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Light-based Solutions for the Acceptance of Facing Rearward in Autonomous Vehicles

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Abstract

The introduction of autonomous vehicles into road traffic is accompanied by the development of innovative seating layouts. Concepts of such layouts often include rotatable front seats, which are supposed to enable a new level of social interaction during autonomous driving and find much approval among potential users. This contrasts with a seemingly very low willingness to be driven autonomously while sitting in the opposite direction of travel. Two reasons for this emerge, lack of trust in the autonomous vehicles and fear of motion sickness. With both being a point of concern in AVs in general, research suggests them being even more eminent when facing against the direction of travel.

Based on current literature, a new model is proposed taking seating orientation and motion sickness into account. Building on this model, the use of light-based HMIs to increase transparency with respect to perception and intention of the AV is discussed. The goal of the work is to gain a more detailed understanding of the acceptance of rearward seating orientations in autonomous vehicles, incorporating trust and motion sickness.

Index Terms: Autonomous vehicle, HMI, motion sickness, trust, acceptance

1 Introduction

SAE L4 and L5 autonomous vehicles (AVs) are anticipated to improve road safety and eco friendliness. Further advantages include an improved utility and comfort for the driver, who's role transitions to that of a passenger free to use the traveling time for non-driving related tasks (NDRTs), such as working, playing games, watching movies or social interaction with other passengers. Many concepts of such AVs, e.g., of autonomous shuttles include seating arrangements with rotatable or rearward facing seats, (Mercedes-Benz F 015, Volkswagen SEDRIC, Yanfeng Automotive Interiors XiM18, Zoox Boz, Volvo 360c, Renault Symbioz, Renault EZ-Ultimo, Nio EVE, …), as they are common in public transportation vehicles such as trains and busses. Advantages of such seating setups include not only a potentially increased safety

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during crashes [28], but also the support of social activities during autonomous rides [27, 30, 49].

2 Motivation

Pettersson and Karlsson found that potential passengers of autonomous vehicles put a focus on social aspects of AVs: "Being able to engage more in other passengers was perceived as one of the main values to be found in autonomous cars" [49]. Participants were asked to draw the car designs they imagined for autonomous driving, with 89% of the participants drawing interior concepts with rotatable seats. In a study conducted by Jorlöv et al., a setup with two front-facing and two rearward-facing seats was preferred over setups with 90-Degree and 46-Degree rotated seats that faced each other [30]. An expert workshop conducted by Sun et al. (2021) to arrive at "a new type of seat, […] which could be adjusted for use on non-driving orientated activities", resulted in an interior concept with rotatable front seats [58]. While there appears to be a general desire for setups with rearward facing seats in autonomous cars, especially when traveling with peers as opposed to strangers, there are reservations towards facing rearwards while being driven. Han et al. (1998) found that train passengers "like being seated in the same direction ('forward') nine times more than the opposite one ('backward')" [21]. A survey conducted by Murphy et al. (2013) revealed that 17% of respondents ruled out sitting backwards in a train entirely. Here the question arises as to the acceptance of sitting backwards in non-rail bound L4 and L5 AVs [43]. The following sections explain why this acceptance is expected to be even lower.

3 Transparency and Trust

Literature suggests that informational needs of passengers of AVs include transparency concerning the vehicles perception and intentions (e.g., [1, 17). Using a simulator study and comparing manual, L2 and L3 automated driving, Beggiato et al. found that the most requested information in automated driving is on system status, current and planned maneuvers, and surrounding traffic [1]. Similarly, Feierle et al. report that mainly information about maneuvers, about reasons for those maneuvers and about the surroundings were demanded by participants of a simulator study with L3 automation [17]. Kaber et al. (2012) stress that passengers of AVs desire to monitor lateral and longitudinal driving maneuvers as well as the cars reactions to the road and traffic situation [31]. Sun et al. found that passengers of L3 AVs "exhibited strong needs to monitor the driving tasks to enhance their situational awareness" [58]. Evidence suggests that these needs persist at higher automation levels, at least in passengers that do not fully trust the AV yet. In a dynamic driving simulator study, Chang et al. (2019) found that the use of a situational awareness display that depicts the AVs perception and intentions increases trust in passengers of autonomous taxis [8]. Choi & Ji (2015) report that system transparency explains a significant portion of variance of trust in AVs [11]. Beggiato et al. report a connection between trust and

