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Blinking, Beeping or Just Driving? Investigating Different Communication Concepts for an Autonomously Parking E-Cargo Bike From a User Perspective

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ABSTRACT

While autonomously parking e-cargo bikes offer the potential to enhance users' comfort and time efficiency at sharing-stations, it is important to ensure a safe and useable interaction. External human machine interfaces (eHMIs) provide a possible solution for highly automated systems to communicate relevant information and to ensure system transparency. We conducted a laboratory study investigating three different communication concepts for autonomously parking e-cargo bikes: (1) a visual eHMI, (2) an auditory eHMI, and (3) a baseline condition. Participants ($N = 36$) watched videos of an autonomously parking e-cargo prototype and assessed each concept regarding user experience, acceptance, perceived safety, and trust. Results revealed a clear ranking of communication concepts with the visual eHMI rated to be most suitable followed by the auditory eHMI, whereas ratings for the condition without eHMI revealed considerable concerns for all aspects. Our findings suggest important implications for designing user interfaces for self-parking e-cargo bikes.

Keywords: E-Cargo bike, Automated driving, External HMI, Communication cues, User study, Safety, Acceptance, Trust, UX

INTRODUCTION

Autonomously parking e-cargo bikes offer the potential to enhance users' comfort and to save time during return at sharing stations and could therefore contribute to higher attractiveness of this sustainable mode of transport. However, to interact safely, efficiently, and comfortably with such autonomous functions, a certain degree of system transparency is of particular importance. Besides, driving also comprises a social facet requiring interactions and communication between all involved traffic participants to ensure a smooth and safe cooperation (Rasouli and Tsotsos, 2018). For this communication and the anticipation of the development of a traffic situation, interaction partners have been found to use implicit (e.g., vehicle trajectory, deceleration) as well as explicit cues (e.g., gestures, indicator; Schieben et al. 2018). Especially in case implicit cues are not sufficient, external human machine interfaces (eHMIs) are discussed as a possible solution for communicating relevant information such as vehicle status when interacting with highly automated systems (Schieben et al. 2018). In this context, shared spaces are of particular interest because of many potential encounters with various traffic participants, especially vulnerable road users, and only limited regulations, resulting in a high amount of ambiguous situations (Hammilton-Baillie, 2008). As (e-cargo) bike sharing stations and the surrounding area could be categorized as shared spaces, the investigation of users' requirements in terms of communication needs during highly automated parking is of high importance.

While to our knowledge there is no human factors research about autonomously parking (e-cargo) bikes, recent studies have been conducted in the field of automated passenger cars (e.g., Hensch et al. 2019). Results of these studies predominantly revealed promising effects and identified users requiring supplementary cues in addition to implicit signals from the automated vehicle's movements for certain scenarios (Faas et al. 2020). In this regard, positive effects in terms of enhanced perceived safety (De Clercq et al. 2019) and trust (Faas et al. 2020) have been shown for eHMIs compared to a baseline condition without additional cues. Besides such directly safety-relevant issues, user acceptance of the signals and a satisfactory user experience (UX) constitute important facets when thinking about the introduction of eHMIs for automated systems. Research so far indicates the potential of eHMIs to increase both acceptance as well as UX in the interaction with highly automated vehicles (Avsar et al. 2021; Faas et al. 2020). The current study contributes to the field of research investigating the effect of different communication concepts taking into account eHMIs as well as a baseline condition for the scenario of a self-parking e-cargo bike.

