NaviLight: Investigating Ambient Light Displays for Turn-by-Turn Navigation in Cars

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ABSTRACT
Car navigation systems typically combine multiple output modalities; for example, GPS-based navigation aids show a real-time map, or feature spoken prompts indicating upcoming maneuvers. However, the drawback of graphical navigation displays is that drivers have to explicitly glance at them, which can distract from a situation on the road. To decrease driver distraction while driving with a navigation system, we explore the use of ambient light as a navigation aid in the car, in order to shift navigation aids to the periphery of human attention. We investigated this by conducting studies in a driving simulator, where we found that drivers spent significantly less time glancing at the ambient light navigation aid than on a GUI navigation display. Moreover, ambient light-based navigation was perceived to be easy to use and understand, and preferred over traditional GUI navigation displays. We discuss the implications of these outcomes on automotive personal navigation devices.

Author Keywords
Light-based navigation; Ambient displays; Navigation; Peripheral visualization

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION
The rapidly increasing amount of computational systems inside a vehicle raises cognitive workload and consumes mental resources of a driver. An effective coordination of such embedded computational systems in a car requires a driver's attention, which can influence situation awareness. Situation awareness is defined as a state of knowledge including the perception of the elements in the environment, the comprehension of their meaning and the projection of their status in the near future [3]. To increase the level of awareness and investigate the external and internal factors that affect situation awareness, a number of measurements, techniques and models were deployed [23], such as Endsley's knowledge network models.

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Figure 1: Participant driving in the simulator using ambient light navigation on the steering wheel.

In an automotive context, car drivers often make use of navigation systems in order to get around in unfamiliar environments. However, a navigation assistant is not the only device in the car. Rather a variety of devices compete for the driver's attention in the car, particularly in the visual tasks accompanying driving. This is illustrated by the following scenario: John is driving with his wife to a restaurant located in an unfamiliar city district. Here, he needs to pay attention not only to the situation on the road to maintain visual awareness of the road situation, but also to the navigation device. Such a competition for a driver's mental resources can cause distractions from the primary driving task, which can increase the risk of accidents.

By using an external navigation display, such as a smart phone or an on-board computer display, drivers typically glance frequently at a navigation system, which causes distraction while driving [24]. One method of increasing a driver's situation awareness without additional distractions is to shift information to the periphery of human attention. To investigate this, we investigated navigation cues to the periphery of the human vision using ambient light, which has shown to be a promising approach in recent automotive research [2, 12, 24, 9, 10].

Moreover, other work has shown advantages of using ambient light as a modality that can facilitate awareness not only in the automotive context, but also in the domestic context, such as for energy consumption awareness [17] or in an office environment for physical activity tracking and awareness [4]. However, to our knowledge, there has been no previous work that used ambient light as an output modality for in-car turn-by-turn navigation.

In this paper, we investigate ambient light as a navigation display method in the car for communicating turn-by-turn instructions in the periphery of the driver's perception. We explore the following research questions: (1) How can we represent navigation information using ambient light in a car? (2) Which light parameters can we use to enable effective and undistracted driving? (3) Can ambient light-based navigation effectively lower distraction during driving tasks? Essentially, our goal is to show that ambient light navigation is an effective in-car navigation modality that results in low driving error rates, and is easy to understand and use. To address this, we derive the most suitable light patterns for in-car turn-by-turn navigation and evaluate them by comparison to a baseline graphical user interface (GUI) navigation display. In order to evaluate the effectiveness of ambient light displays, which essentially draws on visual information processing, we do not consider other modalities and focus only on navigation types that require visual attention. We take the first steps to investigate whether navigation based on ambient light can reduce in-vehicle driver distraction.

This paper makes three main research contributions in how to improve future navigation systems and reduce the level of distraction in a car:

1. We derive a set of light patterns that are suitable for in-car turn-by-turn navigation.

2. We provide an empirical evaluation and show that drivers spend significantly less time looking at the ambient light-based navigation aid in comparison with a GUI-based navigation aid while maintaining a low error rate.

3. We show that ambient light is a suitable modality for lowering in-car distraction during navigation tasks.

RELATED WORK

Attention and performance. Wickens [26] suggested that providing information via different cognitive resources can help to avoid driver overload. Further, Leibowitz et al. [11] showed the importance of using *focal* and *ambient* visual processing to decrease interruptions and distractions during activities that involve multiple tasks. They defined these two separate resources in the sense of efficient time-sharing support, association with both focal and ambient types of information, and being characterized by different brain structures. Horrey et al. [7] investigated the influence of in-car devices on drivers' visual attention and performance. In their studies they concluded that visual distractions have a negative effect on driving performance. However, peripheral displays, as defined by Matthews et al. [14], address ambient vision and therefore allow a person to be aware of information while focusing on a primary task. They identified three issues specific to conveying information in the periphery of human attention: abstraction, notification, and transitions. Abstraction involves an extraction of features that enable easier reading of information "at a glance" in comparison to the raw data, notification related to displaying different levels of information importance, and transition ensures appropriate changes between these notification levels.

