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Human-vehicle interaction with a metaphor based collision avoidance interaction pattern

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Abstract: Following the successful digitalisation of tasks within the aviation domain, this development has now also reached road-based vehicles and is quickly progressing in the form of computer-based, assisted and automated driving. As these systems are becoming increasingly more complex and intelligent, design and interaction patterns can be an effective tool to translate complex systems into schemes that are intuitive to use and thus play a crucial part in the systematic resolution of conflicts between computers and humans.
One example of such a conflict are collision avoidance systems due to it overruling the input of the driver in an emergency. As a potential solution, an interaction pattern approach is presented for a non-line-of sight collision avoidance and subsequently evaluated in a driving simulator setting. Here a state of the art emergency brake was compared with an escalating interaction pattern, implemented with different degrees of multi-modality. The authors propose the use of Image Schemas, applying their underlying metaphorical extensions to support an intuitive interaction. An evaluation with Bayesian regression models suggests that a visual and multimodal implementation improves user experience and safety.

Keywords: interaction pattern; ADAS; interaction design; user experience; safety

1. INTRODUCTION

1.1 Motivation of Research

Current collision mitigation systems aim to avoid collisions with vehicles ahead, and whilst these assistance systems rely on a direct line of sight, future Car-2-Car and Car-2-Infrastructure communication will create new design opportunities for collision avoidance strategies, e.g. Mahler et al. (2014). This is likely to lead to drivers having more time to adjust their current driving behaviour and to be informed about dangers that they are unable to detect themselves. A crucial component however will be the ability of the system to gain the user's attention and prepare an action implementation to avoid critical situations. With the increasing number of warnings in current driver assistant systems, another focus lies on the User Experience and the increased design options these technologies offer.

Previous research has already shown how warning via different modalities might affect response time in collision situations (Scott and Gray, 2008). Other research showed how driver monitoring can assist to avoid collisions (Schenk et al., 2006). The research gap this paper addresses is how the interaction of a collision avoidance system can be designed using patterns incorporating collision situation and driver action. We propose a metaphor based collision avoidance interaction pattern that uses an escalation scheme to alert drivers to possible collisions and supports them in avoiding them. The reasoning for using metaphors is that they improve intuitive usage (Hurtienne et al., 2015). Image schemas are of special interest since they function in a similar subconscious manner as the internal target states but are related to the physical world. Therefore, they can be used to transfer meaning between the source domain, i.e. interaction elements via sensory modalities, and a certain internal target state, e.g. for urgency, importance or power using their metaphorical extension (Lakoff and Johnson, 1980; Johnson, 1987).

1.2 Theoretical Framework

Cooperative Guidance and Control Cooperative Guidance and Control, e.g. Flemisch et al. (2014), is one of the larger research areas where cooperation between humans and computers is studied. Several concepts to improve cooperativity in vehicle control have been studied, e.g. as a haptic multi-modal guidance approach in H-Mode and together with Conduct-by-Wire, as manoeuvre based guidance approaches (Flemisch et al., 2003; Winner and Hakuli, 2006; Kienle et al., 2009; Hakuli et al., 2012). These

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examples underline that a cooperation between humans and machines can be supported by interaction patterns. A basic inspiration of coupling the ideas of cooperative automation with image schemes and escalation patterns, and apply this to breaking comes from Kelsch et al. (2006) and Heesen et al. (2010).

Interaction Patterns Similar to design patterns, as proposed in architecture by Alexander et al. (1977) or in object-oriented programming by Gamma et al. (1995), interaction patterns can be used for interaction design (Borchers, 2001; Kunert, 2009; Baltzer et al., 2019). An interaction or design pattern describes a proven solution to a repeating (interaction) problem (Alexander et al., 1977). A pattern should have a certain level of abstraction in order to be applicable for multiple situations, but should convey the general idea of how the pattern works. Therefore, a pattern description consists of a specific name, a problem description, a description of the driving forces, a solution section and implementation examples.

