# EVALUATION OF INTERFACES FOR AUGMENTING A DRIVER'S ABILITY TO ANTICIPATE FRONT RISKS IN REAL TRAFFIC

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## ABSTRACT

Effective alerts are often subject to a tradeoff between relevance and utility. While it is easier to acknowledge the relevance of a warning about an imminent hazard than a more distant threat, the possibilities to act appropriately in response to notifications decrease with threat distance. To benefit from the advantages of early notifications without creating annoyance and ignorance, we introduce a variety of Human-Machine Interfaces that provide driver assistance by scaling stimulus saliency in accordance with the urgency of a front risk in traffic. Further, we report an initial investigation of the influence of the HMIs on measures of front collision risk and subjective driver experience after prolonged use in real traffic.

Three functional HMI prototypes were implemented in a roadworthy vehicle, equipped with additional hardware for front risk detection, stimulus presentation, assistance control, and data logging. Participants with advanced driving practice received these vehicles for 12 days in total for personal daily use, consisting of 3 guaranteed days of use for one of each HMI prototype and 3 days of driving without any added front risk notifications. Besides continuous logging of driving data and risk estimates, subjective data were acquired in the form of logbook entries and interviews.

Measures of driving safety were high across all conditions, indicating no occurrence of critical situations. No HMI specific safety effects on top of high baseline levels were observed. Subjective ratings show a trend for an increasing perceivability and usefulness of a sound-based HMI with extended system exposure. Participant feedback suggests that no such adaptations may have been necessary for the remaining vision-based HMIs because intuition could be gained quickly. Future HMI iterations should refine the balance between salience and subtlety to better align with actual safety levels while future investigations might benefit from longer individual exposures or an experimental control of safety levels.

## INTRODUCTION

Driving creates a continuous demand for the driver's perceptual system. Traffic elements must be perceived and understood in time to allow for safe maneuver planning and collision avoidance. Yet, this requirement is not always being fulfilled so that around 90% of traffic accidents and critical situations are still attributed to human error [1–3], in particular to recognition failures [2]. To allow drivers to better recognize safety-relevant traffic elements, various driver assistance systems have been developed or proposed. Commonly available systems include forward collision warnings (FCW) [e.g., 4, 5], lane departure warnings [e.g., 6–9], blind spot warning systems [e.g., 10, 11], and parking assistance systems [e.g., 12, 13]. Some proposed systems, such as monitoring aids for laterally crossing traffic [e.g., 14–17], offer support in very specific situations that are known to be challenging. Furthermore, systems that monitor correlates of driver fatigue, workload, and attention [e.g., 18–21] are being introduced as means to account for variable mental states that may affect driving safety. Many of these assistance systems have a binary character: They are activated when a signaling threshold is surpassed and are otherwise silent. For example, a forward collision warning (FCW) may be triggered only once the time-to-collision (TTC) or another risk indicator [e.g., 22, 23] between the ego-vehicle and a front vehicle falls below a specific threshold. It then generates salient visual and auditory warnings to notify the driver about the predicted collision. One shortcoming of such notifications is the potential to disrupt ongoing attention processes [24] [see 25, p. 30], including attention on the driving task. Another issue is that warnings that are perceived as disturbing or unnecessary become likely to be ignored over time [see, e.g., 26, 27]. This creates a motivation to limit warnings to a minimum of cases for which the confidence about the necessity of the warning is high, i.e., situations in which it is certain that the driver appreciates the warning and situations in which a collision is imminent. The former case may be addressed by personalized assistance systems [28] and demand-based assistance triggered by an active user request [e.g., 17, 29, 30]. However, an automatic adaptivity carries the risk of being perceived as inconsistent while systems that rely on a user request are limited by the driver's ability to judge what situations require support.

Also a restriction to situations with an imminent collision risk comes with inherent challenges: From a driver's perspective, two issues of imminent threat conditions are that they leave only little time to react and are of little use for making foresighted maneuver plans. Binary warning systems are hence subject to a tradeoff between how much time they leave for driver reactions and their potential for disturbance [see 25, p. 31]. But this limitation of binary warnings does not necessarily persist for systems with ordinal or continuous properties [31, 32] and systems that provide non-critical warnings [33, 34]. For instance, so called *likelihood-alarm-systems* [31], which produce graded alerts that appear early and become more prominent with increasing event confidence, have demonstrated improvements in driver responses and system trust [31, 32]. Similarly, a proposed assistance that continuously encodes the temporal proximity between traffic participants in the strength of tactile stimuli has been rated as helpful and non-disturbing while improving driving safety [35–37]. As suggested by Krüger [25, pp. 54-56], systems with scalable output that is partially contingent on one's own actions may integrate well with existing sensory processing and possibly be utilized by drivers in a foresighted manner. Compared to binary signaling, utility may further be added through an inherent communication of dynamic aspects of a situation [see 25, p. 32], such as risk development over time instead of mere risk presence or "absence" information.