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information needs: “The more trust, the less information is demanded” [1]. Paddeu et al. (2020) found that rearward facing passengers report significantly lower trust and comfort than forward facing passengers of autonomous shuttles [47]. Since rearward facing passengers experience less trust than forward facing passengers, this lack of trust might be explained by the lack of information due to reduced visibility of the surroundings and upcoming traffic events. Based on these findings, two main differentiators between forward- and rearward facing seating positions in autonomous cars can be distinguished. On one hand, rearward facing passengers experience lower *intention transparency*, that is the vehicle’s ability to adequately communicate it’s planned driving maneuvers to the passengers (e.g., direction and intensity of upcoming longitudinal and lateral motion). On the other hand, they also experience less *perception transparency*, that is the vehicle’s ability to adequately communicate what elements of the driving environment it recognizes (e.g., other relevant road users and objects like traffic signs).

Since the intention to use and the acceptance for such vehicles is dependent on the amount of trust put into them [3, 7, 10, 11, 16, 24, 28, 33, 44, 48, 68, 69, 71, 72], the question arises whether the trust of rearward facing passengers can be increased by increasing to a level as close as possible to that of forward facing passengers by increasing intention transparency and perception transparency. Achieving this goal would aid enabling the advantages of self-driving shuttles and AVs with face-to-face seating layouts in general.

4 Motion Sickness

Lack of trust and information is not the only factor preventing passengers of AVs from wanting to sit facing rearward. While some report that a fundamentally changed interior could scare other road users who are afraid of AVs [49], one of the most fundamental concerns regards the fear of motion sickness [34]. Motion sickness is already a concern in AVs with traditional seating layouts, since the renunciation from the driving task and the increased engagement in NDRTs leads to less predictability of upcoming maneuvers and therefore a higher probability of a neural mismatch between anticipated and felt motion of the passengers [14, 15, 19]. According to the neural mismatch and sensory rearrangement theory [51], this mismatch leads to symptoms like nausea. Another explanation for the occurrence of motion sickness is found in the postural instability theory, which states that the lack of postural stability, which can be caused by not being able to properly anticipate upcoming movements, leads to motion sickness [54]. Literature suggests that motion sickness is significantly higher when being driven and facing rearwards rather than forwards due to an even more impaired ability to anticipate the upcoming motion trajectory [5, 15, 55, 60]. On the contrary, Schmidt et al. (2019) found no effect of seating direction on motion sickness during real highway and inner-city drives [56].

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5 Autonomous Driving Acceptance Model

To improve the acceptance of facing rearwards in AVs, we must first understand how this acceptance comes about. Since no existing model of the acceptance of autonomous vehicles fully accounts for the positive impact of information transparency or the negative impact of motion sickness, current models cannot adequately explain the difference in acceptance between using AVs while being seated facing forwards and being seated facing backwards. Given the theoretical and empirical background presented, a new Autonomous Driving Acceptance Model for SAE levels 4 and 5 (ADAM) is postulated (Fig.1). It builds upon the Autonomous Vehicle Acceptance Model (AVAM) that was proposed by Hewitt et al. (2019) and the model for the acceptance of driverless automated shuttles proposed by Nordhoff et al. (2021a) [25, 44]. AVAM is based on the Universal Theory of Usage and Acceptance of Technology (UTAUT) [61] and the Car Technology Acceptance Model (CTAM) [46]. AVAM predicts the behavioural intention to use AVs on the basis of seven factors: performance expectancy, effort expectancy, attitude, social influence, self-efficacy, anxiety and perceived safety.

