Shared Gaze While Driving: How Drivers Can Be Supported by an LED-Visualization of the Front-Seat Passenger's Gaze

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Abstract. The front-seat passenger in a vehicle may assist a driver in providing hints towards points of interest in a driving situation. In order to communicate spatial information efficiently, the so-called shared gaze approach has been introduced in previous research. Thereby, the gaze of the front-seat passenger is visualized for the driver. So far, this approach has been solely investigated in driving simulator environments. In this paper, we present a study on how well shared gaze works in a real driving situation (n=8). We examine identification rates of different object types in the driving environment based on the visualization of the front-seat passenger's gaze via glowing LEDs on an LED-strip. Our results show that this rate is dependent on object relevance for the driving task and movement of the object. We found that perceived visual distraction was low and that the usefulness of shared gaze for navigational tasks was considered high.

Keywords: Shared gaze · driving · front-seat passenger · LEDs · ambient light systems.

1 Introduction

Driving can be demanding since the driver constantly needs to observe the environment in order to drive safe. The driver needs to identify, interpret, and react to traffic signs and signals, road markings, and the behavior of other drivers and road users. Previous research has shown that front-seat passengers might support the driver by additionally monitoring the environment and providing according hints (e.g., [6, 3]). Since gestures and verbal cues provided by the front-seat passenger might be ambiguous and not properly perceived by the driver, the *shared gaze* approach has been suggested to support front-seat passenger and driver communication [17, 30, 31].

The basic idea of this approach is that the gaze of the front-seat passenger is visualized for the driver in the vehicle, allowing the driver to see where the front-seat passenger is looking at. This is achieved by using an eye-tracking system

Fig. 1. Setup in the car. The gaze of the front-seat passenger is captured with an eye-tracking system and is visualized for the driver with blue glowing LEDs on an LED-strip mounted at the bottom of the windshield. The front-seat passenger is currently looking at the speed sign ahead on the right side of the street.

to capture the front-seat passenger's gaze, which is visualized in real-time for the driver. The visualization could be done in various ways by using, e.g., full windshield visualizations (via an head-up display) or ambient light information (e.g., LEDs). Previous research indicates that using ambient light information is more beneficial in terms of less visual distraction for the driver (e.g., [15, 31]). In our case, we used an LED-strip mounted at the bottom of the windshield in order to provide horizontal spatial information. For example, a front-seat passenger wants to point to a speed limit sign ahead. While looking at the sign, an LED segment is lit at the bottom of the windshield at the corresponding position in line of sight between the driver and the traffic sign, i.e., the gaze visualization is mapped to the driver's perspective (see Figure 1).

The usefulness of shared gaze has been successfully shown in previous research [17, 30, 31]. However, a drawback of these studies is that they were conducted solely in a driving simulator environment, lacking ecological validity. Our aim was to leave the driving simulator and investigate the approach in a real driving situation with the vehicle moving in a realistic three-dimensional environment with a dynamically changing scenery, vibrations in the vehicle and forces affecting the driver and passenger. Transferring the approach from the simulator to the real world required changes of the gaze calibration and mapping procedure and the influences of the real driving environment were not yet clear. Therefore, the present study focused primarily on how well and accurately drivers could perceive the gaze visualization under these new circumstances since an accurate perception is crucial in order for the shared gaze approach to be beneficial.

We conducted an in-situ study with eight participants with the above mentioned LED visualization of the front-seat passenger's gaze. The main aim of the study was to investigate drivers' perception of the gaze visualization and the usefulness of the approach for drivers in a real driving situation. Therefore and for safety reasons, the front-seat passenger's role was taken over by a researcher. In particular, we had the following research questions:

1. How well do drivers perceive the LED-visualization of the front-seat passenger's gaze during actual driving?
2. How well can drivers identify objects in the driving environment based on the visualization and how do specific object properties influence the object identification rate?
3. How distracting do drivers perceive the LED-visualization?
4. How useful do drivers experience the shared gaze approach?

Our study provides insights on different levels: First, it introduces a methodological approach how to map three-dimensional eye tracking data to a one-dimensional representation for the driver's perspective in a car. Second, we provide results on how well the gaze visualization is perceived by drivers in the real driving context. Third, the study provides insights on how natural gazing behavior affects the usability and usefulness of the approach. Our study extends existing research on the use of shared gaze by adding a new domain. Implications for the shared gaze while driving are discussed and recommendations for improvement are provided.

2 Related Work

2.1 The Front-Seat Passenger as Supporter of the Driver

The role of passengers in a car has been highlighted in previous research. The presence of passengers can influence experiences (e.g., [9, 10]) or collaboration happening in the car (e.g., [3, 11, 6]). It was also shown that passengers may assist drivers in different situations. Specifically in navigation scenarios, the front-seat passenger can become a supporter by guiding the driver, or helping in interpreting misleading information provided by a navigation system [6, 3]. However, so far, the ways how the front-seat passenger can communicate with the driver are limited. The sitting position side-by-side and the need of the driver to pay attention to the driving task can hinder efficient communication. It was found that drivers and passenger indeed experience problems due to ambiguity in the communication [5]. Hence, it has been outlined that there is a need for interfaces to support driver and passenger collaboration [4, 6, 20, 23, 24]. One approach was introduced by Perterer et al. [24], who provide the front-seat passenger with more detailed information about a route on a tablet in order to enable better support. In contrast to this, the shared gaze approach aims at enhancing driver and front-seat passenger communication directly.