Accordingly, we developed and investigated assistance prototypes with a variety of human machine interfaces (HMI) that implement an early communication of front collision risks that is subtle at the beginning but can continuously become more salient when the risk increases. Here we introduce three of these HMIs, which use different means of encoding front risk. We aim to support drivers in integrating the conveyed information into their scene understanding to facilitate foresighted driving with a better avoidance of more dangerous situations. However, such an integration may take some practice and time to develop, especially when considering the initial stimulus subtlety at low risks. We hypothesize that extended experience of the HMI output in a wide range of situations will allow drivers to better pick up and use the encoded information. Specifically, we expect subjective measures of the experience with the HMIs to improve and the occurrence of situations that reach more critical levels to decrease over time with the introduced assistance. For this reason we decided to carry out evaluations in real traffic, where drivers are able to experience the HMIs for prolonged periods and in more diverse settings compared to a more controlled driving simulator environment. Following the introduction of three candidate HMIs, we describe a vehicle implementation of functional prototypes and report on a first user study about the effects of these HMIs on drivers in real traffic.

## METHODS

### Estimating Front Collision Risk

A continuous mapping from front collision risk to HMI activation requires an estimate of the front collision risk. For classical forward collision warnings the collision risk is typically estimated through the time-to-collision (TTC). The TTC is a very direct but also erratic predictor of collisions. It falls as another vehicle is approached but quickly jumps to infinity once a distance is stable or increasing. More indirect collision risks, such as those produced by tailgating are not adequately captured. Another temporal measure known as time headway (THW) describes the time at which the current position of a front vehicle will be reached. This makes it continuous in the presence of a front vehicle and sensitive to tailgating but insensitive to the velocity of the front vehicle.

To account for both direct and indirect front collision risk factors while ensuring risk continuity, we have chosen to estimate the front collision risk by a measure known as time to closest point of approach (TCPA) [38–40] within specified bounds. The TCPA interpolates between TTC and THW by a term $a_L$ that expresses the potential deceleration of the leading vehicle at any time. For two vehicles that follow each other on the same trajectory, the TCPA may be obtained as follows.

$$t_L = -\frac{v_L}{a_L}. \tag{1}$$

$$TTC_a = \frac{-\Delta v - \sqrt{\Delta v^2 - 2a_L d}}{a_L}. \tag{2}$$

$$TCPA = \begin{cases} TTC_a, & \text{if } TTC_a < t_L \\ \frac{d - \frac{{v_L}^2}{2a_L}}{v_F}, & \text{otherwise.} \end{cases} \tag{3}$$

Here $t_L$ stands for the potential stop time of the leading vehicle with velocity $v_L$, $d$ is the spatial distance between both vehicles, $v_F$ the velocity of the following vehicle, and $\Delta v$ is the difference between $v_L$ and $v_F$. Normalizing up to a threshold $\theta$ yields a simple collision risk estimate $r$ that can be used to scale HMI output continuously. For all HMIs we have selected an activation threshold of $\theta = 7s$.

$$r = max\left(\frac{\theta - TCPA}{\theta}, 0\right). \tag{4}$$

### HMI Candidates

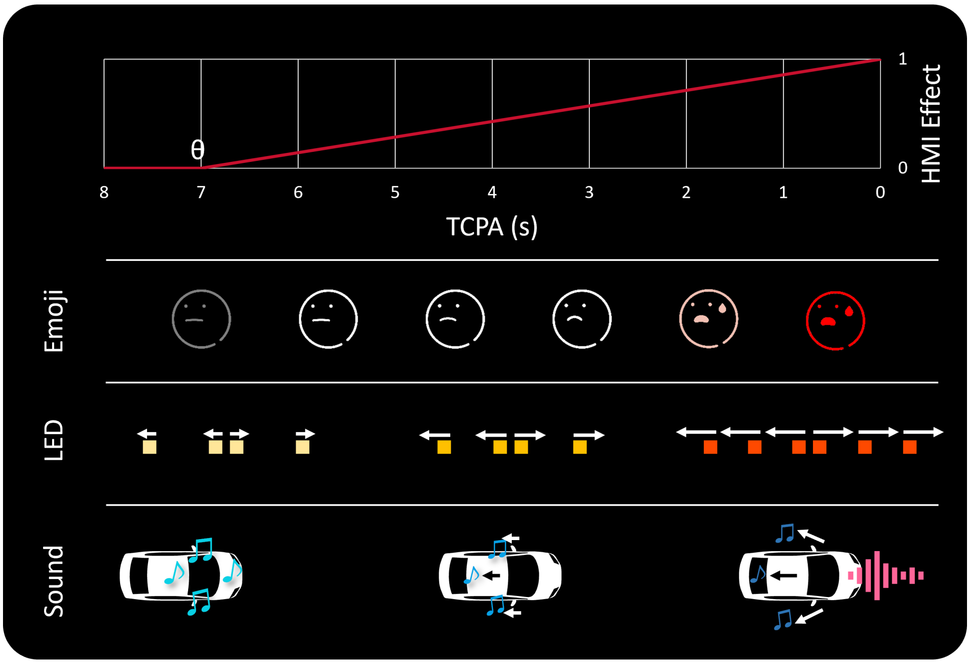

*Figure 1* - **Illustration of the relationship between TCPA and the three described HMIs. Emoji: The face becomes more concerned with increasing risk and changes color at a high risk. LED: apparent movement of light dots from the risk center towards the periphery changes in frequency, speed, and color with increasing risk. Sound: Modulation of infotainment sound source location and presence increases with risk.**

We developed three HMI prototypes that utilize the described TCPA-based risk estimate to continuously adjust aspects of their output. Each HMI targets unique properties of human sensory processing to explore specific potential in driver assistance and allow for redundant or complementary future utilization[1].