Image Schemas Image schemas emerge through experiences of the human with objects and events in the environment. In this sense an *image* is a specific embodied experience (Croft and Cruse, 2004). Domains that create these images are called embodied or grounded, according to the embodiment theory (Lakoff, 1987; Johnson, 1987). The embodiment thesis argues that we know, without knowing how we acquired that knowledge, how our body interacts with our environment. This knowledge is described in psychology and linguistics as body image (Fillmore, 1975). Our language offers us a linguistic framework for the orientation and classification like UP/DOWN, LEFT/RIGHT, IN FRONT/BEHIND we would not understand without our body image. One of the most important aspects why image schemas can be used for interaction is their respective metaphorical extension and their schematic, reusable character. Image Schemas have already been used for the interaction design between humans and technology (Montello et al., 2003; Hurtienne et al., 2009; Macaranas et al., 2012), or specifically for intuitive use, inclusive design and UI innovation in human computer interaction (Hurtienne et al., 2015), or in highly automated vehicles applications (Baltzer et al., 2017, 2019). As a convention, image schemas are written in capital letters (e.g. BIG-SMALL) in literature, therefore this convention is followed in this paper as well.

Different Modalities in Warning Design Although image schemas are not focused on a specific modality, they can be used to effectively implement interaction elements mapping from a target internal state with the schematic nature of an image schema towards a specific interaction element (Hurtienne et al., 2009). In order to address the effectiveness of an interaction pattern different modalities can be applied.

Making use of different modalities, or a combination thereof, when designing warning cues in high-risk scenarios has a number of potential advantages when implemented carefully. Apart from the obvious case in which using one modality cannot convey meaningful information anymore (e.g. warning tone in a loud environment), it was discovered that a combination of visual, auditory and haptic stimuli yielded the most desired responses in participants (Haas and van Erp, 2014; Spence and Ho, 2009). In general, a multi-modal approach does increase the responsiveness as well as performance in the driving task, while lowering the workload. There are notable differences in effectiveness between modalities and certain combinations, which do however depend on the task and can therefore not be generalised.

1.3 "Non-line-of sight Collision Avoidance"-Pattern

The interaction pattern used in this study is called "Collision Avoidance" and the problem it has to solve is a possible collision with another object that needs to be prevented. Forces that determine the performance in this pattern are safety and user experience. While safety represents the main driving force in this pattern, the user experience measures how easy the pattern was understood (perspicuity) and how efficient it is to apply (efficiency).

A solution to preventing a collision is to focus the awareness towards the collision object and to either reduce the ego vehicle's current speed or change the trajectory. In order to focus the awareness, the pattern should supply information on the direction of the collision danger and propose mitigation strategies to reduce the current speed. Internal states that need to be addressed are urgency, importance and the need to act. A possible metaphor to trigger urgency is a traffic light (Wimmershoff and Benmimoun, 2009). A possible metaphor to trigger importance is implied in the BIG/SMALL image schema, which addresses the aspect of importance: "BIG is important" (Tolaas, 1991), meaning the underlying metaphor of a BIG symbol is understood as more important as a SMALL symbol. Respectively a BIG (or STRONG) force implies importance, e.g. when somebody tabs lightly (SMALL force / WEAK) on somebody else's shoulder it is interpreted as less important than when tabbed with a BIGger (STRONGer) force. In order to improve overall performance of the interaction pattern a multimodal approach is proposed, in which image schemas are presented through different modalities.

Following the implications of the reviewed literature it is expected that the implementation of an interaction pattern based collision avoidance system is enhancing driving safety, as indicated by the minimum time to collision, and user experience when comparing state of the art emergency braking systems. Increasingly so, when different modalities and a combination thereof are used.

2. METHOD

2.1 Participants

In total 16 participants completed the study of which 8 were female and 8 were male with a mean age of 40.1 (SD=19.4). Convenience sampling was done, and the majority of the participants were sourced in a local seniors sports club, a local social service club and students from Bonn University with no knowledge of the study's content or dependence on the study's outcome. Individuals were not compensated for taking part in the study.