In the automobile context, plenty of studies investigated eHMIs for different traffic situations and with a broad variety of design options regarding relevant characteristics such as signal modality or abstraction level (Dey et al. 2020). Although a standard aiming at a consistent design of eHMIs would be useful, consensus still has to be found based on results of research. In this regard, the question about the appropriate and most efficient modality for eHMIs has often been raised (Dey et al. 2020; Rasouli and Tsotsos, 2018). Studies investigating auditory eHMIs are rather scarce compared to a clear research focus on visual eHMIs (Dey et al. 2020). Apart from that, studies conducted so far showed mixed effects. For example, Merat et al. (2018) found no clear results when comparing safety measures for visual and auditory eHMIs in a cross-cultural study. In a survey study, Haimerl et al. (2022) observed better assessments for visual compared to auditory communication concepts with regard to UX. We included both modalities as eHMIs in the current study in order to gain further knowledge on the comparison of these concepts and to explore them in the context of self-driving bikes.

To summarize, we addressed two objectives in the scope of our study:

(A) Investigation of the effects of explicit versus implicit communication cues for the interaction between users and highly automated e-cargo bikes regarding users' UX, acceptance, perceived safety and trust.

(B) Exploration of effects of modality comparing assessments of an auditory and a visual eHMI for autonomous e-cargo bike parking in terms of users' acceptance, UX, perceived safety, and trust.

As the user, who shared the e-cargo bike and wants to return it at the sharing station, is an important interaction partner involved, we decided to focus on this perspective for our evaluation in a first step of research.

METHOD

Research Design and Communication Concepts

In order to investigate whether an eHMI is needed in addition to implicit information via the vehicles' movements and to compare two different eHMI modalities, we conducted a laboratory study evaluating three different communication concepts for autonomously parking e-cargo bikes. Applying a one-factorial within-subjects design, we comparatively examined the concepts described below (see Table 1 for detailed descriptions):

(1) a visual eHMI implemented via LED light band (fixed at the handlebar and the cargo box, Figure 1),
(2) an auditory eHMI implemented via signal tones, and
(3) a baseline condition without an eHMI but based on implicit cues.

According to Schieben et al. (2018), the investigated signals predominantly refer to information about vehicle driving mode (takeover from manual to autonomous mode) and next maneuvers (autonomous parking) as well as the perceptions of the environment (detection of obstacle). In the baseline condition, communication was solely based on implicit communication cues such as vehicle trajectory or deceleration without any additional eHMI. For the visual eHMI, the color turquoise as common color in automated driving was chosen, supplemented by a red- and green-colored signal indicating an error state or a successful completion of the task, respectively (confer Dey et al. 2020). When designing the auditory communication concept, the aim was to choose characteristics as similar as possible to the visual concept. However, some modality specific adaptations had to be made for reasons of interaction comfort as decided by the human factors team (e.g., a continuous beep tone without pause during autonomous parking would have been too aversive). For both concepts, we decided for a rather abstract design of the eHMIs, as we believe these are more independent from aspects like language understanding (compared to meaningful words) or symbol recognition and interpretation and therefore more compatible in terms of a Design for All approach.

The video material used in the study showed two different autonomous parking scenarios of the e-cargo bike implemented via Wizard of Oz: (a) an unobstructed (parking process without obstacles) and (b) an obstructed (parking process with a barrier in the parking trajectory) use case (Figure 1). The autonomous parking process was as follows: After the takeover from manual to autonomous mode, the e-cargo bike started the automated drive by an initial steering and backwards movement at walking speed. While the e-cargo

Figure 1: Example screenshots of the presented video displaying the e-cargo bike at the beginning of the autonomous parking process for the unobstructed (left) and obstructed scenario (right) with the visual eHMI.

bike successfully completed the parking process at the charging point in the sharing station in the unobstructed condition, parking was interrupted by deceleration and standstill in front of a bottle crate in the obstructed scenario. The description of the e-cargo bike's actions and the respective visual and auditory eHMI is depicted in Table 1. Both use cases were presented for each communication concept.