However, since ADAM only accounts for L4 and L5 autonomous driving, self-efficacy is negligible because there is no demand regarding specific abilities or competences such as supervising the vehicle or taking over control. Furthermore, Hewitt et al. found the importance of effort expectancy to shrink with increasing automation level [25]. Since L4 and L5 autonomous driving does not require any input from the passengers and instead allows them to pursue NDRTs, effort expectancy should not have an influence on its acceptance. Consequently, Nordhoff et al. (2021a) found no such effect [44]. In their meta-analysis, Zhang et al. (2021) found that perceived ease of use, which they equate with effort expectancy, is a significant predictor for behavioral intention when it comes to partial automation, but not when it comes to full automation [72].

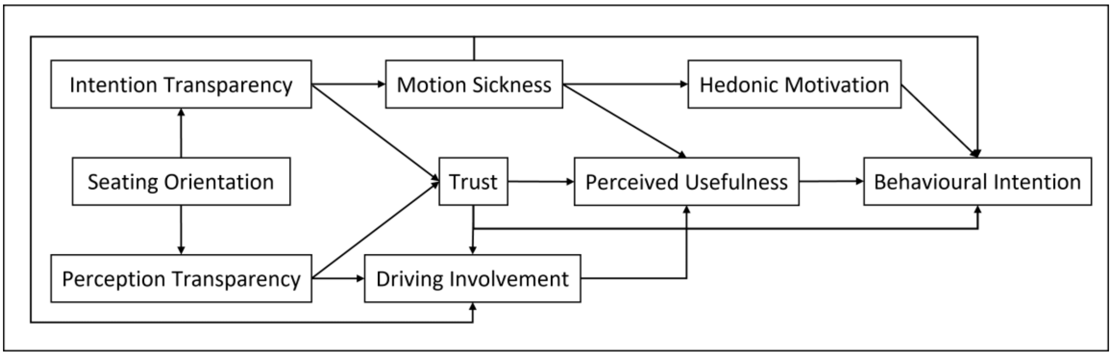

Fig. 1. Autonomous Driving Acceptance Model.

For this reason, effort expectancy too is eliminated from the proposed model. The possibility of NDRTs being one of the biggest advantages of L4 and L5 AVs, performance expectancy is replaced by perceived usefulness, derived from the CTAM. While literature suggests the two to be interchangeable [45, 68, 71],

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perceived usefulness takes the passengers' freedom of choosing how to use travel time to their liking into account and therefore presents a better fit for fully automated and autonomous driving, specifically.

Since trust is highly negatively correlated with anxiety and highly positively correlated with perceived safety, both are removed, as it is assumed that the predictive power of both factors will render insignificant as soon as trust is added to the model. Zhang et al. (2020) proposed a structural model that included initial trust as the main predictor for attitude toward using AVs [70]. In this model, perceived safety risk had a significant effect on initial trust. Similarly, Nordhoff et al. (2021a) included trust as opposed to perceived safety in their "structural equation modeling approach for the acceptance of driverless automated shuttles" and found trust to be the second-strongest predictor for behavioral intention after compatibility [44]. Nordhoff et al. (2021a) adopted compatibility as well as trialability from the Diffusion of Innovation Theory (DIT), [44, 52]. However, along with automated shuttle sharing, these factors specifically aim at the use of shared autonomous shuttles. Rahman et al. (2019) found no effect of compatibility on acceptance of non-publicly shared AVs and since ADAM is universally applicable for both privately owned AVs as well as shared shuttles, these factors are neglected here [53].

Concerning social influence, Zhang et al. (2020) found it to be a significant predictor for trust and perceived usefulness, as well as behavioral intention [70]. For this reason, these effects are integrated into the proposed model. They also found a significant correlation between trust and perceived usefulness. This is in line with the rational that a lack of trust would lead to self-assuring behaviour, such as active monitoring of the vehicle and traffic. Such behaviour would prevent passengers from conducting NDRTs and therefore diminish the usefulness of the autonomous drive. For this reason, trust is anticipated to predict perceived usefulness. Hewitt et al. define attitude toward using technology as "an individual's overall affective reaction upon using a system". However, when establishing UTAUT, Venkatesh et al. (2003) substantiate the omission of attitude by reporting "empirical evidence to suggest that affective reactions […] may operate through effort expectancy" [61]. Since effort expectancy is not anticipated to be influential to the acceptance of L4 and L5 AVs, attitude is replaced by hedonic motivation. Venkatesh et al. (2012) define hedonic motivation as "the fun or pleasure derived from using technology" and establish it as a predictor of behavioral intention in UTAUT2 [62]. Nordhoff et al. (2021b) found hedonic motivation to be the strongest predictor for the intention to use automated shuttles [45].