**Emoji HMI:** In the mobility domain only little time can be spent on the perception and processing of individual areas of interest because information can become outdated in proportion to the velocity of oneself and other traffic participants. Accordingly, an HMI to convey existence and magnitude of a collision risk should facilitate fast and intuitive perception and understanding to minimize interference with the driving task. HMI output in conditions of low risk should further be subtle and be easy to ignore.

For most people, vision is the primary sensory modality in various tasks, especially in those related to mobility [42, 43]. For some types of visual stimuli there are highly specified processing networks that favor and speed up processing and recognition of such stimuli. One prominent form of preferred stimulus are human faces. Already as infants humans start to preferably seek out and focus on human faces [44, 45]. The specialization on faces [46, 47] even leads to commonly experienced forms of pareidolia [48], i.e., a perception of faces on objects and patterns when there are none. Faces are also a primary identifier of individuals and effectively convey most emotions within 200 ms [49], and even in a stylized form such as through cartoons [50, 51].

The first HMI prototype aims to exploit the speed and intuition of emotion processing through faces. It consists of a transparent emoji with a size of 2° of visual angle that appears in the head-up display and displays emotions

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[1] In addition to the HMIs specified here, an investigation of a different set of HMIs for encoding the same underlying risk in a driving simulator environment is reported by Matsuoka et al. [41]

that are mapped to a range of risk values. Starting at a low risk threshold, the face gradually becomes more concerned and eventually transitions into expressions of fear and finally panic at high risk. For high risk values the color of the face further changes from white to red. The transitions are reversed when the risk falls and briefly even change into a smile once a safe TCPA is reached. By being positioned in the head-up display, the face is almost aligned with the movement direction so that it requires only short saccades to come into focus most of the time. Nevertheless, while a transition between emotions may be picked up peripherally, a reliable recognition of the current emotion depends on an actual fixation. Due to this property the information provided by this HMI must be actively sampled by a driver on demand. This makes it unobtrusive but also suggests that it introduces competition with other regions of interest that must be monitored during driving.

**LED HMI:** The second HMI aims to avoid a need for active fixations and competition with existing regions of interest. To achieve this it targets the visual periphery rather than the center. The periphery of the retina and hence the visual field is not capable of processing shapes in detail. However, it is as sensitive to moving stimuli as the retinal center [52, 53] and also able to resolve the direction of movement [54]. This capability allows us to detect moving objects in the environment and also perceive self-movement through optical flow. Optical flow during movement is characterized by a radial expansion of visual elements from the direction of motion to the periphery. Similarly, approaching objects generate a radial expansion from a stable center. The second HMI aims to make use of this property to augment the visibility of approaching risks. It is realized through an LED strip that spans across the whole bottom side of the windshield. When an object in the front is considered to be a risk, the LED strip creates repeatedly appearing dots that move outwards from the direction of the risk, thereby augmenting the optical flow associated with the risk on one dimension. With increasing risk the speed and spatial frequency of the movement pattern increases. Additionally, a gradual color change of the movement pattern from white to yellow to red is applied according to the risk level. The LED movement pattern has the theoretical advantages of being recognizable by peripheral vision alone and of guiding the user towards the direction of risk by tracing the origin of visual expansion. But in contrast to the emoji HMI, individual levels of flow have no direct absolute correspondence to emotions.

**Sound HMI:** The first two HMIs both relied on the addition of visual stimuli to convey risk information. Interference with the visual demands of the driving tasks was designed to be minimal either by reliance on the fast human visual processing of faces and emotions or by avoiding a need for foveal vision. Nevertheless, HMIs that add visual stimuli in a visual task are at the risk of eventually becoming distracting in situations of high sensory load. The third HMI therefore focuses on the potential to make a driver more aware of risks by reducing the efficacy of distracting stimuli. One typical source of stimuli that are not directly relevant to driving safety is a vehicle's infotainment system. In the event of an approaching collision risk the driver's attention should be focused on the driving task as much as possible. To facilitate that focus, this HMI reduces the perceived presence and salience of audible infotainment elements, such as the radio sound, in proportion to the measured risk level. Using a combination of auditory filters and variations in speaker balance and volume, an effect is created that leads to infotainment sound appearing to retreat to a more distant location opposite to the direction of the approaching risk. This modulation is intended to reduce infotainment salience but not take away the driver's autonomy to voluntarily select stimuli to attend to. A reduction in risk reverses the modulation and implicitly rewards the driver with infotainment sounds of improved presence and clarity.