Instruction and Procedure

When arriving at the laboratory, informed consent was obtained from the participants and they received some information about the SteigtUM project as well as the use case of autonomous parking of e-cargo bikes at sharing stations. Furthermore, the investigated communication concepts were explained and presented in a balanced order. Participants were asked to watch the pre-recorded videos from the perspective of a user who wants to return the e-cargo bike after a shared ride and just initiated the autonomous parking process via the user interface of a smartphone app. Subsequent to the introduction and the videos for the respective communication concept presented on a TFT-display and via speakers, participants completed a set of questionnaires to assess each concept. In the end, a short questionnaire containing items about socio-demographic variables was applied and participants had the opportunity to clarify open questions. As compensation for taking part in study, which lasted about 90 minutes, participants could receive course credits in case they were students of Chemnitz University of Technology.

Questionnaires

In order to assess the investigated communication concepts of the autonomously parking e-cargo bike, participants were instructed to complete a questionnaire containing items regarding (UX), acceptance, subjective safety

Table 1. Overview about actions in the autonomous parking process with vehicle movements and description of the respective visual and auditory eHMI.

Action	Without eHMI (e-cargo bike movement)	Visual eHMI (LED strip at handle-bar & cargo box)	Auditory eHMI (signal tones via speakers)
Takeover from manual to autonomous mode	Standstill in front of the sharing station	5 flashes of the LED strip in turquoise (RGB: 1, 128, 181, 600 ms length each, 600 ms pause)	5 beep tones (length: 500 ms, 1000ms pause; frequency: 700 Hz, volume: −19 dbFS)
Autonomous parking	Steering movement and backwards driving at walking speed (further steering & de-/acceleration if needed)	Continuous shine of the LED in turquoise (RGB: 1, 128, 181)	Continuous beep tones (length: 500 ms, 1000ms pause, frequency: 700 Hz, volume: −32 dbFS)
Successful completion of the autonomous parking	Standstill in the sharing station	3 flashes of the LED strip in green (RGB: 0, 255, 0; length: 1000 ms each, 300 ms pause)	Sound sequence (4 tones (frequency: 264, 330, 396, 528 Hz), length: 500 ms, 750 ms pause, volume: −20 dbFS)
Detection of obstacle in trajectory	Deceleration until standstill in front of the obstacle (no movement until obstacle is removed)	Continuously flashing LED strip in red (RGB: 255, 0, 0; length: 500 ms, 300 ms pause)	Continuous warning tones (length: 500 ms, 750 ms pause, frequency: 1000 Hz, volume: −23 dbFS)

and trust. As a tool to collect the subjective impression of users regarding the UX of products, the short version of the *User Experience Questionnaire* (*UEQ-S*; Schrepp et al. 2017) was used. The *UEQ-S* is a semantic differential with eight items that have to be answered on a 7-point scale representing values ranging from -3 (full agreement with negative term) to +3 (full agreement with positive term; e.g., "clear" – "confusing"). The questionnaire was applied to the three communication concepts. Calculating a mean score, a total value reflecting the overall UX was derived (Schrepp et al. 2017) with good internal consistency (Cronbach's $\alpha = .80$ - .84).

In order to assess users' acceptance regarding the investigated communication concepts, users were asked to complete the *Van der Laan Acceptance Scale* (van der Laan et al. 1997). Participants' ratings were collected for nine word pairs on a 5-point semantic differential. The scale consists of two subscales, a *Usefulness*- and a *Satisfaction*-score represented by the calculated means of the respective items of both scales with values ranging from −2 to +2. Four semantic differentials belong to the *Satisfaction* scale (e.g., "pleasant" – "unpleasant"), the other five items belong to the *Usefulness* scale (e.g., "bad" – "good"). The internal consistency of both sub-scales was satisfactory for all investigated communication concepts (*Satisfaction*: Cronbach's $\alpha = .80 - .93$; *Usefulness*: Cronbach's $\alpha = .76 - .83$).

For trust ratings, we applied the *Scale for Trust in Automated Systems* (Jian et al. 2000). The scale consists of 12 Items that have to be answered on a 7-point Likert scale ranging from 1 - "not at all" to 7 - "absolutely". For analysis, all ratings per person were aggregated to a mean overall trust score (Cronbach's $\alpha = .80 - .91$).