Motion sickness expectancy is included to accommodate for the influence of motion sickness on the acceptance of AVs. It is also expected to negatively influence usefulness, since the experience of motion sickness typically leads to motion sickness mitigating behavior, such as staring at the horizon are closing one's eyes. Similar to the effect of lack of trust, this would prevent passengers from conducting their desired NDRTs, again diminishing the autonomous drive's usefulness. Motion sickness is also expected to have a negative impact on hedonic motivation since experiencing symptoms like nausea should reduce the sense of pleasure while using an AV.

6 Interior Lighting

Having identified the factors that determine the acceptance of facing rearwards in AVs, means to enhance that acceptance need to be developed. Since rearward facing passengers are not able to gather information about the vehicle's perception and action via a quick glance through the windshield, the informational demand of such passengers is expected to be even more urgent than that of forward facing passengers. This information should ideally be delivered in ways that make it perceivable and processable without the need for full attention, which would require the interruption of NRDTs. Wolfe et al. (2017) argue that "*The shift towards increased automation in the vehicle will result in increasing periods of time when the driver is oriented well away from the roadway, rendering it imperative that we consider the capabilities and limitations of vision throughout the entire field of view. […] much of visual information acquisition and processing does not require attention*" [67]. They stress the importance of considering peripheral information when designing HMIs of AVs and the necessity to gather a better understanding of the capabilities of the peripheral field of view in this context. To this end, the use of interior ambient lighting emerges as a promising medium to convey such information, since it has shown to be perceivable and processable via the peripheral field of view [2].

6.1 State of the Art

While a handful of manufacturers have already started to implement informational functionality through ambient lighting, primarily in the form of a blind spot warning function (2020 Seat Leon, 2021 Mercedes S-Class), several studies have shown that this functionality can be extended to meet various informational needs. Pfromm et al. (2013) implemented a 360° LED strip in a static driving simulator to indicate the distance of relevant traffic objects to the ego vehicle, which led to shorter gaze attention times [50]. Furthermore, the authors report an intuitive understanding and high acceptance of the system, which indicates that such a function can potentially cater to the informational needs of passengers of AVs by providing them with transparency about the vehicles perceptions from the peripheral field of view. Löcken et al. (2015) visualized lane change recommendations and warnings during manual highway drives, again utilizing a 360° LED strip in a static driving simulator [39]. Using different colors and blinking frequencies, the concept led to significantly less critical lane changes and more lane changes to the right. Meschtscherjakov et al. (2015) used LED strips mounted on the A-Pillars of a manually driven driving simulator to visualize either a predefined speed, the current speed, or the current speed limit [41]. They found that displaying the current speed limit trough LED strips

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improves the convergence of the current speed towards that limit in manually operated cars and conclude that peripherally perceivable speed information is less visually distractive than glances at the speedometer. Matviienko et al. (2016) implemented navigation aids in the form of light signals from an LED strip mounted to the steering wheel in a manually operated driving simulator [40]. They found that the peripherally perceived signals drew less attention time from the driver and were preferred over traditional display-based navigation aids.