2.2 Ambient Light Systems

The main reason for choosing glowing LEDs for visualizing the front-seat passenger's gaze, is that ambient light can draw driver's attention while keeping visual distraction low. In the automotive domain, LED-visualizations are used in various ways, e.g., for take over requests in automated driving scenarios [1, 2], as support of anticipatory driving [12], as aid in lane change scenarios [13, 14], or for gaze and attention guidance of the driver [25, 26, 28]. LEDs also have been used in steering wheels to provide warnings or information [8, 15, 21], in the a-pillars to alter drivers' perception of speed [7, 19], and mounted in glasses to keep up situation awareness [32]. Particularly, Matviienko et al. [15] have shown that an ambient light system could significantly reduce distraction of the driver compared to a GUI-based navigation system. In their design guidelines for the usage of ambient light systems [16], they further state that the position of an LED visualization is one of the essential parameters. An approach to increase the accuracy of LED visualizations was introduced by Trösterer et al. [29], who showed that accuracy could be increased by conducting an individual calibration procedure for the driver.

2.3 Shared Gaze in the Car

So far, the shared gaze approach has solely been investigated in driving simulator studies. While Maurer et al. [17] presented findings from a first exploratory study, Trösterer et al. [30] investigated the approach in an elaborate driving simulator study with driver/front-seat passenger pairs as participants. Thereby, the gaze of the front-seat passenger was visualized as dot in the simulation. In the study, a combination of verbal hints and shared gaze was compared to a condition, where the front-seat passenger only provided verbal hints during a navigational task. The benefit of the shared gaze approach could be successfully shown. A further driving simulator study focused on the kind of gaze visualization, i.e., the dot visualization was compared with an LED visualization shown on a LED-strip mounted at the bottom of the windshield [31]. The LED visualization was perceived as less accurate, but reduced driver's search time and was less distracting for the driver. As outlined, the main aim of the study presented here, was to investigate the approach in a real driving situation, taking into account these previous findings.

3 Method

The study was conducted in a car, which was equipped with an eye-tracking system for capturing the gaze of the front-seat passenger and an LED-strip mounted at the bottom of the windshield for visualizing the gaze.

During a study trial, three people were in the car: the driver (i.e., the study participant), the front-seat passenger, and the experimenter, who was sitting on the right rear seat. The front-seat passenger was a briefed research fellow involved in the project, who was the same individual across all study trials. His task was to aid the driver with the LED calibration, to guide the driver along a predefined route, and to provide hints about objects in the environment with his gaze. The front-seat passenger knew the route by heart. Note that we as researchers had the agreement to refrain from showing the gaze visualization in complex traffic situations, as well as to refrain from showing the gaze visualization at all, if we felt safety was comprised. Additionally, participants could interrupt the study anytime.

Task of the participant was to drive along the predefined route guided by the front-seat passenger. The front-seat passenger told the driver where to go, and at times additionally used the LED visualization to show the way (e.g., the front-seat passenger would say "*We have to turn right there.*" and simultaneously showed his gaze to point out what "*there*" means). The use of the LEDs during navigation was intended to give subjects a first impression how the gaze visualization could aid navigation and allowing for a more differentiated feedback with regard to the usefulness and usability of the approach.

In order to find out how well and accurately drivers could perceive the gaze visualization in the real setting, participants had to perform an object identification task during the drive. Thereby, the front-seat passenger visualized his gaze without saying anything while looking at a certain object in the environment (e.g., traffic lights, traffic signs, other traffic participants). In order to share his gaze, the front-seat passenger used a knob to switch the LED visualization on and off. When turned on, the front-seat passenger's gaze was visualized with glowing LEDs on the LED-strip in real time. The driver then needed to tell, which object the front-seat passenger was referring to (e.g., "*The 50 km/h speed sign*") solely based on the visualization. When a driver had given his/her answer, the front-seat passenger replied verbally whether the given answer was correct or not. In case the driver did not say anything when the front-seat passenger showed his gaze, it was a miss (no reaction), i.e., in such case the driver had not perceived the LED visualization. Note that the participants were instructed accordingly to avoid confusion of the object identification task and navigation, i.e., they knew in advance that navigational guidance will include an according verbal hint by the front-seat passenger.

The object identification task allowed us to objectively and distinctly verify how well drivers perceived the gaze visualization, since it was based on visual information only. Note that combining shared gaze with verbal hints from the outset would have provided less clear evidence, since verbal cues in a realistic scenario usually reduce the search space and may compensate for inaccuracies of the visualization (cf. [30, 31]).

3.1 Technical Setup

The car used in the study was a Ford Galaxy with automatic transition. For the LED-visualization, a 1.5 m LED-strip with 216 LEDs was mounted at the bottom of the windshield of the car. The LED-strip was controlled by an Arduino controller. For the LED-visualization, three blue glowing LEDs were used. We chose this number and the color based on pretests. The light intensity was chosen considering proper visibility without being visually distractive. Since the weather was sunny during the whole study, the intensity was set at the highest value.