2.2 Apparatus and Materials

Equipment A fixed based driving simulator was used, consisting of six horizontally mounted screens providing a 160 degrees field of view (see Fig. 1).

As simulation software, SILAB 6 [1] from the Center for Traffic Sciences Würzburg (WIVW) was used to create the virtual environment. The single monitor resolution was 1280x720 pixels, giving a total resolution of 7680x720 pixel resolution.

An active gas pedal from Sensodrive [2] was used for the haptic feedback.

As middleware to apply the interaction patterns and for logging synchronized event data, the Robot Operating System (ROS [3]) was utilised.

Scenario Design The maps through which the participants had to drive in this study were situated in an urban environment, consisting of a main road with several intersections. Each was composed of the same amount of corresponding subparts whose order was altered to form four different maps. Refer to Table 1 for a more detailed description.

The subparts were quasi randomly changed for the four different maps with the stipulation that no potential collision situations (Fig. 2) should directly follow another. On average going through one map with the maximum velocity of 50$\frac{km}{h}$ (maximum speed within city limits) took 20 minutes.

Measurements To measure user experience, the user experience questionnaire (UEQ) by Laugwitz et al. (2008) was employed. It assesses the six sub-dimensions attractiveness, perspicuity, efficiency, dependability, stimulation and novelty through asking for a rating of 26 aspects on a 7-point likert scale. Afterwards, three dimensions are aggregated from the subdimensions: attractiveness (made up solely from the attractiveness subdimension), pragmatic quality (average of the subdimensions perspicuity, efficiency and dependability) and hedonic quality (average of the subdimensions stimulation and novelty). To have an indication of safety, minimum time-to-collision (TTC) for each potential collision situation was calculated in

[1] URL: https://wivw.de/en/silab
[2] URL: https://www.sensodrive.de/produkte-leistungen/force-feedback-simulator-pedale.php
[3] URL: https://www.ros.org

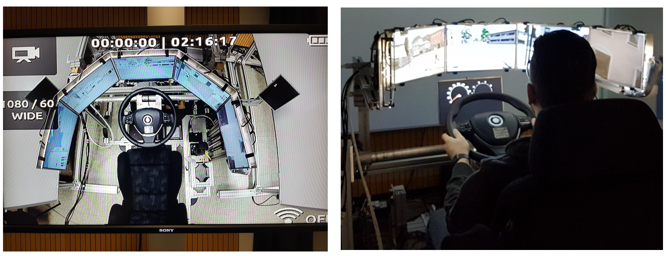

Fig. 1. Mockup of the fixed based driving simulator. Left: Birds-Eye perspective. Right: Over-the-shoulder perspective.

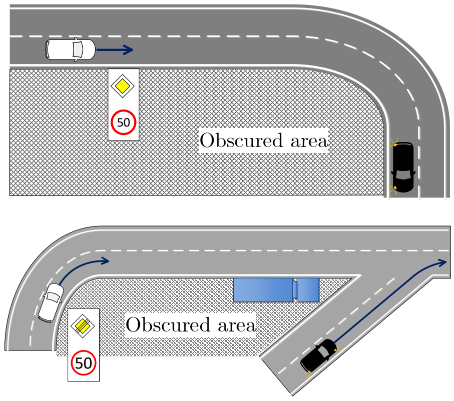

Fig. 2. Top: Overview of potential collision situation A with a parking vehicle behind a curve. Bottom: Overview of potential collision situation E, with a suddenly appearing vehicle coming from the right.

seconds. The TTC is calculated as described in formula 1, where d represents the distance between ego-vehicle and obstacle and v_{rel} the relative speed between obstacle and ego vehicle.

$$TTC = \frac{d}{v_{rel}} \tag{1}$$

If there had been a collision, this means that the TTC was 0, therefore this is the natural minimum of this measurement.

2.3 Stimuli Design

Four conditions were implemented for the experiment, a control condition (emergency brake) and three interaction pattern designs: The control condition was an emergency brake. Additionally, three designs of the interaction pattern "Collision Avoidance" were implemented: (1) Visual, (2) Haptic and (3) Multimodal. The next subsections describe the implementions in more detail.