Ambient displays. Ambient vision has already been explored for various assistance systems in vehicles. For example, Laquai et al. [10] developed light patterns which indicate a safe distance and speed. Pfromm et al. [19] created a system which displays critical objects on a surrounding light display. Müller et al. [18] and Qin et al. [22] used light to visualize off-screen objects and distance to them on the handheld devices. Langlois et al. [9] designed a display that presents several chunks of relevant information, including distance alerts and warnings for lane departure. Loehmann et al. [13] used ambient light to show the current state of charge of electric vehicles. Finally, Löcken et al. [12] developed a lane change decision aid system with a light display which adapts to the driver's needs.

Multimodal car navigation systems. Automotive navigation systems have been commercially available for more than a decade now. Most of these systems use voice commands and a dedicated visual display for navigation aids. In addition, much research has been done for different modalities. For example Kun et al. [8] compared driving performance for visual and spoken output of a navigation device to only spoken output. They did not find a significant change, but established that drivers spend less time looking at the road using spoken output only. Wilson et al. [27] built a wearable auditory navigation system (SWAN) that used acoustic signals to encode location and distance. They showed that the SWAN system can potentially guide users along way-points across non-road areas such as parks or large campuses. Ho et al. [6] showed the potential of vibrotactile signals to shift drivers' visual attention to time-critical information or events. They showed that drivers responded more rapidly and accurately to critical visual driving events preceded by vibrotactile cues from the same spatial direction rather than from the opposite direction. In addition, Asif and Boll [1] used a vibrotactile belt to give navigation instructions in an urban environment. While the authors did not observe a significant difference for performance or workload, they saw indicators for better orientation performance with these tactile cues.

While the above works focused on alternative ways to provide navigation information to make automotive navigation more efficient, less frustrating or less demanding, ambient light displays have so far not been used for automotive navigation yet. However, Matviienko et al. proposed classifications and design guidelines for ambient light displays [15, 16], where they derived that LED position is the most important parameter for direction encoding as well as initial and end color in the fade of a light pattern. Therefore, our focus lies on two information classes: *Spatial* for encoding direction and *Progress* for encoding the distance to the next turn. In addition, Costanza et al. [2] and Poppinga et al. [20] proposed wearable navigation glasses that indicate directions with the help of embedded LEDs. Another wearable helmet-based visual guidance was also explored for navigation on scooters [24]. The results of their simulation study suggest that light movement in the peripheral vision can effectively direct drivers without introducing visual distractions. These recent works show us the suitability of ambient light for navigation purposes in different contexts and form factors, and indicate an open gap for investigation of ambient light as a navigation method in automotive contexts.

To summarize, automotive navigation has been implemented and tested for various modalities and ambient light has been tested for different automotive applications. However, it remains to be explored whether a navigation system which uses ambient light to encode navigation information can be effectively and unobtrusively used to support in-car turn by turn navigation.

STUDY DESIGN

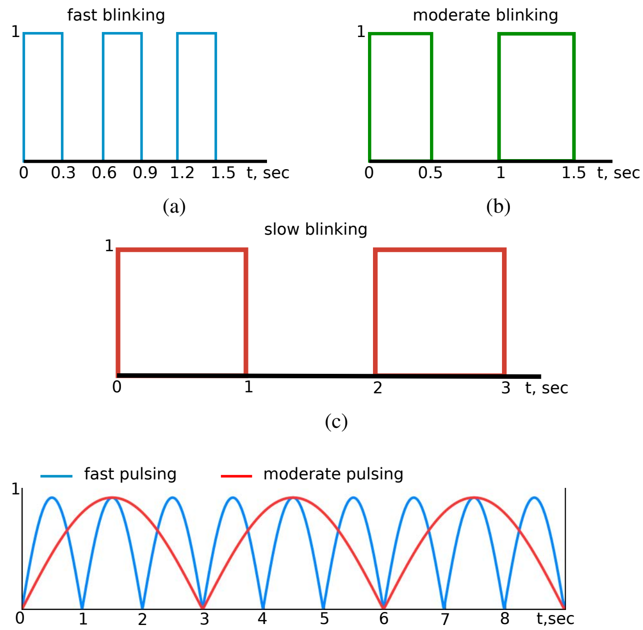
The study design consists of four consequent stages: focus group session and interviews, online questionnaire, exploratory study, and an experiment. The goal of the focus group session and interviews was to derive initial navigation light patterns together with experienced drivers. These initially derived light patterns were evaluated in the online questionnaire in order to define important light parameters and their levels. Based on these main light parameters of light patterns we derived new light patterns and explored them in the exploratory study. The light patterns with the best performance from the exploratory study were further evaluated in comparison to a GUI-based navigation display as a baseline in the experiment. Both, the exploratory study and the experiment, were conducted in the driving simulator. In the following, we will provide detailed information regarding the study design stages.

Focus Group Session and Interviews

The aim of this stage was to receive an input from drivers regarding their preferences of ambient light navigation in cars and derive light parameters and their levels for navigation encoding.