The described form of assistance relies on the presence and activation of an infotainment system. A second component of this HMI therefore acts independent of the availability of infotainment sounds. This second component consists of the generation of an artificial ambient "noise" sound that becomes more prominent with increasing risk. This noise sound contains oscillating low frequency components for a loose association with objects in motion as well as slightly dissonant components that are intended to create a feeling of uneasiness. It is set to appear from the direction of the risk to draw focus to that direction. At low risks the noise is faint with a low and narrow frequency spectrum. With increasing risk it becomes more prominent and localizable through added volume and a gradual activation of higher frequency components that facilitate identification of interaural intensity and spectral differences [55–57]. A reduction in risk reverses the prominence of the noise component and eventually makes it disappear. In contrast to the infotainment modulation, the onset of this noise is set to a higher risk (5 seconds TCPA instead of 7 seconds). This, coupled with its directionality, makes it more a complementary escalation step in HMI output than a redundant stimulus. Conceptually the infotainment modulation clears the space that is then occupied by the noise and the risk it represents.

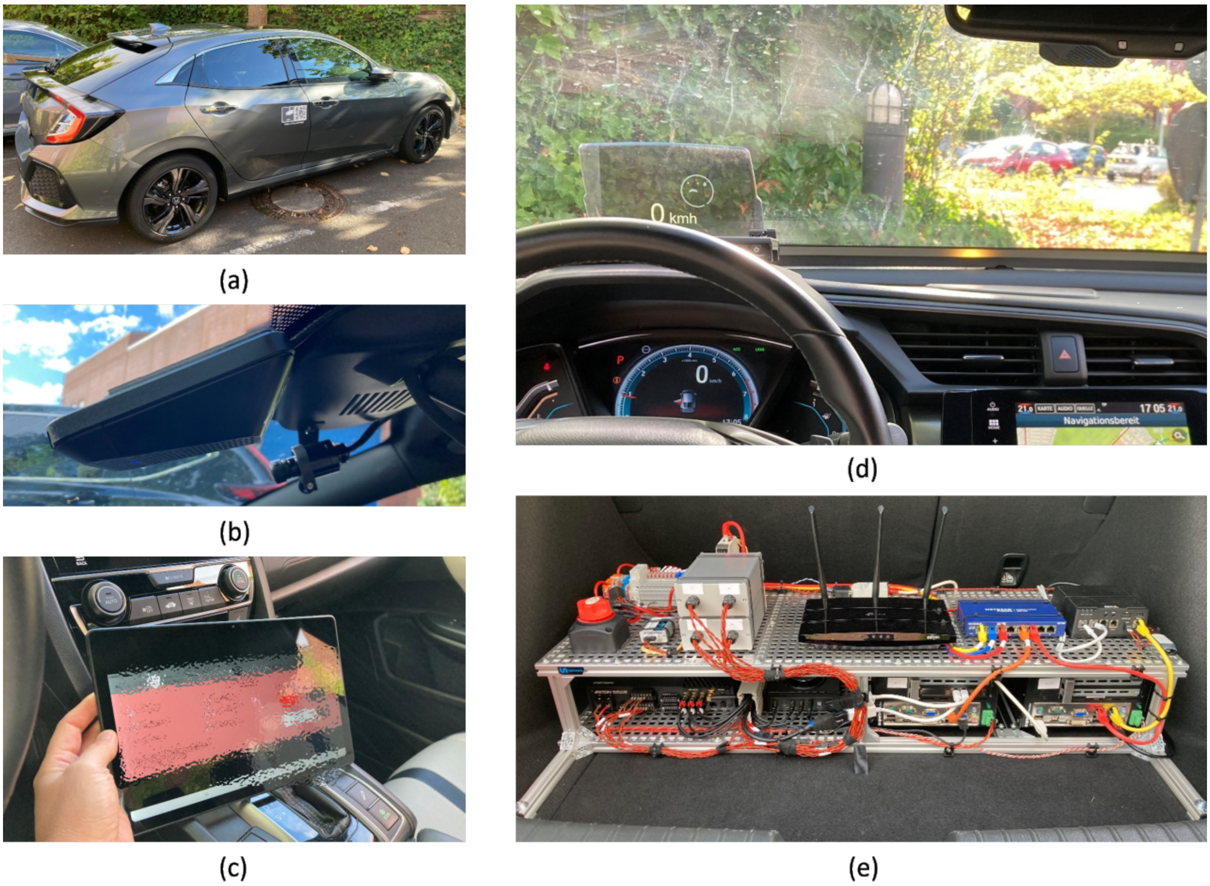


***Figure 2 -* Overview of the vehicle setup for functional prototype realization. (a) 2017 Honda Civic, (b) aftermarket computer vision system and scene camera, (c) user interface for HMI parameter control, (d) head-up display with concerned emoji on top of the dashboard and LED strip with intermediate risk light pattern below the windshield, (e) hardware for computation, network, power-, and sound control installed in the car trunk.**