Emergency Brake (control condition 0) The control condition was an acoustic warning tone played in a loop (see Fig. 3) alongside an emergency brake starting at a $TTC = 1$ seconds.

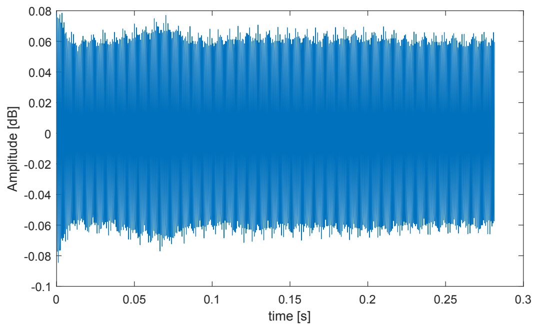

Fig. 3. Warning tone amplitude curve.

Table 1. Index, amount per map and description of the different subparts that made up one map.

index	*amount*	*description*
A	3	Potential collision situation with a vehicle parking behind a sharp curve. An overview of the situation is depicted in Fig. 2
B	3	Same as A, but without the potential collision situation
C	7	Comparatively lengthy, curvy section without potential collision situation
D	6	Comparatively lengthy, less curvy section without potential collision situation
E	3	Layout is the same as D, but with a potentially colliding vehicle that is approaching from the right at an intersection and is covered by a standing truck. An overview of the situation is depicted in Fig. 2
F	3	Same as E, without the potential collision situation

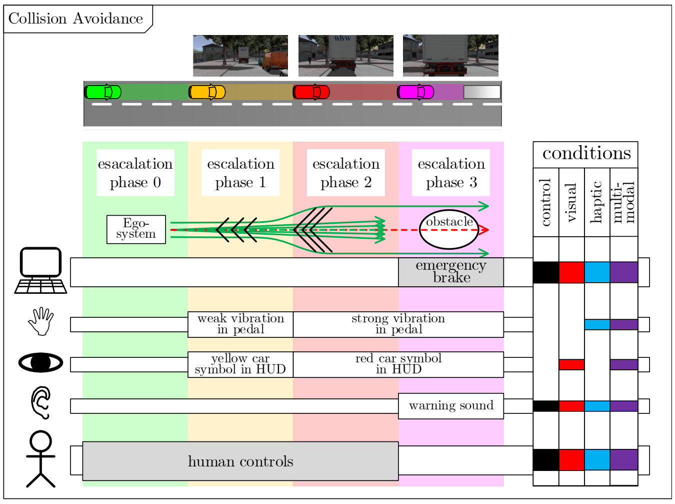

Fig. 4. Multimodal implementation of the collision avoidance pattern.

Since there is no temporal escalation present (active or inactive) in this pattern, the emergency brake is actually no collision avoidance pattern as described before, but can be combined with an escalation pattern, e.g. "Inform-Warn-Intervene" (Wimmershoff and Benmimoun, 2009; Blanquart et al., 2016), to form a collision avoidance pattern.

In Fig. 4 we see the different implementations of the interaction pattern "Collision Avoidance".

The escalation phases are defined by the time to collision (TTC), i.e. the ratio of distance between the ego vehicle and the collision object, and the speed difference of the ego vehicle's and the collision object's speed. With a TTC of 5 seconds, escalation phase 1 starts. With a TTC of 2 seconds, escalation phase 2 starts. With a TTC of 1 second, escalation phase 3 is initiated. Different interaction elements become active depending on the escalation phase.