Focus Group Session

The focus group session consisted of two parts: brainwriting [25] and discussion. We have chosen brainwriting to enable participants of the focus group session to do brainstorming alone, and further expand and improve the ideas of others. Five car drivers (three female) participated in the focus group. All of them had driving experience of at least five years. In the beginning all participants received ten cards with three types of car maneuvers – left, right, U-turn – with three different levels: approaching, get ready, and turn now (3 x 3), and one card with "go straight ahead". We chose the aforementioned maneuvers and their levels based on the work of Prasad et al. [21]. Participants were asked to draw and describe light patterns in written form for all cards on the piece of paper. When they finished writing their suggestion, they passed it to the neighbor to the right for further suggestions or modifications.



(a) (b) (c) (d) Pulsing patterns.

Figure 2: Blinking (a-c) and pulsing (d) patterns.

Thus, everyone could add their ideas or write a suggestion to an existing light pattern. The whole procedure lasted until all members of the group received papers with their own ideas back.

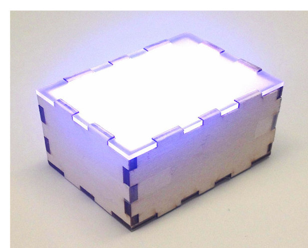


Figure 3: Arduino-based Light prototype.

Participants finished the brainwriting session in 30 minutes. Afterwards all suggestions were collected and placed on the whiteboard for further discussions with participants. They were asked to give feedback regarding the presented light patterns. Additionally, we used a light prototype based on an Arduino Mega[1] with twelve RGB LEDs[2] grouped together and enclosed into a small wooden box (7x9x5cm) with diffused acrylic glass side as shown in Figure 3. Through the diffuse acrylic glass side of the box we displayed blinking and pulsating light patterns in monochrome white color, as sketched in Figure 2, in order to better understand what level of brightness or frequency of blinking participants wanted to have for the suggested light patterns. When explaining the patterns, participants were using three levels for blinking, such

[1] https://www.arduino.cc/en/Main/ArduinoBoardMega2560
[2] https://www.adafruit.com/category/168

Light Pattern	Navigation Phase	Brightness Progression	Color Set	Position
LP1	Approaching	Linear fade from off to on	☐	NSW
	Get ready	Moderate blinking		
	Turn now	Fast blinking		
LP2	Approaching	Slow blinking	☐	NSW
	Get ready	Moderate blinking		
	Turn now	Fast blinking		
LP3	Approaching/ Get ready	The sequential progression of activating LEDs (the more side LEDs on, the closer the turn is)	☐	NSW
	Turn now	Moderate pulsing in the corresponding direction		
LP4	Approaching	Moderate pulsing	☐	Long Stripes NSW
	Get ready	The sequential progression of activating LEDs		
	Turn now	Fast pulsing in the corresponding direction with all LEDs on		
LP5	Approaching	Static light	🟨	NSW
	Get ready	Moderate blinking light	🟨	
	Turn now	Static light	🟩	
LP6	Approaching	Moderate pulsing	☐	OSW
	Get ready	Fast pulsing		
	Turn now	Moderate blinking		
LP7	Approaching	Static light	🟨	OSW
	Get ready	Moderate blinking	🟨	
	Turn now	Static light	🟩	

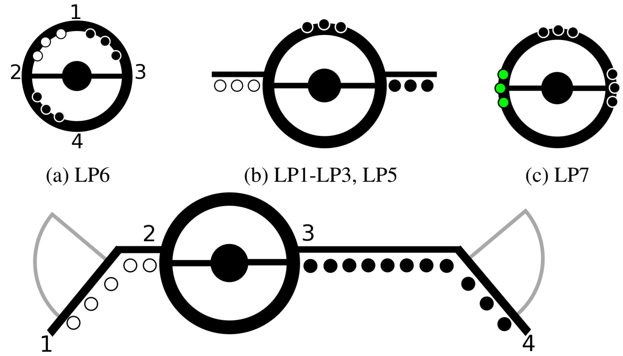
Table 1: Light Patterns Description. LP = Light Pattern. OSW - On the Steering Wheel, NSW - Next to the Steering Wheel.

as slow, moderate and fast, and two levels for pulsing, such as moderate and fast. In the end of the session, we collected five light patterns on three different positions in the car, which are next to the steering wheel (NSW) and Long stripes near the steering wheel.

Interviews

In an inspiration phase for our design, we interviewed another two car drivers each with 1.5 and 13 years of driving experience. We interviewed the drivers in order to get a deeper understanding and an additional feedback regarding light-based in-car navigation. They were given the same set of cards and the light prototype which was used in the focus group session. Verbal suggestions of the participants were noted down by the interviewer. Following the interviews, we derived four light patterns for navigation information encoding in a car on two different positions, such as next to the steering wheel (NSW) and on the steering wheel (OSW).