For capturing the gaze of the front-seat passenger, we used a SmartEye Pro eye-tracking system with 60Hz. Three cameras were mounted in front of the front-seat passenger's seat. Since the SmartEye system allows to define a 3D world model of the environment, we measured and defined the windshield of the car as a plane in the model. That is, if the front-seat passenger looks at an object outside, his gaze intersects with the windshield and the eye-tracking system provides the x- and y-coordinates of the intersection. In turn, the x-coordinate can be easily transferred in the according LED-pixel position, since the LED-strip covers the windshield width.

A Java application was developed for controlling the setup. The application provides a graphical user interface for conducting a calibration procedure for the driver and the front-seat passenger, and for managing settings (e.g., LED visualization width and intensity). It further executes the transformation and mapping of the gaze data to the LED-strip. The application was running on a laptop. In addition, two hardware devices (a rotary knob to manually change the position of the glowing LEDs for the calibration and a knob to switch on and off the LEDs) were used.

In order for the setup to work, an LED calibration (cf. [29]) and gaze mapping procedure needed to be performed. This was done in four steps: (1) Driver and front-seat passenger agreed on two distinct points in the environment, which could be perceived by both and could be mapped to the LED-strip (preferably in-plane in about 5-10 meters distance to the car). (2) Using the rotary knob, the driver manually adjusted the position of one glowing LED shown on the LED-strip until it reflected the position of the outside point most accurately from his/her point of view. S/he then pressed the knob and the LED-position was saved in LED-pixel. (3) The front-seat passenger looked at the point outside and when he pressed the knob, the gaze position was captured, transferred in LED-pixel (see above) and saved. In this way, position data was provided in LED-pixel for each point and each perspective (driver's and front-seat passenger's). (4) Based on the values and by using linear interpolation, the final mapping of the gaze visualization for the driver's perspective was done mathematically.

For analysis purposes, two GoPro Hero 7 cameras were mounted in the car. One was fixated at the top center of the windshield filming the scenery in front of the car including the windshield and the LED-strip. The other one was mounted at the left side window, filming the driver.

3.2 Participants

All participants were recruited at our research institution. This was deliberately done due to safety and ethical reasons. Participants were selected based on their self-assessment of driving experience, driving safety, and regularity of driving. Our sample included daily commuters, as well as drivers, who had particular experience in driving unfamiliar (rental) cars. None of the participants was familiar with the study setup. In total, eight subjects (five male, three female) participated in the study. The youngest participant was 24, the oldest participant 36 years old (M=30 years, SD=4.12). On average, participants had their driver's license for 12 years (SD=3.45). Half of the subjects possessed an own car. On average, subjects reported an annual mileage of 8,300 km (min=300; max=25,000 km).

Three subjects indicated that they usually drive alone, while five subjects reported to often have one passenger or more. Two subjects reported that they rarely drive on routes they are unfamiliar with, five subjects did this sometimes, while one subject reported that this happens often. All subjects were familiar with using a navigation system during driving. Seven subjects reported to have been supported by a passenger in finding a route before. Thereby, the support by the passenger was perceived as helpful by six subjects.

3.3 Procedure

The participant was welcomed and accompanied to the car, which was parked in the underground garage of our institution. The participant was asked to sit down in the driver's seat and was introduced to the front-seat passenger, who already sat in the car. The experimenter sat down in the right rear seat of the car.

Introduction First, the participant was given a short introduction into the shared gaze approach and the purpose of the study. They had to read a sheet containing general information about the study including safety instructions. The participant was told to drive carefully and to follow traffic rules at all time. Whenever a participant felt uncomfortable or unsafe s/he could interrupt the study. S/he then had to sign an informed consent. After checking the participant's driver's license, the experimenter asked the subject to adjust the seat and mirrors, and to buckle up. Furthermore, the subject was given a short introduction into the car. After that, the subject was asked to drive to a nearby parking lot outside in order to get familiar with the car.

LED Calibration and Gaze Mapping At the parking lot, the front-seat passenger asked the participant to park at a specific position. For the LED calibration and gaze mapping, front-seat passenger and driver verbally agreed on two distinct points in the environment (like, e.g., a back-light of a specific parked car). The LED calibration and gaze mapping procedure was conducted following the steps described in the technical setup section. After that, the accuracy of the LED visualization was controlled. Therefore, the front-seat passenger looked at some points in the environment and pressed the knob to show his gaze, which was visualized for the driver with three glowing LEDs on the LED-strip. It was task of the driver to tell, which points were meant. In case of inaccuracies, the calibration procedure was repeated.

Drive and Object Identification Task The participant was then told that his/her task was to drive to a village nearby and that the front-seat passenger would tell him/her where to go. It was explained that the front-seat passenger may simultaneously use the LED visualization to show the way. Furthermore, the participant was instructed for the object identification task. It was explained that during the drive the front-seat passenger would point at certain objects in the environment (e.g., traffic signs, other vehicles, buildings) with his gaze and without saying anything. It was pointed out that it was the participant's task to tell, which objects were meant solely based on the LED-visualization of the gaze. In case the driver had no further questions, the video camera recordings were started and the drive began.