Additionally, participants indicated their feeling of safety by a single item measurement ("I felt safe when interacting with the autonomously driving e-cargo bike") on a 7-point Likert scale ranging from 1 - "completely disagree" to 7 - "completely agree".

Participants

A total of $N = 36$ participants, amongst them $n = 17$ women, $n = 18$ men and $n = 1$ diverse, took part in the study. The sample had a mean age of $M = 26.5$ years ($SD = 6.4$; $Min = 18$ years; $Max = 48$ years) and was predominantly highly educated (53% with university degree, 36% with abitur, 11% with secondary school certificate).

RESULTS

The effect of the different communication concepts on participants' assessments was analysed calculating repeated measures ANOVAs. In case the assumption of sphericity was violated (Mauchly's test), the Hynh-Feldt correction was applied.

User Experience

In order to get an impression about the UX of the tested eHMIs, we applied the *UEQ-S*. The repeated measures ANOVA resulted in a highly significant effect for the communication concept with a large effect size, $F(1.45, 50.90) = 90.924$, $p < .001$, $\eta_p^2 = .722$. Bonferroni-corrected pairwise comparisons revealed differences for all conditions on a highly significant level ($p < .001$). As depicted in Figure 2, the visual eHMI received the highest UX ratings, which could be interpreted as good UX on a descriptive level. The auditory eHMI ranged in a medium to good UX-level, whereas the condition without eHMI received low values representing a rather poor UX assessment.

Acceptance

Investigating the acceptance of the three communication concepts, we applied the *van der Laan Acceptance Scale* comprising a *Satisfaction*- and a *Usefulness*-scale. Regarding *Satisfaction*, the repeated measures ANOVA resulted in a highly significant large effect for the communication concept, $F(1.61, 56.42) = 56.411$, $p < .001$, $\eta_p^2 = .617$. All Bonferroni-corrected pairwise comparisons showed highly significant differences between all communication concepts ($p < .001$) with best ratings for the visual eHMI, followed by the auditory eHMI and the baseline condition. On a descriptive level, the visual eHMI reached scores representing a satisfying communication concept

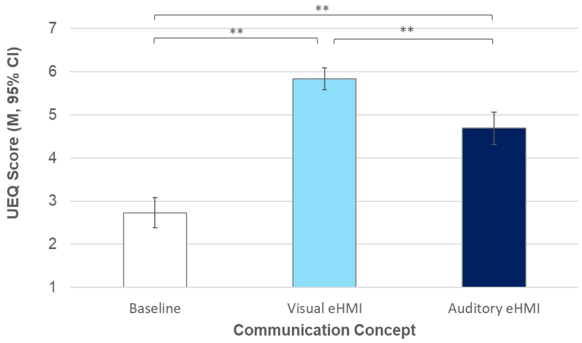

Figure 2: Comparison of UX-ratings for the three communication concepts. $^{**}p < .001$.

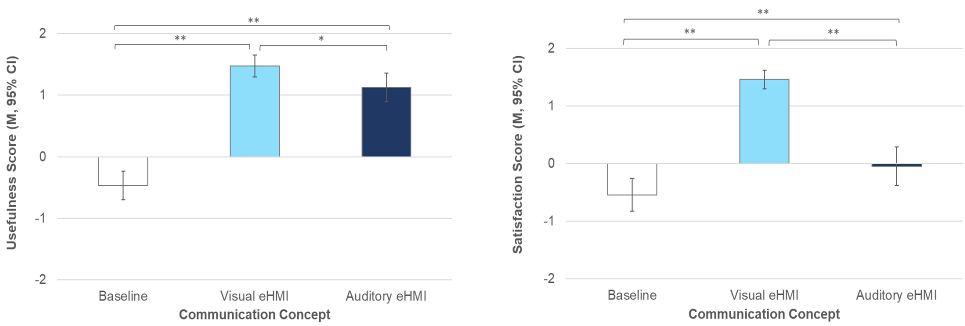

Figure 3: Comparison of acceptance assessments for the investigated communication concepts (left: scale *Usefulness*; right: scale *Satisfaction). $^{*}p < .05$; $^{**}p < .001$.*

(Figure 3). For the auditory eHMI, ratings were at a rather neutral level. For the baseline condition without any external communication cue, we observed rather poor *Satisfaction* scores represented by negative values.