Altogether after focus group session and interviews, we derived nine light patterns which were reduced to seven distinct patterns due to similarities between the suggestions (Table 1). Light pattern LP1 was suggested three times. We derived three main light parameters for light patterns in a car, which are color, brightness progression, and position. The position of the LEDs that are on corresponds to the direction: LEDs are on on the left/right side – turn left/right, LEDs are on both sides – make a U-turn, all LEDs are off - drive straight forward (Figure 4). The exception is LP7 (LP = Light Pattern) that has a red moderately blinking light on the left side for U-Turn



(a) LP6 (b) LP1-LP3, LP5 (c) LP7

(d) LP4

Figure 4: Light patterns: positions. All figures show turn left. LP6: left - 1 to 2, right - 1 to 3, u-turn - 1 to 4. LP4: left/u-turn - 2 to 1, right - 3 to 4.

and together with LP5 has a green light on top on the steering wheel as an indication for going straight.

Online Questionnaire

To verify the light patterns derived from the previous sessions, we conducted an online questionnaire. The aim of the online questionnaire was to evaluate whether the light patterns are understandable by others and to receive additional suggestions for improvements. In the questionnaire participants were presented with seven videos which contained the light patterns integrated into a static car altogether with textual explanations about the maneuvers and their levels (Figure 5). The participants were asked to rate the suitability of the shown light pattern for a navigation task using a 5-point Likert scale and to suggest possible improvement to it. Additionally, they were asked to rank all seven presented light patterns. We received 35 responses, but removed ten of them due to incomplete responses.

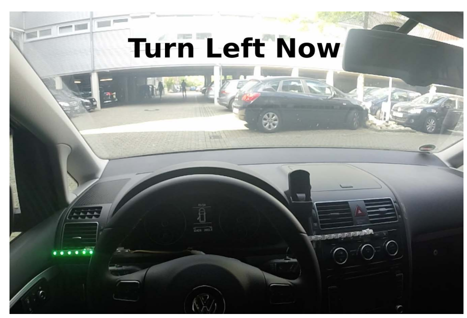


Figure 5: Online questionnaire: Video screenshot.

Results

Based on the results of online questionnaire we derived that light patterns LP1 (Md = 3, IQR = 2) and LP5 (Md = 4, IQR = 1) received the highest ratings in both the Likert scale and ranking LP1 (M = 4.72, SD = 2.09) and LP5 (M = 4.72, SD = 1.77). LP4 received the lowest ratings in Likert scale (Md = 1, IQR = 1) and ranking (M = 2.88, SD = 1.82). The summary of Likert scale is shown in Figure 6.

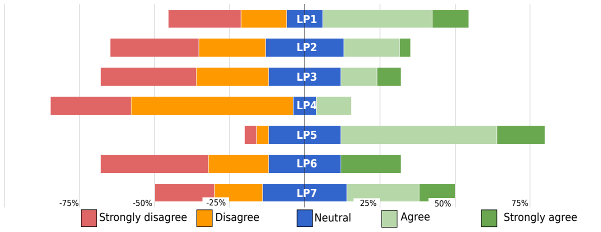


Figure 6: Online questionnaire results.

Out of 25, 16 participants reported that they do not need light navigation aid for going straight. 19 suggested to shift the LEDs on sides to the inner side of the steering wheel for LP7 (*Md* = 3, *IQR* = 2) to avoid covering LEDs with hands. Three perceived red as a signal/danger color. Five preferred the color change to distinguish among the turn phases and to use green for turning now.

Due to the high ratings in Likert scale and Ranking for LP1 and LP5, we confirmed three important light parameters for out navigation system: ***color set***, ***brightness progression***, and ***position***. Further, we took into account that a high number of people suggested to change the location of LEDs for LP7 and shifted the LEDs position to the inner side of the steering wheel. Additionally, we excluded red light from light patterns, eliminated light for going straight ahead, as well as one LED position – Long Stripes near the steering wheel – due to the low grades of Likert Scale and ranking. Therefore, we defined two levels for each of the parameters: **color set** – yellow-yellow-green (YYG) and white-white-green (WWG), **brightness progression** – static-blinking-static (SBS) and static-blinking-blinking (SBB), **position** – on the steering wheel (OSW) and next to the steering wheel (NSW), and kept three turn phases suggested by Prasad et al.[21]. Thus, with a help of focus group session, interviews and online questionnaire we defined light parameters and their levels for in-car navigation. To explore the light parameters and their levels, we derived another eight light patterns (2 x 2 x 2) as all possible combinations of parameters for the exploratory study.

Exploratory Study

After investigating the main light parameters for navigation in a car and defining the levels of them, we decided to explore the eight derived light patterns in an exploratory study by giving participants an opportunity to experience light navigation in the driving simulator. The aim of the exploratory study was to investigate whether an ambient light navigation works and if yes, to determine the best light patterns based on the feedback from participants.

Participants

We recruited 24 participants (16 female) aged between 19 and 47 (*M* = 23.79, *SD* = 5.33) with two to 29 years of driving experience in a car (*M* = 5.98, *SD* = 5.29) All of them had normal or corrected vision without color blindness.