### Vehicle Setup

Functional prototypes for the three HMIs have been implemented in a 2017 Honda Civic with automatic transmission. Figure 2 shows an overview of the installed components. For sensing of external risk-relevant measures, such as object presence, distance, and relative velocity, an aftermarket open protocol computer vision system (Mobileye Global Inc.) was mounted to the top of the windshield next to a front facing camera for optional scene recording. Measures from the ego-vehicle are accessed through a CAN read-only interface (Vector Inc.). Data integration, risk calculation, HMI control, and data logging are carried out on two PCs mounted in the trunk of the car together with a Wi-Fi router, sound card, amplifier, and voltage distributor. The SOLID software platform (Usaneers GmbH) is used as a backend for data integration, risk calculation, logging, and HMI control. Access to HMI toggles and parameters is realized through a custom Android app (Usaneers GmbH) installed on a tablet that connects to an on-vehicle Wi-Fi network.

For the emoji HMI an aftermarket head-up display (Maxwin) was installed on top of the dashboard. For the LED HMI an RGB LED strip was installed below the windshield, ranging across the full width of the windshield base. To realize the sound HMI, sound signals from the vehicle's amplifier are relayed to a sound card via a Hi-Lo converter. The signals are then modulated according to the current risk and output via the vehicle's original 7.1 speaker system. This allows us to modulate any sound generated through the vehicle's infotainment system, including the radio sound. Technical elements and cables are hidden within the car trunk and behind components of the interior to maintain the look and feel of a regular vehicle and reduce the risk for interference of the setup with the driving task and safety.

### User study

We used the described vehicle setup in a first user study to investigate the development of effects of each HMI on driving experience and safety-relevant driving behavior and to find potential issues that could inform future system refinements. Specifically, the study should investigate the following research questions for each HMI:

1. Does driving safety with respect to front collision risks improve with HMI use compared to a classical forward collision warning?
2. Does driving safety, in terms of front collision risk, increase with HMI exposure over time?
3. Does the subjective HMI experience improve with HMI exposure over time?

We wanted drivers to put their main focus on the driving task rather than on the HMIs. Further requirements were an extended exposure to each HMI for multiple days and a natural variability in driving situations. To that end, we opted for a study setup in which participants would use the vehicle as a temporary substitute for their personal vehicle for multiple consecutive days. By using the vehicle in daily driving, such as for commuting, we hoped to facilitate the participants' natural driving behavior.

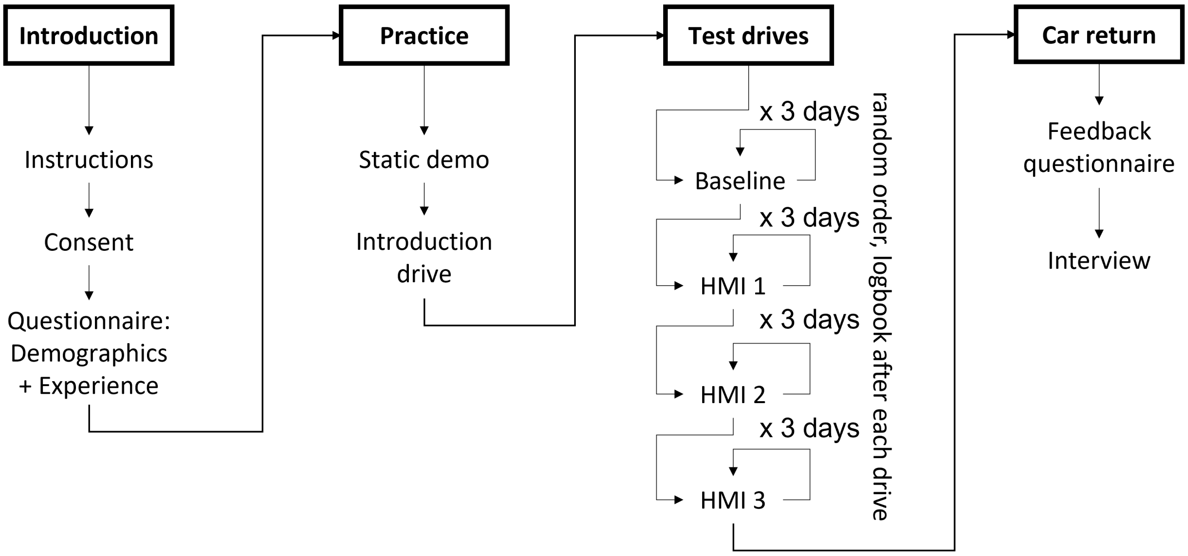


*Figure 3 -* **Study procedure for each participant.**

**Procedure:** Before the start of the study, each participant received an introduction that explained the procedure and conditions of the study. After giving written consent about their understanding of the study and the permission to use their collected data, participants completed a short questionnaire about their demographic data and driving experience. Next, a 30 minute introductory session was conducted, consisting of a demonstration of each HMI in a standing vehicle, followed by an accompanied introductory drive with each HMI.