Since then, the rise of interest in AVs spawned research on the application of ambient lighting functions for automated and autonomous driving. Van den Beukel (2016) compared light-based iHMIs with auditive and graphic iHMIs with regards to their ability to aid drivers in L3 AVs [4]. He found light-based information transmission to be superior to displays and acoustic information transmission in terms of situational awareness, acceptance, and the perceptibility of potentially dangerous situations from the peripheral field of view, further exemplifying the benefits of transmitting information that is perceivable and processable without the need for full attention. Löcken et al. (2016) used LED strips between A- and B-pillars to indicate acceleration, deceleration, turning- and lane change maneuvers in L4 highway drives with a static simulator [37]. They conclude that the depiction of intended maneuvers of automated vehicles through LED strips helps passengers to understand these maneuvers. However, the system was only evaluated qualitatively and no conclusion with regards to trust, acceptance or user experience was made. Wilbrink et al. (2020) conducted a VR study with a virtual L4 vehicle in urban driving scenarios and displayed either the vehicles intentions or it's perception via LED strips [65]. They found that both variants can increase the usability of L4 AVs as well as trust in them, with no significant differences between the two concepts. This begs the question whether the simultaneous display of both perception and intention has additional benefits.

Lau et al. (2020) found that passengers of L3 AVs prefer the depiction of the vehicle's status, it's intended maneuvers and the detection of other road users through LED strips during NDRTs [36]. Without NDRTs, they prefer the depiction of only the vehicle's status. Colley et al. (2021) used LED strips as well as augmented reality (AR) and a head-up-display (HUD) in a VR study to visualize critical vulnerable road users and the vehicles intended reaction to them. They found that each concept increases perceived safety and trust in L5 AVs as well as perceived intelligence and intention of the developers compared to a baseline with no visualization. While there was no evidence for the superiority of the LED based iHMI compared to the AR and HUD based iHMIs, this might be explained by the fact that the participants did not engage in any NDRTs during the rides, which renders the LEDs' advantage of visibility via the peripheral field of view insignificant. Schneider et al. (2021) conducted a study with a static driving simulator and found that system information transmitted via a combination of app, augmented reality and LED strips improves usability, user experience and perceived control during L5 autonomous rides [57].

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Again, the participants were not instructed to engage in any NDRT, so conclusions on the effectiveness in use cases with occupied passengers cannot be deduced. Hecht et al. (2022) utilized LED strips that color coded the remaining time until the next takeover request in L3/L4 AVs through a study with a static simulator [22]. The concept led to higher usability and lower workload compared to a baseline without such functionality. Using an online video study, Tinga et al. (2022) found that displaying the reliability of the automation via LED strips increases usability, number of correct statements during thinking-aloud and less subjective expenditure of time in automated vehicles [59]. Interestingly, Colley et al. (2022) found that not displaying the AVs perception or intention at all, but instead masking the environment and replacing it by an alternative one without any traffic leads to even higher trust, usefulness, perceived safety, and satisfaction [13]. However, these findings are based on an online video study, which raises the question whether passengers still prefer such a system in real traffic, which might differ in terms of perceived risk.

Additionally, video studies are not feasible to investigate the mitigation of motion sickness as another enabler for the acceptance of facing rearwards in AVs. Concerning this mitigation, Diels et al. (2016) suggest to "*allow occupants to anticipate the vehicle's motion trajectory*" and consider this a fundamental principle for the design of AVs [15]. Kuiper et al. (2018) asked participants to conduct tasks on a tablet that was either mounted on the dashboard of an L5 AV or at height of the glovebox [35]. Participants using the former experienced significantly less motion sickness. Based on these findings, the authors conclude that stimuli perceived via peripheral vision can help mitigate motion sickness. In recent years, the use of light-based cues to achieve this purpose has been investigated by a handful of researchers. Bohrmann et al. (2021) investigated the effect of ambient lighting that dynamically adapts to the current speed and change of speed of an AV on Motion Sickness and conclude that visualizing the longitudinal vehicle dynamics "*could have potential benefits in the mitigation of carsickness*" [6]. They stress that "*subsequent studies should consider additional visualization of lateral vehicle dynamics to extend the functionality of the feedback system as well as adding diffuser covers to potentially mitigate mental workload or overstimulation*." However, the authors focused on displaying current as opposed to upcoming maneuvers, which might not be an ideal approach to resolve a neural mismatch between anticipated and felt motions. Additionally, only longitudinal dynamics were visualized, which raises the question what the ideal visualization for lateral or circular motions would be. Using a motion platform in combination with VR, Bloch investigated the effect of visual cues on the door panels, between the back seats and on the floor of the AV that represent an AV's motions either in real-time or half a second in advance [5]. Participants were seated facing rearwards and occupied by playing a computer game while being driven. Bloch found a reduction of motion sickness symptoms of 8% for real-time cues and 9% for predictive cues, both statistically significant. A possible explanation for these relatively small effects could be the confounding impact of simulator