Apparatus

We conducted the exploratory study in a fixed-based driving simulator with automatic transmission and a field of vision of 150°. The simulation was implemented using SILAB[3]. The city in the simulation consisted of 7 x 7 grid of street blocks. The maximum allowed driving speed was 50 km/h.

(a) (b)

Figure 7: Ambient light displays next to (a) and on (b) the steering wheel.

For both light-based navigation methods near and on the steering wheel we used an Arduino Mega programmable board connected to RGB LEDs[4] placed next and on to the steering wheel accordingly. The chosen RGB LEDs are based on WS2812 3-pin chips with a resolution of 72 LEDs per meter. The sets of RGB LEDs grouped together (7 per side) were placed inside an aluminum profile and covered by a milky diffuser to ensure the effect of the single light source and to avoid dazzling the driver. The light display on the steering wheel had a curved shape according to the curved shape of the steering wheel and another light display was placed next to the steering wheel as shown in Figure 7.

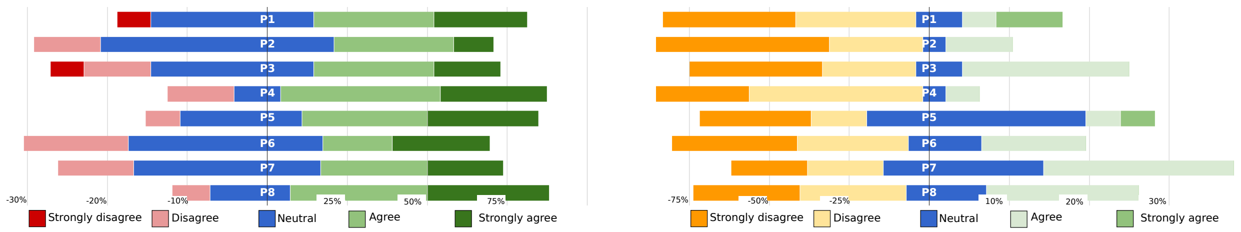
The driving simulator software was sending information to a PC regarding position of a car in the simulation via Ethernet. The received data was processed by our Java application that was transmitting the data further to an Arduino Mega, which updated the light displays accordingly.

Task and Study Design

The participants were seated in the driving simulator and were asked to drive in the simulated city without traffic and pedestrians. At this stage we decided to exclude traffic and pedestrians from the simulation in order to investigate light-based in-car navigation without additional mental load. As far as a city simulation had a block structure they could turn left, right, or keep on going straight at every junction. After the seventh block there was a roundabout where participants could make a U-turn.

Participants were given navigation aids represented via different light patterns: one light pattern per trial. The order of all eight conditions was counterbalanced. Before starting the test, every participant got some time to get familiar with the driving simulator environment and made a trial. All four maneuvers were shown three times for all eight conditions (4 turns x 3 times x 8 conditions = 96 maneuvers). The order of turns was randomized. When a participant made a maneuer at the location when it was not meant to be in accordance to a navigation aid, we counted it as wrongly performed maneuer. Each wrongly performed maneuver was counted as an error.

[3] https://wivw.de/en/silab
[4] https://www.adafruit.com/category/168



(a) Helpfulness. (b) Distraction.

Figure 8: Exploratory Study: (a) 5-point Likert item results for *Helpfulness* and (b) 5-point Likert item results for *Distraction*. P1-P8: light patterns.

After each of the conditions we asked participants to estimate the level of helpfulness (5 - very helpful) and distraction (5 - very distracting) using 5-scale Likert scale. At the end of the study we asked the participants to rank all of the used light patterns and interviewed them about the argumentation. Each trial took around seven minutes and it took on average one hour per participant to complete the study.

Results

The light patterns P2 (P = Light Pattern) and P6 received the highest grades in the ranking – 7/24 and 9/24 accordingly. These light patterns are different from the ones explored in the online questionnaire. The error rate over all light patterns was not higher than 4.17%. The median value for all light patterns for the factor helpfulness is 4, except for P2 which has 3.5. The median value for all light patterns for the factor distraction is 2, except for P2 which has 1 and P7 which has 3. The Likert scale results for levels of *helpfulness* and *distraction* of explored light patterns are shown in Figures 8a and 8b accordingly. The summary of quantitative results is presented on Table 2.

Light Pattern	Color Set	Brightness Progression	Position	Error Rate, (%)	Ranking Count
P1	yellow, yellow, green	SBS	NSW	4.17	1
P2	white, white, green	SBS	NSW	4.17	7
P3	yellow, yellow, green	SBB	NSW	1.39	-
P4	white, white, green	SBB	NSW	0.69	1
P5	yellow, yellow, green	SBS	OSW	0	4
P6	white, white, green	SBS	OSW	2.78	9
P7	yellow, yellow, green	SBB	OSW	2.08	-
P8	white, white, green	SBB	OSW	0	2

Table 2: Exploratory Study: summary of results.
SBS – static-blinking-static, SBB – static-blinking-blinking, NSW – next to the steering wheel, OSW – on the steering wheel.