For the subsequent testing period, participants were asked to drive for at least three days with each HMI. As a baseline condition, participants further drove for three days without any of the new HMIs. Instead, only a classical late forward collision warning (FCW) was available, consisting of a salient visible and auditory alert at a higher risk level. Participants were instructed to fill out a logbook after each drive, which contained fields to indicate their experience in the interaction with the car and the HMI. At the end of the last drive, participants were further asked to comment on their overall experience with the HMIs and general comments and remarks. In addition to these subjective evaluations, video data of the front scene and driving data required for risk calculation, such as front and ego vehicle location, relative velocity, acceleration, and braking, were recorded during each drive. The described study procedure has been evaluated and approved by the Honda R&D Bioethics Committee.

**Participants:** Six participants (aged between 30 and 59 years, one woman) took part in the study. All participants are experienced drivers with an annual mileage of at least 15000 km and certified advanced qualifications for handling vehicles in critical situations. This added qualification reduced the risk of being unable to safely handle the vehicle in cases of system failure at the expense of reducing generalizability to a more diverse population. All participants had a valid driver's license and normal or corrected-to-normal vision.

**Dependent Measures:** Because of the real traffic setting of the study the participants were not subjected to any specific predetermined traffic situations. The occurrence of front collision risks was out of experimental control and depended on the increasing chance for a natural occurrence of HMI-relevant conditions with prolonged exposure. This design choice makes safety evaluations through, e.g., activation-frequency measures uninformative. Instead we looked at measures that can be obtained within periods of HMI-relevant conditions, i.e., situations with a TCPA below the 7 s HMI activation threshold.

As a first measure of driving safety within those periods we chose the minimum TCPA. For each HMI-relevant period this minimum TCPA expresses how dangerous the corresponding situation became at most. Besides this measure of risk magnitude we were interested in how well drivers would prevent such situations from developing into situations with medium or higher risk. We defined medium risk as the midpoint between HMI onset and a collision, i.e., at a TCPA of 3.5 s. The inverse of the ratio between medium risk situations and all HMI-relevant situations indicates the success in risk prevention. To assess the subjective driving experience we analyzed interview responses and 7-point logbook ratings on HMI usefulness, annoyance, difficulty, and naturalness.

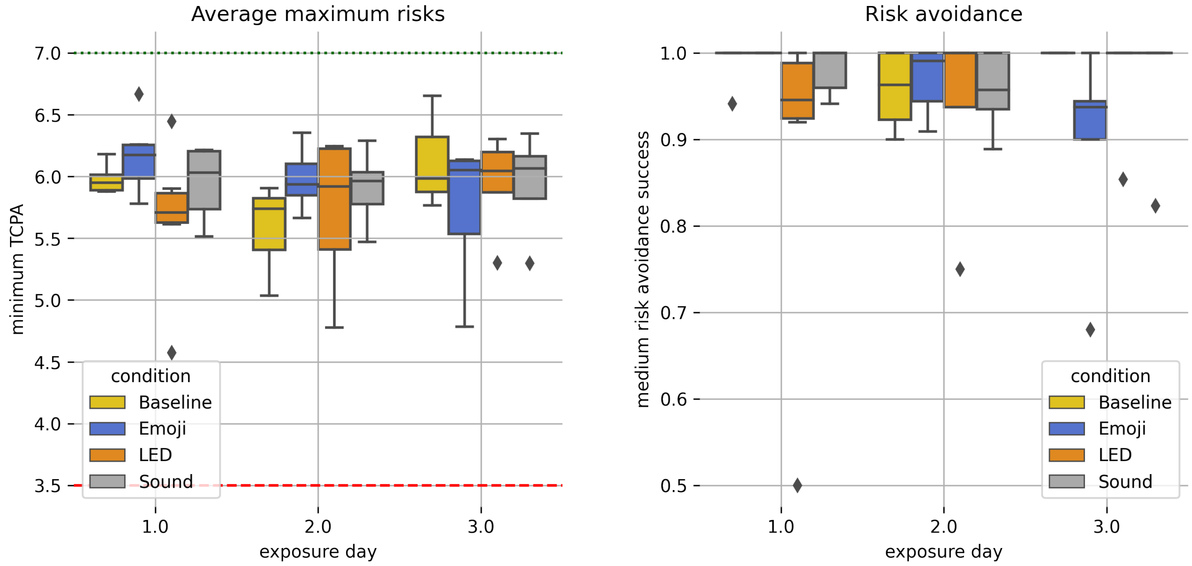
## RESULTS

### Safety

***Table 1.***
**Occurrence of HMI-relevant conditions during free driving**

| condition | count | mean | std | min | 50% | max |
|---|---|---|---|---|---|---|
| Baseline | 6.0 | 112.00 | 65.22 | 30.0 | 129.0 | 194.0 |
| Emoji | 6.0 | 142.50 | 60.55 | 57.0 | 142.5 | 243.0 |
| LED | 6.0 | 150.16 | 46.01 | 88.0 | 163.5 | 201.0 |
| Sound | 5.0 | 199.20 | 58.99 | 131.0 | 187.0 | 284.0 |

For each condition, participants entered HMI activation ranges more than 100 times in total on average and 30 times at minimum (see Table 1 for further details). This suggests that the requirement for a regular natural occurrence of HMI exposure could be met and that a statistical analysis of the targeted safety effects is possible.