During the drive, the front-seat passenger could visualize his gaze by pressing the knob. Foremost, the front-seat passenger chose objects depending on the traffic situation. The front-seat passenger also indicated verbally, whether the answer of the driver was correct or not, or whether the driver had missed a visualization (i.e., did not respond verbally to a visualization). The experimenter in the rear seat noted these comments. When arriving at the village, the subject was directed to a parking lot and parked the car. In case any problems (e.g., an apparent offset of the LED-visualization, eye-tracking problems) had been observed up to this point, the LED and/or eye-tracking calibration was repeated. Otherwise, the subject could immediately begin with the drive back. Again, the front-seat passenger told the driver where to go and pointed to objects with his gaze. At the end of the drive, the subject was asked to park the car in the underground garage of our institution.

Questionnaires and Final Interview The subject was then asked to fill in a questionnaire with several self-generated items and the Driving Activity Load Index (DALI) [22]. This questionnaire allows to evaluate mental workload and is specifically designed for the driving context. Finally, a semi-structured interview was conducted. Interview questions focused on the usefulness of the gaze visualization, perceived distraction, possible problems, suggestions for improvement, and the use of shared gaze as a driver or front-seat passenger. The subject was then thanked for participation and left the car. The duration of one study trial was about one hour.

3.4 Route

The driving route we used in the study was predefined. Our requirements were that it should allow fluent driving, while comprising different driving scenarios. Starting point was our research institution near the city boundary of Salzburg. The route led along a national highway (with driving speeds up to 100 km/h) and through some smaller villages. It contained several roundabouts and traffic lights. Turning point was a village about 7.5 km away from the starting point. When entering the city on the way back, a detour was made through the city, before arriving at our research institution. The total length of the route was about 17 km. The driving side was right. During the study, traffic along the route was dense but fluent (i.e., no traffic jams). Driving time varied between 22 and 25 minutes (24 minutes on average). Half of the subjects were familiar with parts of the route, i.e., they knew about the village and had a basic idea how to get there. Note that in the village and the last part of the route, they also needed to rely on the navigational guidance by the front-seat passenger.

4 Data Analysis

For the analysis of data, we coded the video recordings showing the forward scenery and the LED-strip. For the coding, we used the following parameters: Each time, the LED-visualization was used by the front-seat passenger, we noted

- to which object the front-seat passenger was referring to with his gaze (*object type*),
- where the object was placed in the scenery (right side of the road, left side of the road, central in front of the car) (*object position*),
- whether the object itself was moving (e.g., another driving car) or not (e.g., a traffic sign) (*object movement*),
- whether the object itself was relevant for the driving task (e.g., traffic sign) or not (e.g., bus station) (*object relevance*),
- whether the subject correctly identified the object or not (*object identification*),
- whether the subject corrected a previously given answer immediately (*object correction*), or
- whether s/he had perceived the visualization at all (*object perception*).

Furthermore, we noted all verbal navigational hints, and whether the gaze visualization was used for support or not. All data was entered in Microsoft Excel for further analysis. We also transcribed comments of the participants during the drive. Questionnaire data was analyzed with IBM SPSS Statistics 24. The final interviews were transcribed as well, categorized, and analyzed following the basics of a qualitative content analysis [18].

5 Results

In the following, we provide a detailed description of the results including object identification rates, general functionality, perceived distraction, and usefulness of the approach.

5.1 Object Identification Rates

For the object identification task, the front-seat passenger visualized his gaze without saying anything while looking at a certain object. The driver needed to tell, which object the front-seat passenger is referring to solely based on the visualization. In total, the front-seat passenger notified the participants about objects in the environment 483 times. The amount of notifications varied between 49 and 77 times per drive (M=60, SD=10.48), depending on the traffic situation. On average, a notification was provided every 24 seconds within a drive (the average duration of a drive was 24 minutes).

Overall Rates With regard to our first research question (RQ1), whether drivers do perceive the LED-visualization of the front-seat passenger's gaze, we found that in only 2% of the cases, the driver did not react to the visualization, i.e., they said nothing when the visualization was shown. In all other cases (98%), the drivers commented verbally what they thought the front-seat passenger was referring to.

The overall correct object identification rate was 77% (min=65%, max=85%; SD =7.64). This result is significantly above chance level (χ^2=29.16, p<.001). In 7% of the cases, the drivers said something different first, but corrected their answer immediately, thus, the object was correctly identified in the end. In 14% of the cases, the object was not correctly identified. Table 1 provides an overview of the object identification rates overall and per object categories. Most objects fell in the category *traffic signs, lights, and markings*, followed by *other vehicles*, *points of interest*, and *vulnerable road users*. Correct object identification was highest when the front-seat passenger was referring to vulnerable road users (85%; χ^2=49.00, p<.001), and lowest when referring to other points-of-interest (67%; χ^2=11.56, p<.05 when comparing it to an equal distribution of correct and incorrect answers).

Table 1. Object identification rates per object categories and overall.