VISUAL (condition 1) In *condition 1 (visual)*, *condition 0* was extended with visual interaction elements. Since the these elements are intended to communicate an increasing urgency, the traffic light metaphor is proposed, based on Wimmershoff and Benmimoun (2009). Additionally the implied metaphors of the image schemas BIG-SMALL for increasing authority/importance and NEAR-FAR (NEAR things appear BIGger than SMALL things) are applied. In phase 1 a yellow car symbol was placed in the Head Up Display (see Fig. 5). The symbol was 225 pixels wide and

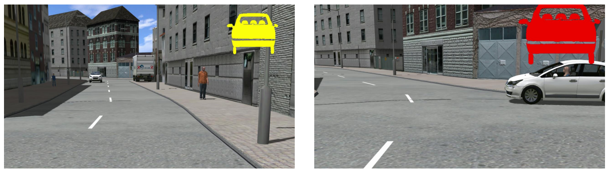

Fig. 5. View in the central screen. Left: Escalation phase 1 with yellow and SMALL car symbol. Right: Escalation phase 2 & 3 with red and BIG car symbol.

180 pixels high and designed in preceding participatory design sessions.

The vertical placement was constant to prevent obscuring the direct view on the road. The horizontal placement was dependant on the projected direction directly above of the obstacle's centre of mass. In phase 2 the car symbol was increased by 60 percent (BIG-SMALL image schema) and a red colour (traffic light metaphor) was used. In the final third escalation phase the warning tone and emergency brake were activated, removing the driver's ability to control longitudinal acceleration.

HAPTIC (condition 2) In *condition 2 (haptic)*, *condition 0* was extended with haptic interaction elements. Design options for haptic feedback could be the driving seat or, as proposed in some driver assistant systems, the steering wheel. Since the intention is to create an action stimulus where action is needed, the gas pedal was chosen as the location for the haptic interaction, as the aim is to release it, in order to reduce speed. In escalation phase 1 a WEAK vibration (amplitude: 20.0N, frequency: 150.0Hz), implementing the image schematic metaphor of a WEAK RESISTANCE (Talmy, 1988), is supposed to increase the comprehension of the required action; releasing the gas pedal, which will reduce the strain induced by the vibration. In escalation phase 2 a STRONG vibration (amplitude: 32.0N, frequency: 15.0Hz), implementing the image schematic metaphor of a STRONG + RESISTANCE is introduced. The respective vibration values were empirically determined in preceding participatory design sessions. In the final third escalation phase, the warning tone and emergency brake are activated, stripping the driver completely from longitudinal control.

MULTIMODAL (condition 3) *condition 3* combined the aspects of *condition 0, 1* and *2*.

2.4 Experimental design

Differences in the performance of the different designs is expected to be correlated to the modalities used as well as the metaphoric aspects of the interaction elements. A study was conducted to determine the consequences of the different implementations.

As previously stated, the relevant system quality attributes for the collision avoidance pattern are safety and user experience, especially the aspects of understanding, interaction speed and controllability.

The independent variables in this study were the different collision avoidance implementations (see section 2.3), where the emergency brake design represents the control condition, and the visual, haptic and multimodal designs the other respective conditions.

The experiment was a within-subject design, i.e. all participants tested all conditions. In order to avoid learning effects a counterbalanced design was chosen, i.e. every participant experienced a different order of conditions as well as a different order of scenarios.

2.5 Procedure

In the beginning, participants were asked to fill out a demographic questionnaire, asking for sex, age, driving experience (years and kilometres), their experience with advanced driving assistance systems, their experience with driving simulators and their driving style. Furthermore, an informed content to record video and sound was signed and their current simulator sickness score recorded using the simulator sickness questionnaire (SSQ) by Kennedy et al. (1993).

Following the introduction, the participants had the possibility to get used to the simulator and the interfaces during a trial run lasting a maximum of 10 minutes.

Afterwards, participants experienced the first trial run and map combination. At the end of the scenario, they were asked to fill out the SSQ, as well as the UEQ. Furthermore, participants were asked to give their comments on the current design. A trial run lasted approximately 20 minutes and was repeated four times, once per condition. Between trials, the participants had a pause of approximately 15 minutes.

3. RESULTS

3.1 Descriptive Statistics

The single means of the six UEQ sub-dimensions and the TTC, together with standard error bars, are presented in Fig.6. In Table 2, the means and standard errors for the measured variables can be found.