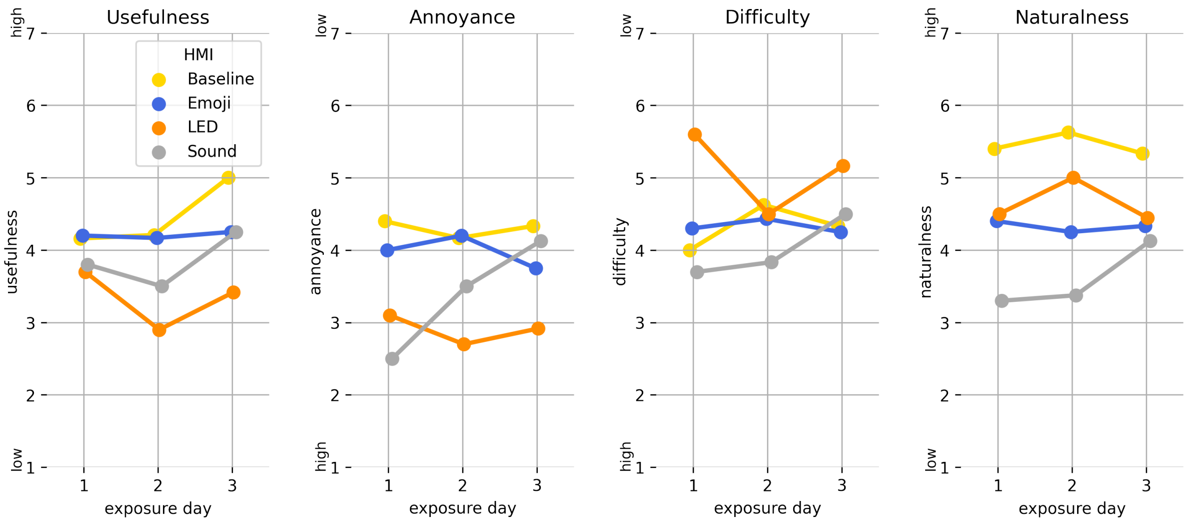
*(a)* *(b)*

*Figure 4 -* **Safety measures within periods of HMI-relevant conditions. 4a: Distribution of maximum risks quantified inversely (high value → low risk) as minimum TCPA for each condition and day of HMI exposure. 4b: Distribution of ratios for the avoidance of medium risks (TCPA $\leq$ 3.5 s).**

For all HMIs and exposure days the minimum TCPA values within relevant periods were on average between 5.6 and 6.1 s (min and max ranges per HMI - Baseline: 5.03-6.65; Emoji: 4.78-6.66; LED: 4.57-6.44; Sound: 5.29-6.35). This means that the highest risks were, on average, still close to the 7 s TCPA threshold, i.e., in a range that can still be considered as rather safe. A two-way ANOVA with the factors condition (HMI) and day of exposure indicated no main effect for condition (F(3,49) = 0.76, p = 0.52), day of exposure (F(2,49) = 0.65, p = 0.52), or their interaction F(6,49) = 1.19, p = 0.32. Participants typically drove safe, irrespective of whether one of the newly introduced HMIs or only a classical FCW was available. This also means that there was almost no HMI activation at all in the baseline condition because the FCW onset threshold lies much lower.

The high level of driving safety is also reflected in the measure of risk avoidance. Risk avoidance, defined as a minimum TCPA above 3.5 s, was high for all HMIs and exposure days with an average success rate between 0.88 and 1.0 (min and max ranges per HMI - Baseline: 0.9-1.0; Emoji: 0.68-1.0; LED: 0.5-1.0; Sound: 0.82-1.0). A two-way ANOVA with the factors condition (HMI) and day of exposure indicated no main effect for condition (F(3,49) = 0.98, p = 0.4), day of exposure (F(2,49) = 0.07, p = 0.93), or their interaction F(6,49) = 1.3, p = 0.27. The data therefore provide no answers to the first two research questions concerning differences in safety compared to a classical FCW or changes in safety with increasing exposure.

## Subjective Experience



*(a)* *(b)* *(c)* *(d)*

***Figure 5 -*** **Averaged subjective ratings on perceived usefulness, annoyance, difficulty, and naturalness for each HMI and day of exposure.**

**Logbook Ratings:** The subjective experience, quantified in terms of perceived usefulness, annoyance, difficulty, and naturalness, was assessed through logbook ratings, which participants were asked to provide after each drive. This request was met in 76% of all cases, yielding an average of 1.2 ratings per participant, condition, and exposure day. Due to this small sample size no inferential statistics on the ratings are provided. Figure 5 shows the average experience ratings for each HMI and day of exposure.