Object category	N	Identified	Corrected	Not identified	No reaction
Traffic signs, lights, markings	**233**	**78%**	**7%**	**13%**	**2%**
information sign	25	84%	0%	12%	4%
place-name sign	17	82%	0%	18%	0%
road mirror	16	63%	6%	25%	6%
road sign	100	73%	11%	16%	0%
speed limit sign	52	88%	4%	6%	2%
traffic light	21	76%	10%	10%	5%
zebra crossing	2	100%	0%	0%	0%
Other vehicles	**109**	**76%**	**6%**	**17%**	**1%**
incoming vehicle	5	80%	0%	20%	0%
oncoming vehicle	75	80%	5%	15%	0%
parked vehicle	27	63%	7%	26%	4%
vehicle ahead	2	100%	0%	0%	0%
Vulnerable road users	**60**	**85%**	**3%**	**10%**	**2%**
cyclist	22	77%	5%	18%	0%
motor cyclist	8	100%	0%	0%	0%
pedestrian	30	87%	3%	7%	3%
Points of interest	**81**	**67%**	**15%**	**16%**	**2%**
billboard	41	83%	7%	10%	0%
building	8	100%	0%	0%	0%
bus stop	19	32%	26%	32%	11%
miscellaneous	13	46%	31%	23%	0%
Overall	**483**	**77%**	**7%**	**14%**	**2%**

Table 2. Object identification rates based on object relevance for the driving task and per object categories.

Object relevance for driving task	N	Identified	Corrected	Not identified	No reaction
Relevant	**223**	**81%**	**6%**	**12%**	**1%**
traffic signs, lights, markings	208	80%	6%	12%	1%
other vehicles	7	86%	0%	14%	0%
vulnerable road users	8	100%	0%	0%	0%
Irrelevant	**260**	**73%**	**9%**	**17%**	**2%**
traffic signs, lights, markings	25	60%	12%	24%	4%
other vehicles	102	75%	6%	18%	1%
vulnerable road users	52	83%	4%	12%	2%
points of interest	81	67%	15%	16%	2%
Overall	**483**	**77%**	**7%**	**14%**	**2%**

Object Properties Regarding object properties (RQ2), we took a look at object relevance, movement, and position. As a first step, we analyzed to which degree the relevance of the object for the driving task impacts object identification rates. As depicted in Table 2, we could find that the object identification rate tended to be higher when the object was relevant for the driving task (81% for relevant vs. 73% for irrelevant objects). Both rates are significantly above chance level (χ^2=38.44, p<.001 for relevant and χ^2=21.16, p<.001 for irrelevant objects). Among the relevant objects, *vulnerable road users* were identified correctly in all cases.

As indicated in Table 3, most of the referred objects were static (n=353), while *other vehicles* and *vulnerable road users* could also be in movement (n=130). We could find that the object identification rate tended to be higher when the objects were in movement (83% for moving vs. 74% for static objects). Identification rates were highest, when the objects were also relevant for the driving task (93% for moving and 80% for static objects). The rates were lower when the objects were irrelevant for the actual driving task (82% for moving and 66% for static). Again, all rates were significantly above chance level.

Table 3. Object identification rates based on object movement and per object categories.

Object movement	N	Identified	Corrected	Not identified	No reaction
Moving	**130**	**83%**	**5%**	**12%**	**0%**
other vehicles	79	80%	5%	15%	0%
vulnerable road users	51	88%	4%	8%	0%
Static	**353**	**74%**	**8%**	**15%**	**2%**
traffic signs, lights, markings	233	78%	7%	13%	2%
other vehicles	30	67%	7%	23%	3%
vulnerable road users	9	67%	0%	22%	11%
points of interest	81	67%	15%	16%	2%
Overall	**483**	**77%**	**7%**	**14%**	**2%**

Finally, we analyzed the object identification rates for the different object positions. Since the driving side was right, a large portion of objects were also located on the right side (n=297). We found, that objects in front of the car (n=12, central position), were correctly identified in 92% of the cases (χ^2=70.56, p<.001). Those objects were also all relevant for the driving task, since they could impact driving behavior. For objects at the side of the road, the object identification rate was comparable (74% for left and 77% for right objects).

5.2 Use of the LED-Visualization for Navigation

As outlined, the front-seat passenger navigated the driver along the route by telling him/her where to go, and at times he complemented verbal hints with the visualization of his gaze. The average number of navigational hints was 21 per drive (min=18, max=27). About 21% of the navigational hints were given solely verbally, 76% verbally with simultaneous LED-visualization of the gaze, and in 3% of the cases, the LED-visualization was used alone for guidance (i.e., subsequently to a verbal hint). Most navigational hints were advice, where to turn right (49%) or left (21%), or to drive straight on (3%). Furthermore, the front-seat passenger communicated, where to exit the roundabouts on the route (27%).

Seven of the eight drivers followed the navigational hints properly and drove along the route without any problems. One driver missed a roundabout exit (and drove an additional round in the roundabout) and missed a further road exit later on (the driver needed to stop and turn around to follow the route again). The roundabout exit was solely communicated via LED-visualization. In the latter case, the driver overlooked the exit, which was located shortly behind a bend, despite verbal and LED notification.

