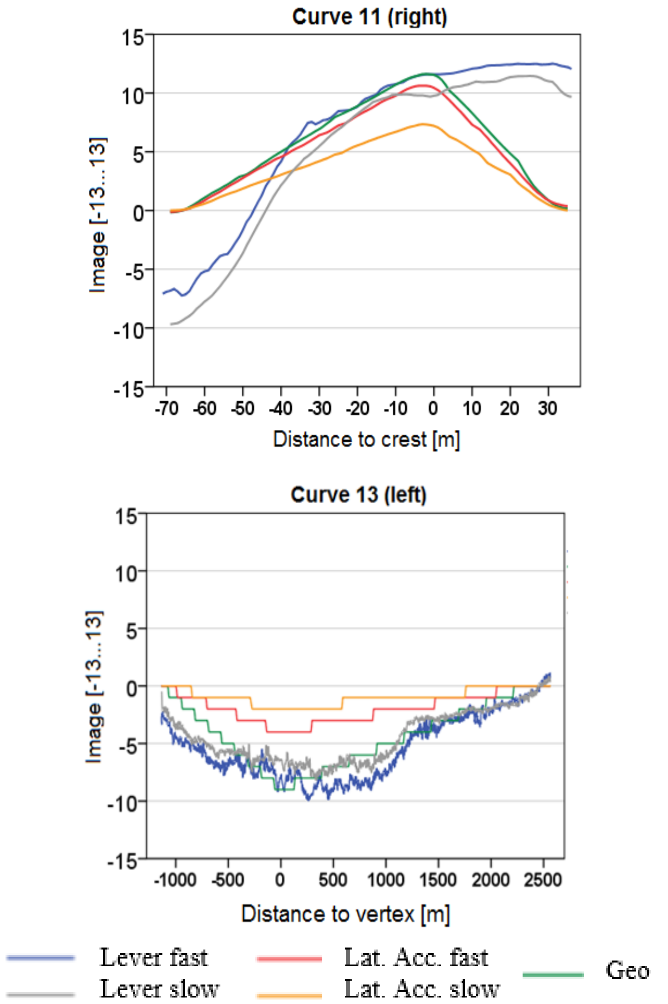

Fig. 13. Profiles of images shown in the display for a selected narrow curve (top) and a wide curve (bottom). The blue and grey lines indicate the pictures created by participants moving the slider in the fast and the slow run. The red and yellow lines indicate the profile used for the “acc” concept in the fast and the slow run. The “geo” concept (green) did not differ between fast and slow runs.

Additionally, the profiles in the narrow curve show that the drivers kept up the maximum slider position longer than we had pre-defined for the animation in the display. In our pre-defined profiles, the animation returned to the “straight” position after passing the vertex of the curve. Other than that, the participants kept the maximum beyond the vertex of the curve.

The accordance of drivers’ impressions with the “geo” concept is also shown when passing wide curves (Fig. 13, bottom). Here, the “acc” concept in the fast drives led to different maximum images compared to the “geo” specification. The maxima of the curves produced by the drivers using the slider matched the curve maxima defined in the “geo” concept.

IV. Discussion

We conducted two studies investigating HMI concepts of a predictive display that indicates the upcoming curvature in the road sensed by an automated driving system. The HMI is intended to allow drivers to supervise systems with automated lateral control in L1 or L2 automated driving.

In general, there was a positive attitude towards the predictive curvature display. Based on the results of the second study, we conclude that the geometric concept (i.e. curve representation in the display according to the curve radius independent of driving speed) matches best the drivers’ expectations. This conclusion is based on the direct ratings for the display concepts, the forced choice selection and the accordance of manual production of the display images by the slider and the geometric concept. Hence, drivers evaluate the upcoming scene based on what they visually perceive rather than on what they expect to feel kinaesthetically.

A reason for the high correlation between driver impression and lateral acceleration of the curve in the first study might be that we tested curves in which the lateral acceleration and the radius of the curve correlated, due to the constant driving speed we defined. As seen in the narrow curves in the second study, fast driving led to similar visualisations between “geo” and “acc” concept. Only the variation of driving speed realised in the second study allowed us to differentiate the two basic concepts and specify the driver preferences.

From a technical perspective, the results are pleasing because the “geo” concept does not require an estimation of lateral acceleration in the vertex. Sensor input from the camera and map based data might be sufficient to support the display.

Interesting is the observation that drivers kept up the maximum picture selected by the slider beyond the vertex of the curve. Future research could focus on the perception of curve exits and how drivers expect the display to behave in curve transition situations. In line with this, the preference for one of the concepts might be based on the specific parameterisation we used for each concept. It could be that a concept using lateral acceleration with a different algorithm (e.g. non-linear mapping of display pictures and acceleration values) leads to different evaluations of the concept. Even though, from the slider movements of participants we conclude that the linear mapping of curve images and radii seems to be an appropriate method during the approach of the curve.

In the current study, we did not utilise any system failures. Further studies could investigate how drivers react to situations in which the displayed curvature does not match the environment at all (e.g. showing a straight section in a sharp curve) and measure driver reactions to it. In relation to this, situations could be tested in which the perception of the curve is disturbed by the environment and the prediction range is limited. This data will allow final conclusions on the usability of the display for supervising the automated driving system.

Additionally, the results should be discussed in the context of the graphical depiction used for showing the curvature in the display. Our results might be influenced by the type of graphics we used. With the "geo" concept, the two lines approaching in infinity match the visual impression of the road scene. It might be that visual depictions that trigger an evaluation of the road scene based on dynamic criteria lead to different expectations on display dynamics.

Moreover, future studies should integrate the display with other information units relevant for supervising Level 2 automated driving. For example, other road users or speed information might include dynamic visualisations, too. Integrating all relevant (and dynamic) parts of information into a clear display that does not overload the driver represents a big challenge to HMI designers.

We conclude with a methodological evaluation. Our low fidelity Wizard-Of-Oz vehicle was successfully used as experimental tool for investigating Level 2 automated driving. The drivers were able to imagine driving in an automated vehicle. Due to the simple obscuration, drivers believed the experimental driver of the vehicle actually used a Level 2 feature.

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