3.2 Inferential Statistics

To see which of the experimental conditions did have an effect on the respective measurements, Bayesian regression models were employed based on the method described by Muth et al. (2018). Using Bayesian models has proven to be advantageous in multiple aspects when compared to classic frequentist approaches (Wagenmakers et al., 2008). The generalized linear mixed-effects models were formulated in the statistical programming environment

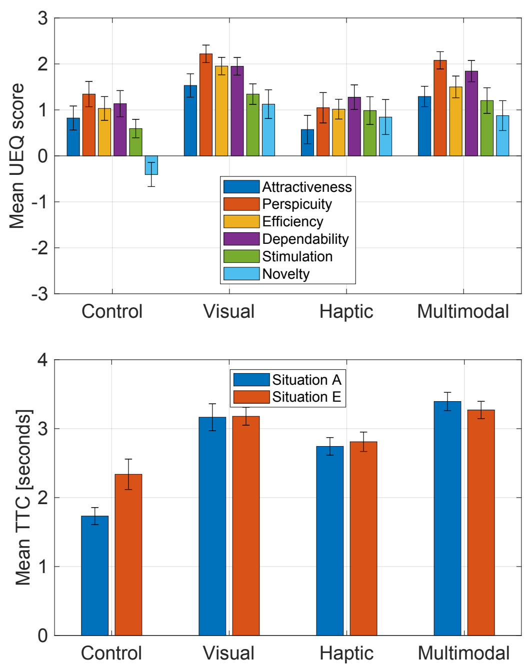

Fig. 6. Mean scores of the UEQ sub-dimensions (top) and TTC (bottom) for the different experimental conditions with standard errors (cf. Table 2).

'R' (R Core Team, 2017) using the package 'rstanarm' (Stan Development Team, 2016). The main focus of the study was to find out if the different dependent variables (Y_{UEQ}, Y_{TTC}) were affected by the different conditions (with β_i:= the effect strength/ slope of the curve, X_i:= the independent variable of i:=condition 1, 2, 3). Due to the nature of the study, repeatedly reacting to a supposedly surprising situation, relatively strong learning effects were expected. This is regarded in the model through including the trial number (β_{rn}) and the repetition (β_{rp}). Further, a random effect for the participants was incorporated to account for individual differences in performance in the statistical model (u_{VP}). These models were compared for the inclusion of all the relevant dependent variables using the Cross-Validation method Leave-One-Out (CV-LOO) by Vehtari et al. (2016). In case of the user experience, the model of condition and the random effect for participant, see equation 2, had the largest expected log predictive density (ELPD), indicating superior model fit. In case of the TTC, the model of condition, run, repetition and the random effect for participant, see equation 3, had the largest ELPD.

$$Y_{UEQ} \sim (\underbrace{\beta_0}_{\text{control condition}} + \underbrace{\sum_{i=1}^{3} (\beta_i * X_i)}_{\text{conditions 1-3}} + \underbrace{u_{VP}}_{\text{random effect}}) \quad (2)$$

$$Y_{TTC} \sim (\beta_0 + \sum_{i=1}^{3} (\beta_i * X_i) + \underbrace{\beta_{rn} * X_{rn}}_{\text{run}} + \underbrace{\beta_{rp} * X_{rp}}_{\text{repetition}} + u_{VP}) \quad (3)$$

Table 2. Mean scores and standard errors for the UEQ dimensions and TTC

	Attractiveness		Hedonic Quality		Pragmatic Quality		TTC, situation A		TTC, situation E	
Condition	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Control	0.82	0.26	0.09	0.19	1.17	0.25	1.73	0.12	2.34	0.22
Visual	1.53	0.25	1.23	0.26	2.04	0.17	3.17	0.19	3.18	0.13
Haptic	0.57	0.31	0.91	0.32	1.11	0.26	2.74	0.13	2.81	0.14
Multimodal	1.29	0.22	1.04	0.26	1.81	0.20	3.39	0.13	3.27	0.13

After the model was fitted, posterior intervals were obtained and the 90% confidence intervals of the estimates evaluated. If both the 5% and the 95% estimate are either larger or smaller than 0 (so 0 is not within the range of the interval) this indicates a main effect of the specific factor. The described procedure was used for analyzing the three UEQ dimensions (attractiveness, hedonic quality and pragmatic quality) and the TTCs.