Similarly, we observed a highly significant effect with a large effect size for the communication concept regarding *Usefulness*-ratings, $F(2, 70) = 84.215$, $p < .001$, $\eta_p{}^2 = .706$. Bonferroni-corrected pairwise comparisons resulted in highly significant differences between the baseline condition and the visual eHMI ($p < .001$) as well as the auditory eHMI ($p < .001$) with higher *Usefulness* ratings for conditions with eHMI, respectively. Furthermore, we obtained higher *Usefulness* scores for the visual compared to the auditory eHMI ($p = .043$). While negative values for the baseline condition represent rather poor *Usefulness*, the ratings for both eHMI conditions revealed a medium (auditory eHMI) to rather high *Usefulness* (visual eHMI; Figure 3).

Trust

To compare users' trust in the autonomously parking e-cargo bike, participants rated trust in the system according to Jian et al. (2000). Results of the repeated measures ANOVA revealed a highly significant effect for the communication concepts regarding trust with a large effect size,

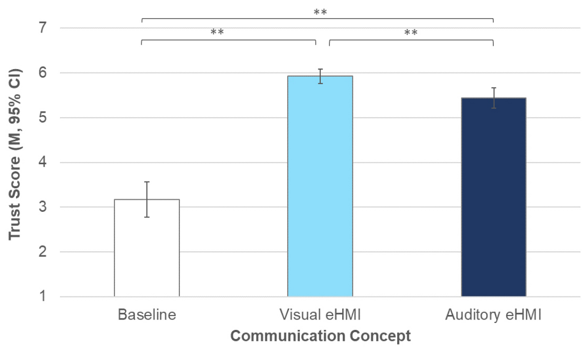

Figure 4: Comparison of trust ratings for the different communication concepts. $^{**}p < .001$.

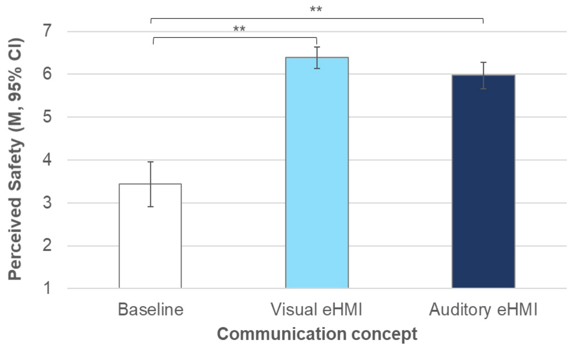

Figure 5: Perceived safety compared for the investigated communication concepts. $^{**}p < .001$.

$F(1.39, 48.57) = 118.314$, $p < .001$, $\eta_p^2 = .772$. Bonferroni-corrected pairwise comparisons resulted in highly significant differences for all tests ($p < .001$) with highest trust scores for the visual eHMI followed by the auditory eHMI. As can be also seen in Figure 4, the trust scores for the baseline condition, where no eHMI was applied, were rather low.