19 participants reported that a combination of green and white is easier to distinguish in the periphery of vision in comparison to yellow and green color combination, because they are the neighboring colors on the color wheel[5]. During the interview, they provided an argumentation based on the warm-cold metaphor – green and yellow are warm while white is cold. Therefore, for a combination of yellow and green, participants had to explicitly and often check the color to ensure it is already green and not yellow anymore. 21 participants preferred having static-blinking-static (SBS) brightness progression, because blinking and static light changes are easy to perceive in the periphery. The combination of color (white-green) and brightness (blinking-static) change from middle to last step increased an awareness of the upcoming turn (Table 2). 18 participants also mentioned that three steps in light patterns is sufficient and they did not want more or less.

Experiment

From the exploratory study, we learned that a combination of green-white colors and SBS brightness progression are the most preferable light parameters. However, we did not derive the most preferable light position, because the ranking results for both positions NSW (next to the steering wheel) and OSW (on the steering wheel) were nearly the same. Thus, for the experiment we decided to keep on and next to the steering wheel positions and compare two light patterns (P2 and P6) to a standard GUI display navigation as a baseline. Our aim was to compare light and GUI navigation at two different positions only on the visual level without additional navigation support, such as auditive or vibrotactile cues. All four navigation conditions for the experiment are shown on Figure 9.

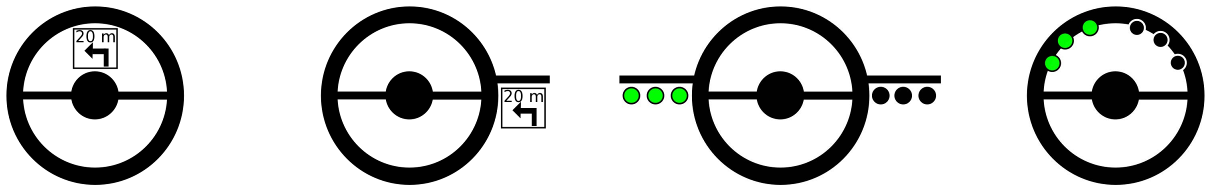
We measured time spent on looking at the navigation interface (total time and time per glance), number of glances, error rate. After each trial we asked participants to rate the level of helpfulness and distraction of the navigation aid they just used using 5-point Likert scales, asking the following questions: (1) How acceptable do you find this navigation method? (2) How demanding do you find this navigation method? In addition, we interviewed participants at the end of the study.

Participants and Apparatus

We recruited another 24 participants (13 female) aged between 20 and 35 (M = 25.92, SD = 3.8) with an experience of driving a car between 0.5 and 17 years (M = 7.56, SD = 3.84). All of them had normal or corrected vision without color blindness.

Participants sat in the same driving simulator with automatic transmission and drove a car in the same simulation as in the exploratory study. This time in order to determine the users' eye gaze we used the *Dikablis Glasses* by Ergoneers[5].

[5]http://www.ergoneers.com

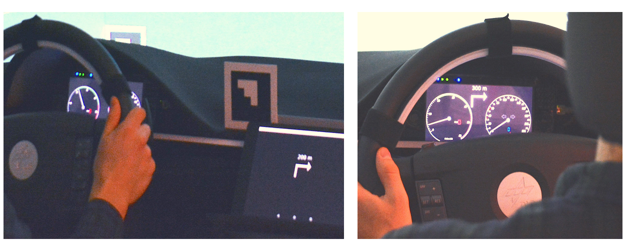


(a) GUIF (b) GUIS (c) LNSW (d) LOSW

Figure 9: Experiment conditions: (a) GUIF - GUI display in the Front, (b) GUIS - GUI display on the Side, (c) LNSW - Light display Next to the Steering Wheel, (d) LOSW - Light display On the Steering Wheel.

The *Dikablis Glasses* are head-mounted glasses that detect the position of the eye gaze in the visual marker coordinate system. We used three physical markers on the front panel of the car and four virtual (shown within the city simulation) visual markers in order keep a permanent track of the participants' eye gaze. We used the standard eye tracker software to record two videos (from field and eye camera) per each trial and for further video analysis. The eye tracker was calibrated with a standard procedure that comes with the eye tracker software. We calibrated the eye tracker before each trial to ensure the precise eye tracking. Each calibration took about 30 seconds.

For light-based navigation we used the same hardware as for the exploratory study. For a GUI navigation display we used an Android tablet Nexus 9[6] that showed a number of meters left before the next maneuver and an arrow above as an indicator of the maneuver type – left, right, or U-turn. All of the navigation methods show an indication of the next turn every 100 meters, starting from 300: 300, 200, and 100. However, in order to increase the precision of GUI navigation methods we added a navigation cues after 100 meter with a step of 20 meters: 80, 60, 40, and 20.



(a) (b)

Figure 10: GUI navigation displays next to (a) and behind (b) the steering wheel.