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sickness [42]. Low fidelity in VR and dynamic simulators can cause this subtype of motion sickness even when the passengers have full vision on the road ahead [9, 26, 66]. Sensory conflicts due to simulator sickness were not addressed by the visual cues used in the experiment, which might be why motion sickness was only mitigated partially. This raises the question on how effective these motion cues would render in actual car rides.

Using a hidden driver, Bin Karjanto et al. (2017) conducted a Wizard-of-Oz (WoZ)-Study to simulate a L5 AV and compared drives with LEDs that indicate turning maneuvers 3 seconds in advance to drives without such LEDs [32]. The LEDs led to significantly lower motion sickness and higher situational awareness. Similarly, Hainich et al. (2021) used ambient LED strips to visualize upcoming turning maneuvers via light signals [20]. The function was able to mitigate motion sickness in especially susceptible passengers during drives on a test track with a L4 AV. However, NDRTs were operationalized by completely blocking the outside view. While this proves to be an effective way of inducing a neural mismatch, the external validity of such an operationalization seems questionable, since NDRTs like using a phone, reading, or working still allow for occasional glances through the car's windows. Nevertheless, there is evidence for the effectiveness of visualizing upcoming motions to mitigate motion sickness. Still the question arises as to whether this effect can be enhanced by providing a finer graduation of the vehicle's dynamics, similar to the approach by Bohrmann et al. [6].

6.2 Requirements for Future Concepts

The visualization of the AV's intended maneuvers and perceived environment is expected to increase the intention transparency and perception transparency and therefore counteract the negative impact of a rearward facing seating position on these factors. That in turn should then improve motion sickness expectancy, trust, NDRT-freedom, perceived usefulness, hedonic motivation, and behavioural intention (Fig. 2).

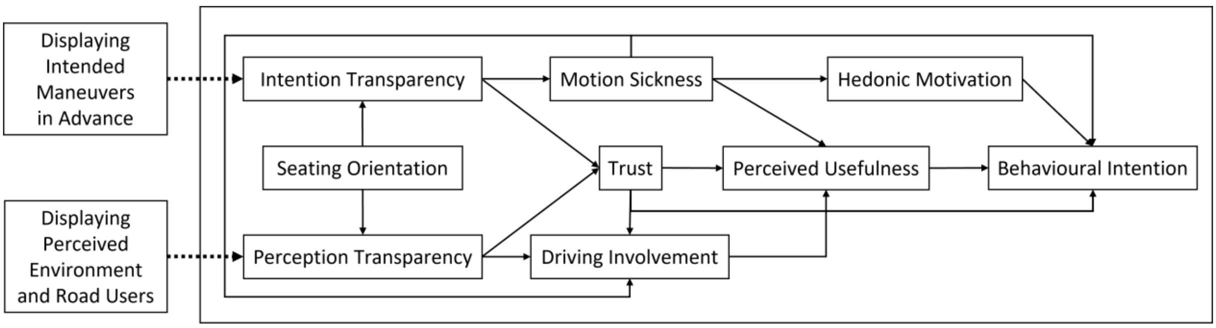

Fig. 2: Increasing acceptance by improving intention transparency and perception transparency.