Perceived Safety

As another important facet in the evaluation of potential communication concepts for autonomous e-cargo bike parking, we investigated users' perceived safety during the autonomous parking process via single item measurement. Results of the repeated measures ANOVA, again, showed a highly significant and large effect for communication concept, $F(1.39, 48.57) = 77.515$, $p < .001$, $\eta_p^2 = .689$. Consistent with the results of the other measures, we observed highly significant differences between the condition without eHMI compared to the visual ($p < .001$) and auditory eHMI ($p < .001$) as revealed by Bonferroni-corrected pairwise comparisons. Participants indicated higher perceived safety ratings for both eHMI conditions compared to the baseline condition (Figure 5). There was no significant difference for the comparison of both eHMIs.

DISCUSSION AND CONCLUSION

In order to investigate the effects of different communication concepts for the communication of autonomously parking e-cargo bikes from a user perspective, we conducted a study based on pre-recorded videos comparing a visual eHMI, an auditory eHMI and a baseline condition based on implicit cues. In sum, results consistently showed better assessments for eHMIs compared to the baseline condition without additional cues confirming findings of research in the automotive context (e.g., Faas et al. 2020). Especially with regard to safety aspects in the interaction with the autonomously parking vehicles, users' perceived safety was significantly enhanced by an eHMI regardless of signal modality in contrast to solely implicit communication cues. While participants indicated rather high feelings of safety for situations with explicit communication signals, the baseline condition received rather low to medium safety ratings. For the other investigated constructs, we observed differences between all communication concepts. More concretely, the visual eHMI received best assessments with consistently good or high scores on a descriptive level regarding UX, acceptance as well as trust in the automated system. For these aspects, the visual was preferred over the auditory communication concept, which has been similarly found by research investigating automated cars (He et al. 2021). As we observed biggest differences for UX and *Satisfaction* ratings for the auditory eHMI, we interpret these results rather in terms of the need for increased interaction comfort than claiming a big safety or usefulness issue. The ratings for the baseline condition, however, resulted in rather low to medium scores indicating that solely implicit communication according to the vehicle's movements is not as sufficient, safe, acceptable and trustworthy as needed. Comparable results have been shown in research for automated cars, implying a certain need for additional communication cues in specific situations (e.g., Merat et al. 2018).

Our study provides important insights into the field of interaction with autonomously parking e-cargo bikes. Some aspects of the study, however, have to be considered when interpreting the results or rather open the field for further in-depth research. The focus of the study was the perspective of the user who just shared the e-cargo bike and is now monitoring the highly automated return at the sharing station. As stated in the beginning, sharing stations might be located in shared spaces, where interaction with many different traffic partners (e.g., passengers) could occur, whose perspective should be incorporated in future evaluations. Furthermore, also other interaction scenarios and signal information, for instance incorporating cues regarding yielding scenarios, might be investigated. Although we tried to design both the visual and auditory eHMI in a comparable way (similar length, amount and abstractness of signals), there were some differences due to certain design considerations and specifics of modality. For example, the visual eHMI was presented continuously during the parking process, while the auditory signal was interrupted by pauses in order to prevent it from appearing aversive. While we do not have any hints in this direction, this, however, may have led to unintentional effects that might have also been reflected in users' assessments. Furthermore, as also raised by Dey et al. (2020), evaluations in a next step should incorporate design solutions which take into account the inclusion of people with special needs such as a visual impairment. In this regard, one option in terms of an inclusive design might be the combination of visual and auditory cues in the communication concept. Apart from that, the study set-up could play an important role. For this first step, we chose a laboratory setting to investigate the effects of the different communication concepts in a controlled environment with a high safety standard. Future studies, however, should aim at gaining knowledge about the assessment in the field, facing real conditions such as different surrounding light and noise conditions, further enhancing the external validity of data.

Taken together, results revealed a clear ranking of communication concepts from a user perspective indicating the visual eHMI to be most suitable for the investigated scenarios followed by the auditory eHMI. Participants' assessments imply that a communication concept implicitly interacting with users is not suitable for the investigated scenarios. Our findings suggest important implications for the design of the user interface for the automated parking process and offer a basis from which to start in-depth investigations regarding this emerging application in the field of highly automated (e-cargo) bike functions.

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