Usefulness of all HMIs including Baseline (FCW) was initially rated neutrally (Figure 5a). While ratings were constant over days of exposure for the Emoji HMI, the perceived usefulness for LED and Sound HMI dropped on day two but returned to neutral or slightly positive levels on the third day. Only the Baseline (FCW) ratings increased from neutral to positive on day three.

The LED and Sound HMIs were initially perceived as slightly annoying (Figure 5b). But while LED ratings remained low, the Sound HMI appears to have lost its perceived annoyance over time. Baseline and Emoji were rated neutrally for all days.

Difficulty ratings (Figure 5c) indicate whether participants found it difficult to notice and interpret HMI output. All except the LED HMI were assigned neutral difficulty ratings on the first exposure day while the LED HMI was easy to perceive on the first and the third but not the second day. Over time the sound HMI appears to have become easier to perceive whereas ratings stayed similar for Emoji and Baseline conditions.

The temporal upward trend of the Sound HMI also repeats for naturalness ratings (Figure 5d). It was perceived as slightly strange on the first two days but shifted towards more neutral ratings on day three. Emoji and LED HMI were perceived as more natural from day one. Baseline drives were perceived as the most natural. In these drives HMI output could only appear in situations of high risk, making them mostly identical to unassisted driving (see Section 4.1).

In summary, the subjective HMI experience only appears to vary consistently for the Sound HMI in line with our third research question. This variation is characterized by an initially slight rejection and perception difficulty that develops into a more positive and accessible perception with added exposure. LED HMI ratings are less consistent, showing no clear recovery from negative ratings despite low difficulty and high naturalness ratings. The Emoji HMI was consistently rated slightly above neutral and not difficult or unnatural to perceive. Baseline drives were mostly rated neutrally but also as the most natural, in line with the absence or rarity of HMI output.

**Interview Feedback:** Final interviews with participants provided some general insights on the common approach of the newly introduced HMIs. The different levels of expression that scaled with risk were regarded as a desirable property and were reported as helping in understanding the front risk reference. However, it was not universally understood whether situations were already serious at HMI onset, especially when initial stimuli were strongly perceived. An overly strong onset was further regarded as potentially distracting.

For the Emoji HMI it was appreciated that information could be accessed through fixations on demand without being obtrusive. However, the requirement for a fixation and the low salience were also seen as weaknesses. Some participants requested the Emoji to disappear more quickly after risk reduction while others would have preferred them to stay longer, suggesting potential in customization. One participant reported that Emoji appearance at HMI onset was more noticeable than Emoji changes at increasing risk.

The LED HMI was described as very recognizable and intuitive. It could capture a drivers attention also peripherally, e.g., while looking at the navigation screen, suggesting a better compatibility with the largely vision-guided driving task. However, it was also interpreted as urgent soon after onset and as drawing attention too strongly.

For the Sound HMI it was reported that the reference to a developing risk became easy and intuitive over time. However, a temporal impairment to listen to the radio was partially seen as a weakness. Furthermore, perceivability was reported to vary depending on the radio program and driving speed.

## CONCLUSIONS

Here we introduced three human-machine interfaces (HMI) for a driver assistance designed to inform a driver about the presence and estimated urgency associated with a detected front collision risk. The HMIs continuously scale aspects of their output (one auditory, two visual) with the risk level to realize a risk communication that starts informing a driver much earlier than classical warning systems to facilitate foresighted driving. Functional prototypes of the interfaces were realized in a vehicle for further investigation in real traffic. We carried out a user study to investigate effects of the HMIs on driving safety and subjective user experience, as well as the potential role of the amount of HMI exposure.

Driving safety, in terms of front collision risk, was high across all conditions, including largely unassisted driving and irrespective of the amount of exposure. A safety-level benefit on top of high baseline levels was not observed. If such effects should exist, more data would likely be required to detect significant differences within low risk ranges and to detect any exposure-related safety effects. Alternatively, more controlled experimental settings that artificially provoke situations with higher risks or situations that are less predictable could facilitate an understanding of HMI effects on safety and driver behavior in general.

On the subjective experience level exposure-related benefits on ratings for usefulness, annoyance, difficulty, and naturalness were observed for a sound-based HMI. No such effects were observed for the two visual HMIs. However, a potentially higher initial intuition for these HMIs, which are exploiting specific pre-existing aspects of human visual processing such as optical flow and emotion recognition, might account for a reduced need for initial adaptations.

Overall the need for both sufficient stimulus salience to appropriately capture a driver's attention and initial subtlety to avoid causing driver distractions remains a challenge. Participant feedback suggests that this may be partially addressed by parameter adjustments and personalization. Investigations of future HMI refinements should further adjust the experimental design to promote a detection of potential effects on driving safety.

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