To balance the factor position of navigation aid, we decided to investigate GUI navigation methods on two different positions: behind the steering wheel and next to the steering wheel. This decision was made based on the derived positions for light-based navigation displays from the exploratory study. The angle of view for light display on the steering wheel and a GUI display behind the steering wheel, as well as the angle of view light display next to the steering wheel and a GUI display next to the steering wheel were comparable. The positions of GUI navigation displays are shown on Figure 10.

The *task* of the experiment was the same as for the exploratory study and took about 6 minutes. Based on the results and observations regarding drivers' eye focus from the exploratory study, we hypothesized the following outcomes:

H1: Participants spend on average less time explicitly looking at a navigation aid using ambient light than a graphical user interface.

H2: Participants spend less time looking at a light-based navigation aid on the steering wheel than next to the steering wheel.

RESULTS

We revealed that a light-based navigation method on the steering wheel has the lowest *duration of glances* (M = 1.42, SD = 2.12), followed by a light-based navigation method next to the steering wheel (M = 2.29, SD = 3.42), a GUI display behind the steering wheel (M = 9.19, SD = 7.74), and a GUI display next to the steering wheel (M = 14.45, SD = 8.38).

A light-based navigation method on the steering also has the lowest *frequency of glances* (M = 8, SD = 12.25), followed by a light-based navigation method next to the steering wheel (M = 11.67, SD = 15.28), a GUI display next to the steering wheel (M = 48.91, SD = 22.99), and a GUI display behind the steering wheel (M = 59.9, SD = 23.22).

Based on the Likert scale results we derived that for the factor *acceptance* (5 - very acceptable) a light display on the steering wheel (LOSW) (Md = 4.21, SD = 0.88) received the highest rating, followed by a light display next to the steering wheel (LNSW) (M = 3.79, SD = 1.06), a GUI display behind the steering wheel (GUIF) (M = 3.21, SD = 0.88), and a GUI display next to the steering wheel (GUIS) (M = 2.33, SD = 1.01).

As for the factor *demand* (5 - very demanding) we derived that a light display on the steering wheel received the lowest rating (M = 1.58, SD = 0.72), i.e. it is the least demanding navigation aid among four evaluated, followed by more demanding a light display next to the steering wheel (M = 1.92, SD = 0.93), a GUI display behind the steering wheel (M = 2.54, SD = 1.18), and a GUI display next to the steering wheel (M = 3.08, SD = 1.21) as the most demanding navigation method.

[6] https://www.google.com/nexus/9/

Regarding the ranking of the navigation methods we report the following results (out of 24): LOSW - 12, LNSW - 7, GUIF - 4, and GUIS - 1. All of the navigation methods had an error rate lower than 2.08%: GUIF - 2.08%, GUIS - 1.39%, LNSW - 1.39%, LOSW - 0%. The summary of the descriptive statistics is shown on Table 3.

Navigation Method	**Duration of glances**		**Frequency of glances**		**Acceptance**		**Demand**	
	M	*SD*	*M*	*SD*	*Md*	*IQR*	*Md*	*IQR*
GUIF	9.19	7.74	59.9	23.22	3	1	2.5	2.25
GUIS	14.45	8.38	48.91	22.99	2	1	3	2
LNSW	2.29	3.42	11.67	15.28	4	2	2	1
LOSW	1.42	2.12	8	12.25	4	1	1	1

Table 3: Experiment: Summary of results. Acceptance: 5 - very acceptable, Demand: 5 - very demanding.

We analyzed the following dependent variables using Friedman tests: *duration of glances*, *frequency of glances*, *acceptance* and *demand*. We observed a significant effect for *duration of glances* (χ^2 = 43.81, p < 0.001), *frequency of glances* (χ^2 = 44.78, p < 0.001), *demand* (χ^2 = 25.5, p < 0.001), and *acceptance* (χ^2 = 33.654, p < 0.001).

Using the post-hoc Wilcoxon signed-rank test we revealed a significant difference between all navigation methods for a factor *duration of glances*, except for two light-based methods (Z = -1.696, p = 0.09). We derived that the average glancing duration on both navigation aids with an ambient light in comparison to is significantly shorter than using a GUI display (Figure 11a). Moreover, the *duration of glances* for a GUI navigation display placed in the front was significantly shorter than for a GUI navigation display placed on the side (Z = -2.226, p = 0.026).

The post-hoc Wilcoxon signed-rank test revealed a significant differences between all navigation methods for a factor *frequency of glances*, except for two light-based (Z = -1.755, p = 0.079) and GUI-based navigation methods (Z = -1.208, p = 0.227). We observed that the number of glances on the navigation aid using ambient light on the steering wheel is shorter in comparison to a GUI navigation display behind the steering wheel (Z = -4.015, p < 0.001) as well as a GUI navigation display next to the steering wheel (Z = -4.107, p < 0.001) (Figure 11b). There was also a significant difference between light display next to the steering wheel and a GUI display behind the steering wheel (Z = -3.980, p < 0.001), and with a GUI display next to the steering wheel (Z = -4.108, p < 0.001).