5.3 General Functionality of the Eye-Tracking and LED-Calibration

For two subjects, it was necessary to recalibrate the LED-visualization when arriving at the turning point since an offset became apparent during the drive. In all other cases, we could continue with the initial calibration. In general, the eye-tracking system worked stable during the study and it was never necessary to repeat the eye-tracker calibration for the front-seat passenger within a study trial. However, during the drives, it sometimes happened that eye-tracking errors occurred, causing the LED-visualization to jump or freeze. Nonetheless, this happened very seldom - in total, we noted 11 cases, where such problems occurred.

5.4 Perceived Distraction and Usefulness of the Shared Gaze Approach

In order to capture participants' perceived distraction (RQ3) and impressions regarding the usefulness of the approach (RQ4), we used different questionnaire items and conducted a semi-structured final interview.

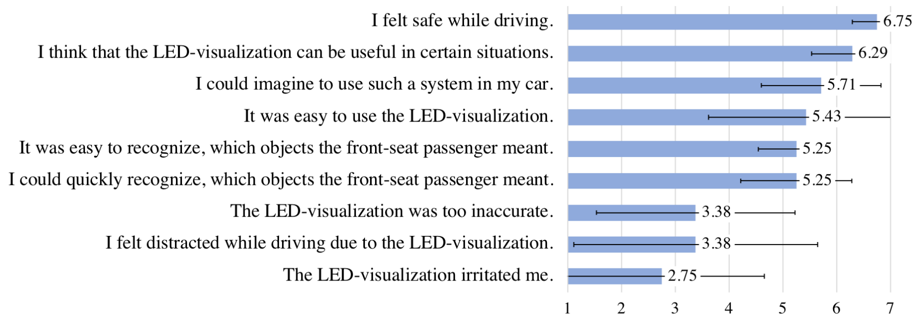

Fig. 2. Means and standard deviations of drivers' ratings of statements (1=does not apply at all, 7=does fully apply).

Figure 2 provides an overview of drivers' ratings of statements, which had to be rated on a 7-point Likert scale (1=does not apply at all, 7=does fully apply). It is apparent that the ratings regarding the usefulness of the visualization (M=6.29, SD=0.76), or whether one could imagine to use it in their own car (M=5.71, SD=1.11) are rather high. Participants also tended to agree that it was easy to use the LED-visualization (M=5.43, SD=1.81), and that they could easily (M=5.25, SD=0.71) and quickly (M=5.25, SD=1.04) recognize, which objects the front-seat passenger meant. Mean ratings regarding LED-visualization inaccuracy (M=3.38, SD=1.85), perceived distraction (M=3.38, SD=2.26), and irritation by the LED-visualization (M=2.75, SD=1.91) were below average. In general, participants felt safe while driving (M=6.75, SD=0.46).

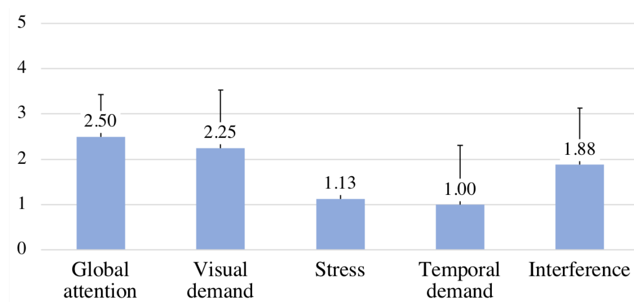

Fig. 3. Means and standard deviations for selected factors of the DALI questionnaire (0=low, 5=high).

In order to capture constraints with regard to the driving task, we used the DALI questionnaire (note that we left out the auditory demand factor, since the notification of the driver during the object identification task was purely visual). Figure 3 provides an overview of the mean ratings for each factor.

It is apparent that the ratings for temporal demand (M=1.00, SD=1.31) and stress (M=1.13, SD=0.35) are particularly low. Also, drivers rated interference (M=1.88, SD=1.25) and visual demand (M=2.25, SD=1.28) below average. The mean rating of global attention was average (M=2.5, SD=0.93).

5.5 Findings from the Interviews

At the end of a study trial, participants were interviewed. Interview questions targeted their general impression about the shared gaze approach, its usefulness, perceived distraction, and suggestions for improvement.

All participants found the gaze visualization to be useful. "*I think it's useful. It's often the case that other people see things, which you don't perceive - like for example a speed limit sign.*" (P3). Seven participants outlined that they found the approach worked well and was practical, specifically for navigation. "*I think it worked surprisingly well, particularly for navigation. I could also imagine it for a navigation system - when the computer gives directions.*" (P4). "*I think it's cool for navigation. I hope this will break into the market.*" (P2). Two subjects meant that the accuracy of the LED-visualization could have been generally better for object identification, while four subjects outlined that it was sometimes difficult to tell which object was meant when objects were overlapping from their point of view. For example, P8 stated "*Sometimes it was not possible to identify the object, because there were several objects in one line.*" "*When there was a sign in front of a bus stop, it was difficult.*" (P1).