The estimates for the effects of the different conditions on the three dimensions of the UEQ together with the 5% and 95% confidence boundaries and the TTC in situation A and E (see Fig. 2) are presented in Table 3. Note that the Control parameter is the intercept. Positive main effects are highlighted in green, negative main effects in red.

The summary statistics of the model show that there only was a main effect of visual on attractiveness. It also shows that there were main effects of visual and combined on hedonic quality. Furthermore, it shows that there were main effects of all three experimental manipulations (i.e. visual, haptic and combined) on pragmatic quality. Also all experimental conditions as well as run and repetition show a main effect on the TTC in both situations.

4. DISCUSSION

4.1 User Experience

Overall, it can be seen that all four conditions, including the emergency brake, provided an overall positive user experience, as all scores are positive. The sole exception is the novelty rating of the emergency brake, which is not surprising given that this is an off-the-shelf technology.

When looking at the attractiveness of the different implementations in detail, only the visual pattern was judged as more attractive than the control condition. For the dimension hedonic quality, there is an indication of a positive effect of visual as well as the multimodal implementation. Each of the three experimental manipulations showed a positive effect on the pragmatic quality.

Thus, summarizing the effect the implemented collision prevention systems had on the user experience, the data supports the statement that the dimensions attractiveness and hedonic quality, which relate more to the subjective likeability of a specific system, are most strongly influenced by the visual condition, as the haptic one alone did not show any effect. This might be an indication of a stronger attribution of subjective attractiveness through visually perceived objects; however, it might also be that the implementation in its current form was disliked by the participants. Each of the three implementations showed a higher pragmatic quality than the emergency brake. This effect might very well be mediated by the fact that in the control condition no priori warning of the impeding potential collision situation was given to the driver, while in each of the experimental ones some kind of early warning was present. This needs to be kept in mind when interpreting this particular result.

4.2 Safety

The evaluation showed that the estimate for the true minimum TTC before the collision situation of all participants in the control condition was 1.96 seconds in situation A and 2.14 seconds in situation E. It was expected that the minimum TTC would increase with all interaction patterns, since due to the non-line-of-sight situation, drivers have no braking cue in the control condition other than the appearance of the other car in the line of sight. Fitch et al. (2007); Telpaz et al. (2015) suggest that haptic cueing leads to fast and precise responses towards the cues direction. Therefore it was expected that the visual pattern would lead to a lower minimum TTC than the haptic or multi-modal pattern. Furthermore, it was assumed that the multi-modal pattern would lead to the highest TTC due to the combination of haptic action stimuli on the gas pedal combined with contextual information via the visual channel. It was further expected that with increasing repetition the TTC would increase due to the learning effect and increasing expectation of a collision situation by the driver.

The first expectation was fulfilled. As Table 3 shows, using a visual interaction pattern increased the TTC by approximately 1.42 seconds in situation A and 0.83 seconds in situation E. Similar improvements were observed with a haptic (1.00 seconds / 0.47 seconds) and multimodal interaction pattern (1.65 seconds/ 0.93 seconds). This supports the argumentation that an escalating interaction pattern greatly improves the safety as it gives drivers more time to adjust their driving inputs.

Interestingly, the breaks between the different runs caused a slight negative main effect on the TTC. In situation A, the TTC was reduced by 0.76 seconds and in situation E it was reduced by 0.56 seconds. As expected, the TTC increased slightly with increasing repetitions. In the model this is factored in with 0.26 seconds per repetition.