Functional interior lighting is anticipated to also improve those variables in forward facing passengers, as they also engage in NDRTs, therefore do not have full information about the vehicle's perception and intentions and should profit from information provided to them via their peripheral field of view. However, this improvement is expected to be lower than in rearward facing passengers, since they have even less information about the vehicle's perception and intention. To enable this information transfer, perceptibility via the peripheral field of view needs to be ensured. Simultaneously, passengers must not be blinded or distracted from their NDRT, since this would negatively impact their acceptance of facing rearwards. A balance for achieving visibility and avoiding distraction and glare needs to be established by identifying ideal parameters for position and size of the light sources in the vehicle interior. Addressing the question concerning the position of light-based in-vehicle HMIs is necessary because existing research on this topic mainly focuses on a traditional driver's position [38, 39]. According to Funke and Frensch (2006), color detection is expected to be worse in peripheral vision than in foveal vision, since the number of cones on the retina diminishes with increasing distance from the fovea [18]. Regarding the size of the light source, Wernecke and Vollrath (2010) found that larger light sources are easier to perceive via the peripheral field of view [63]. According to Funke and Bengel, a sufficient size of the peripheral object can aid the perceptibility of changes in color via the peripheral vision. Since coding different messages via light signals at once might prove to be beneficial, enabling passengers to clearly distinct between different colors and color changes through the use of appropriate sizes of the peripheral light displays is desirable. However, it is still unclear whether simply maximizing the size of the light source is helpful for information transfer during NDRTs or rather distracts from them.

Additionally, light sources need to be positioned in a way that ensures equal perceptibility and understandability for forward facing passengers and rearward facing passengers. Weirich et al. (2022) conducted an online study and compared various positions for LED-strips through preference ratings on abstract renderings of car interiors [62]. For manual driving, they found a preference for LED-strips beneath the side windows and at the foot area, both of which are already established positions in modern cars. Interestingly, preferences where much more equally distributed between various positions, such as at the ceiling and the a-pillars for autonomous driving. The finding that there seems to be no clear preference for positioning of interior lighting during autonomous driving might suggest that the ideal positioning depends on the current NDRT, since the peripheral field of view changes with the orientation of the passenger and the current NDRT. For example, light from surfaces on the ceiling of the vehicle might prove to be more perceptible from a reclined seating position used for relaxation. Light signals from the floormats could be more perceptible when the passenger reads a book or works on a tablet, which often entails a downward tilt of the head. Light from the door panels and the pillars of AVs could be used to enhance the visibility of signals during social interaction, since these surfaces are more at level with

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the faces of other passengers. Overall, illuminating these surfaces could aid to make displayed signals more perceptible than using only LED strips beneath the windows, which have already been investigated extensively. A comparison between light-based HMIs on these surfaces during various NDRTs is necessary to identify optimal positions. Existing HMI concepts typically display simple information like system status or intended turning maneuvers via LED strips (e.g., [20, 22]) and more complex information like allowed NDRT in current driving mode or detected other road users via displays (e.g., [8, 58]). However, the display of complex information via the peripheral field of view might prove to be superior to the use of traditional displays that require direct attention. To this end, the use of larger light-emitting surface areas provides new possibilities in terms of pattern complexity. In comparison to LED-strips, which typically only have a single LED in one dimension and multiple LEDs in another, LED-arrays consist of multiple LEDs in both dimensions. These “two-dimensional” arrays allow for the depiction of symbols and more complex animations. Optimal light-signals for coding different messages about the vehicles perception and intention need to be identified to ensure that those messages are not only easy to perceive but also to comprehend.

7 Conclusion and Outlook

While rotating seats in AVs offer opportunities for new levels of social interaction during car rides, motion sickness and lack of trust inhibit their acceptance from potential passengers. Perception transparency and intention transparency are elaborated as key factors to manipulate these factors in order to facilitate acceptance. Interior lighting is identified as a promising medium to convey information about the vehicle intention and perception to passengers without causing distraction from NDRTs. Future research needs to examine the required parameters for position, size, and visual qualities e.g., resolution and luminance of the interior lighting elements to prevent distraction and ensure peripheral visibility. Furthermore, an optimal degree of complexity for light-based messages needs to be identified to ensure comprehensibility while still providing sufficient details.

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