Participants generally considered the shared gaze approach to be helpful for navigation and providing directions. However, it was also outlined by four participants that the LED-visualization rather served as additional source of information, when they already knew where to go (because they knew parts of the route, read the information provided on the information signs, or the verbal hint by the front-seat passenger was enough). Participants stated that the approach could be particularly feasible when navigating in unfamiliar regions or more complex driving scenarios. "*I think, if the driving situation is more complex, like in cities, it could help*" (P8). Two participants had doubts that the LED-visualization would provide the adequate accuracy for navigation scenarios. "*I would not be sure, whether I could really tell which street I should take when there are three in a row.*" (P6). Three participants also outlined that the timing (i.e., at which point the front-seat passenger shows his/her gaze) may be a crucial factor. Specifically, with regard using the LED-visualization to indicate a roundabout exit, three subjects expressed concerns. "*Sometimes I had the feeling that I should continue to drive in the roundabout, because the light started to move to the right quite late.*" (P5).

As regards distraction, seven participants stated that they didn't feel visually distracted by LED-visualization. Only P8 meant "*I think I looked at the visualization directly, because the LEDs were not so bright.*" However, almost all participants (n=7) outlined that they rather felt a bit distracted by the task they had to do, i.e., that they were rather cognitively distracted. "*I was distracted by the task. The anticipating - what does he* [the front-seat passenger] *mean.*"

(P7). "*When I was unsure, whether it was the bus stop or the sign - then it was a bit distracting, because I had to think about it. But when it was unambiguous, it was not distracting at all*" (P1). "*Usually, the front-seat passenger would look at something that is important for the driver. So it does not distract, but rather guide the driver.*" (P2).

As regards the LED-visualization itself, seven participants stated that they found the visualization with three LEDs to be adequate. "*I think it's fine with three LEDs. Using just one LED might be difficult to perceive, using more LEDs would decrease accuracy.*" (P7). Participants were also fine with blue as color. Suggestions for improvement were, e.g., to implement an additional audio or vibration signal so that the driver can additionally perceive when the front-seat passenger starts showing his/her gaze. It was suggested that head tracking of the driver could increase accuracy, or that gaze tracking of the driver could be used for gaze guidance, i.e., that it is also considered where the driver is currently looking. Color and brightness of the LED visualization should be adapted depending on the weather conditions. All participants stated that they had no problems with the LED-calibration, which had to be done at the beginning. *"That was super easy."* (P5).

We also asked study participants, whether they could imagine to use the shared gaze approach as a front-seat passenger. Seven participants stated that they could imagine it, particularly for navigation. "*It really makes sense to use it, when I know where to go and the driver doesn't.*" (P7). "*Yes, I can imagine to use it. For example, when searching for a parking space, there are often agile discussions in the car. Here it would be really helpful.*" (P5). P6 had doubts he would use it, but he noted that the approach could be probably very beneficial for rally co-pilots, who guide the rally driver. "*The rally co-pilot is a real expert and knows where to go. That's mostly not the case for normal passengers.*" P4 also thought that rally drivers could benefit from the approach.

Finally, we asked participants whether they could imagine to use the system in their own car. Seven participants said that they could imagine to use it. They found the system to be "*unagitated*", "*simple*", "*funny*", "*supportive in typical scenarios*", and "*nice to have*".

6 Discussion

6.1 Drivers' Perception of the LED-Visualization

With regard to our first research question, we found that drivers did perceive the LED-visualization in almost all cases (98%). As regards the question, how well the drivers could identify objects in the environment based on the visualization (RQ2), we found an overall object identification rate of 77%. We consider this as a good rate, taking into account that inaccuracies could happen on three different levels. That is, the eye-tracking accuracy in general plays a role, as well as the accuracy of the mapping of the gaze to the LED-strip and the mapping of the LED-visualization to the driver's perspective. Furthermore, the three-dimensional spatial information is reduced to a simple one-dimensional representation, i.e., depth or height information was not provided. It also needs to be outlined that the found rate basically reflects the worst case, since solely visual information was available for the driver during the object identification task. We expect the rate to be even higher, when according verbal hints are provided by the front-seat passenger. As outlined in the method section, the object identification task was chosen to ensure that an objective and distinct verification, how well drivers perceive the gaze visualization in a real driving situation, is possible.

Our results also suggest that certain object properties play a role when it comes to correct identification. We found that the object identification rate tended to be higher, when the object was relevant for driving task and was especially high when the object was a vulnerable road user. Also, objects were identified more easily when they were in movement or central in front of the car. Several factors need to be considered when interpreting these tendencies.

First, *anticipation* is certainly an important factor, i.e., drivers had a certain expectation, what the front-seat passenger could mean most likely. This was also mentioned in the final interviews. As pointed out, a front-seat passenger would usually refer to something that's relevant for the driver. Therefore, it also seems likely that the driver would rather identify a relevant object based on the visualization. That is, anticipation might influence how the LED-visualization is perceived.

Another factor, which plays a role here, is the *saliency* of the object in the respective scenery. Driving is dynamic and involves constant changes of the environment. Hence, when the front-seat passenger showed his gaze, the scenery could be more or less cluttered, thus, making it more or less difficult to identify the object. Furthermore, the different viewing perspectives of driver and front-seat passenger can have an impact. An object, which can be clearly perceived by the front-seat passenger, may appear to be overlapping with other objects from the driver's perspective. This was also mentioned as a problem in the final interviews.