Furthermore, the participants noted in the comments that the haptic interaction pattern sometimes caused confusion in regards to what the assistance system was trying to communicate: (VP0) "I interpreted the vibration as the ABS signal respectively pushing harder and nearly crashing into the obstacle."; (VP3): "I didn't understand what the vibration wanted to tell me, so it just confused me."; (VP4): "To brake would be a later thought. First I would ask myself if there is a defect in the car or if it has to do something with my ABS". Furthermore since during coasting the foot does not rest on the pedal, a warning could be noticed too late: (VP5): "The warning

Table 3. Parameter estimates (Est) together with the 5% and 95% confidence interval boundaries for the UEQ's dimensions attractiveness, hedonic quality, pragmatic quality and the TTC in situation A and E (see Fig. 2).

	Attractiveness			Hedonic Quality			Pragmatic Quality			TTC, situation A			TTC, situation E		
Parameter	Est	5%	95%	Est	5%	95%	Est	5%	95%	Est	5%	95%	Est	5%	95%
β_0	0.84	0.41	1.27	1.19	0.37	1.32	0.11	-0.34	0.57	1.96	1.56	2.35	2.14	1.70	2.58
β_1	0.69	0.17	1.20	0.84	0.37	1.32	1.12	0.68	1.56	1.42	1.10	1.74	0.83	0.52	1.15
β_2	-0.26	-0.77	0.26	-0.07	-0.53	0.40	0.79	0.35	1.26	1.00	0.67	1.32	0.47	0.14	9.79
β_3	0.46	-0.06	0.96	0.62	0.14	1.09	0.93	0.48	1.37	1.65	1.33	1.96	0.93	0.61	1.25
β_{rn}										-0.76	-1.20	-0.33	-0.56	-0.99	-0.13
β_{rp}										0.26	0.12	0.40	0.25	0.11	0.39

system should warn EVERYTIME, but my feet are not EVERYTIME on the pedal. It would be better used for a speeding situation.". The haptic cues were also interpreted as coming too early, when no reason to brake was apparent, as the collision object was not visible.

Altogether, the study had certain limitations. Due to the high number of repetitions of collision situations, i.e. in an experiment participants observed 12 times the identical collision situation A and 12 times the identical collision situation E. Therefore, a learning effect and corresponding precautionary actions are highly certain. Ideally, each situation would only be presented once to each participant, making a between subject design a favourable choice. However, due to the limited availability of participants and time constraints this was not feasible for this study.

Another aspect that could not be answered in this study but that might be worthwhile to study is the correlation of the patterns' safety aspect and uncertainty: how does the TTC between different pattern implementations change (maintaining of more space / time) depending on whether the driver sees the collision situation or not.

Literature proposed a multi-modal interaction design to be the most desired, due to higher performance and responsiveness (Haas and van Erp, 2014; Spence and Ho, 2009), which was partly supported in this study. Since comments from participants suggest that the haptic interaction element came to early and had a too prompting character, different temporal combinations of visual and haptic cues should be examined, e.g. first a visual (informing) and afterwards a haptic (warning) cue. The effect of the used image schematic metaphors on the participant's user experience ratings or safety ratings could not be clearly distinguished. Therefore, the dependency of used modality versus dependency of the used image schematic metaphor on situation understanding should be deeper analysed. As a number of collision mitigation strategies were observed which could be dangerous with oncoming traffic or traffic behind the ego vehicle, the study should be extended to handling multiple collision possibilities and how an interaction pattern could prevent dangerous avoidance strategies. Furthermore, the aspect of interaction in false positive collision detections should be examined, leading to a higher focus on the bi-directional arbitration character of interaction patterns and showing the migration path of non-perfect assistance systems.

5. CONCLUSION

In this paper a non-line of sight collision avoidance pattern with different degrees of multi-modality was studied in terms of safety and user experience. All implementations showed improved safety, in terms of increasing minimum TTC, compared to a basic emergency brake system. User experience suggested that the best results can be achieved using a visual implementation while the haptic implementation needs further studies to improve appropriate timing and criticality when used. Future studies should focus on the reuasability of interaction patterns. Therefore, a next step should be to implement the proposed interaction pattern also in different domains, e.g. when avoiding a collision with a remote controlled vehicle or an aerial vehicle, to generalize the results.

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