As outlined, the LED-visualization of the gaze is a one-dimensional representation of spatial information. However, we found that the LED-visualization provided another quality, i.e., the *movement* of the glowing LEDs depending on the gazing behavior. That is, if the front-seat passenger fixates a static object while the car is moving, the visualization will move accordingly depending on the object position and distance. If the front-seat passenger looks at a moving object and follows it with his gaze, this results in much quicker movements. We believe that this superordinate information made it easier for drivers to identify moving objects.

On the other hand, we also found that the natural gazing behavior of the front-seat passenger could be misleading. This became most apparent when using the gaze to point at a roundabout exit, since the front-seat passenger looked in the roundabout first and then at the exit (i.e., the LED-visualization was moving from the left to right, which was experienced as too late by some drivers).

6.2 Perceived Distraction and Usefulness of the Shared Gaze Approach

Participants generally indicated that they were not visually distracted by the LED-visualization. This is in line with previous findings [30, 31, 15] and is also supported by the ratings in the questionnaires. Mean ratings for distraction and irritation caused by the LED-visualization were low. Also, visual demand and interference were rated below average in the DALI questionnaire.

However, it turned out that the participants felt rather cognitively distracted by the object identification task, especially when the LED-visualization was not distinct. This finding can be seen twofold. On the one hand, it is a consequence of our chosen methodological approach. Our aim was to gain sufficient data about object identification accuracy without the need to make an extensive drive. On the other hand, our results underline that it needs to be considered in the future that an ambiguous visualization of the front-seat passenger's gaze may cause cognitive distraction of driver. It should be noted, though, that (opposed to the object identification task in the study) the gaze visualization would usually be accompanied by some verbal comment of the front-seat passenger, thus, reducing the cognitive effort for the driver.

Drivers could also experience this during the study, since the shared gaze approach was used for navigation as well. Thereby, the front-seat passenger used the gaze visualization in addition to his verbal hints where to go. Almost all participants agreed that the shared gaze approach could be useful and helpful for navigation. This is in line with what was found in the driving simulator studies [30, 31]. Especially for unknown areas and more complex driving scenarios, shared gaze might be valuable. However, our results also show that there still might be some problems that need to be solved. For example, the timing (i.e., when gaze is visualized) may play a crucial role in such scenarios. Also, natural gazing behavior needs to be considered, which might be misleading (like, e.g., in the roundabout scenario).

6.3 The Role of the Front-Seat Passenger and Further Application Scenarios for Shared Gaze

In our study, the role of the front-seat passenger was taken over by a researcher, who was used to the approach and controlled his gaze to a certain degree, e.g., he knew that he had to fixate an object for some time to be recognizable for the driver. It is questionable if similar results in detection rates can be achieved when the front-seat passenger is not used to the approach, or whether a certain training would be necessary. Indeed, Trösterer et al. [30] found in their first simulator study, that a proper instruction of the front-seat passenger may be crucial. Nonetheless, the important role of a front-seat passenger to support the driver was expressed by almost all participants. This also includes the willingness to use shared gaze as front-seat passenger. Also, shared gaze could be a valuable approach in professional areas (for, e.g., rally co-pilots, driving instructors).

With respect to design considerations, the in-situ study showed that the number of glowing LEDs (three) and their color (blue) was perceived positively by the participants. Also, the merely horizontal spatial information was perceived positively. In contrast to what was expressed by participants in the driving simulator study [31], provision of additional depth or height information turned out to be less relevant in real driving situations.

Potential improvements of shared gaze with LEDs could be a *gaze lock* (i.e., the possibility for the front-seat passenger to "lock" the gaze after having looked at an specific object, so that s/he needs not to stare at the object all the time), gaze guidance (i.e., also taking into account where the driver looks at; cf. [26, 27]), or a different way to activate or deactivate the gaze visualization (e.g., by means of gestures instead of using a knob).

6.4 Limitations

There are some limitations with respect to the study presented here. First, we only investigated the perspective of the driver and not the role of the front-seat passenger. It is unclear, whether detection rates would be similarly high with an inexperienced front-seat passenger. Second, the number of participants was rather low in order to be able to generalize the results for a broad range of different drivers. However, the large number of identified objects and the high identification rates suggest that the shared-gaze approach and the LED visualization is effective. Third, the object identification task was rather artificially with respect to frequency and mental effort. However, as pointed out, the task was necessary in order to get a clear verification of drivers' perception of the gaze visualization in the real driving context. Fourth, the chosen route was rather short and in parts familiar to the drivers. Future work should focus on unknown areas and more complex driving environments. Finally, we only assessed perceived visual distraction of the driver. Future studies should use eye-tracking of the driver to investigate visual distraction also objectively.

7 Conclusion

Based on our results, we conclude that the shared-gaze approach and its implementation with glowing LEDs on an LED-strip worked well in the real driving scenario. The adapted gaze calibration and mapping procedures showed to be successful. The LED-visualization was recognized in almost all of the cases and the correct object identification rate was with 77% significantly above chance level. We found that this rate was influenced by different object properties and assume that drivers' anticipation, object saliency, and the natural gazing behavior of the front-seat passenger determined the differences in perception. The study participants experienced the shared gaze approach as particularly useful for navigation, however, the role of the front-seat passenger needs to be further examined. In future work, we plan on a comparative study in a more complex driving environment to further investigate the approach for navigation and with front-seat passengers as study participants as well.

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