As for a factor *demand* we observed a significant difference between all pairs of navigation methods (Table 4). Regarding the *acceptance* of navigation methods we observed no significant difference between the methods that use ambient light (Z = -1.564, p = 0.118). However, we observed a significant differences among all the other navigation methods (Table 4). The results of all post-hoc Wilcoxon signed-rank tests are shown on Table 4. All post hoc analyzes were conducted with a Bonferroni correction to avoid type I errors.

During the interview after the study, we asked participants, whether they would find it distracting if other people would use ambient light for navigation in other cars. All of the participants answered that they do not see any possible difficulties. In total 22 participants mentioned that they trusted the system during the experiment, did not feel confusion in understanding and interpretations, and would integrate an ambient light navigation system in their cars. One of the participants said: "I like it, because I do not actually have to look straight at the navigation aid". Regarding more complicated situations on the road, such as a highway with multiple lanes or roundabout with multiple exits, 21 participant suggested to add an additional navigation modality. They mentioned that they would like to have a sound feedback, an additional GUI display or an augmented reality navigation aid to ensure taking the right exit or lane. The feedback from 19 participants was very positive about the ambient light navigation. They argued this by its high precision, i.e. they knew exactly where to take a turn. One of the participants said: "With light navigation I don't experience a confusion: do I have to turn left now, or not yet?"

	Duration of glances	**Frequency of glances**	**Demand**	**Acceptance**
GUIF GUIS	Z=-2.226 **p=.026***	Z=-1.208 p=.227	Z=-2.217 **p=.027***	Z=-2.527 **p=.012***
GUIF LNWS	Z=-3.835 **p < .001****	Z=-3.980 **p < .001****	Z=-2.095 **p=.036***	Z=-1.793 **p=.005***
GUIF LOSW	Z=-4.021 **p<.001****	Z=-4.015 **p<.001****	Z=-2.8 **p=.005***	Z=-2.824 **p<.001****
GUIS LNSW	Z=-4.078 **p<.001****	Z=-4.108 **p<.001****	Z=-3.535 **p<.001****	Z=-3.788 **p<.001****
GUIS LOSW	Z=-4.110 **p<.001****	Z=-4.107 **p<.001****	Z=-3.666 **p<.001****	Z=-4.04 **p<.001****
LNSW LOSW	Z=-1.696 p=.090	Z=-1.755 p=.079	Z=-2 **p=.046***	Z=-1.564 p=.118

Table 4: Experiment results: Summary of the post-hoc Wilcoxon signed-rank tests.* **<.05** ** **<.01**

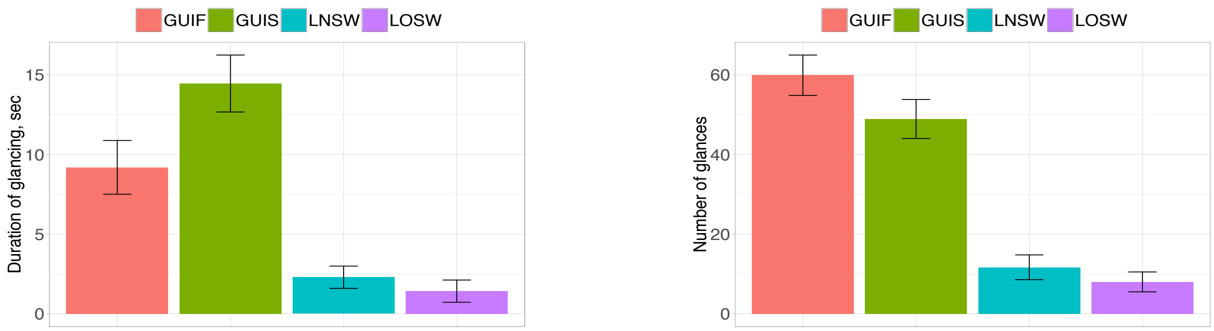
Supporting the guideline for *spatial* information encoding from the work by Matviienko et al. [15] that a position of LEDs is important light parameter of spatial information encoding, we derived two positions for ambient light navigation displays and showed their suitability. The results also showed that having a light display on the steering wheel is less demanding, because a driver did not have to check the sides repeatedly to ensure there is no navigation light shown yet. Moreover, some participants also wished to have an adjustable dynamic brightness change based on the brightness of the environment, in order to avoid the dazzle and minimize the distraction.

DISCUSSION

By exploring ambient light patterns as an output modality for in-car navigation systems, we provided a proof-of-concept that such ambient light displays not only lower driver distraction, but can be effectively used to aid in-car navigation tasks.

Use of Ambient Light for Turn-by-Turn Navigation Instructions

Based on the results of our simulator experiment, we accept our first hypothesis (H1) and conclude that participants do indeed spend on average less *time glancing* at navigation aids



(a) (b)

Figure 11: Experiment results: Means and standard errors for duration of glancing (a) and for a number of glances (b).

using ambient light in comparison with GUI displays. By presenting navigation information to the periphery of human vision, our system can help drivers to spend more time concentrating on the traffic situation, especially while driving in an unfamiliar area while maintaining a good navigation performance.

For the factor *acceptance* of navigation methods, we showed that both ambient light-based navigation methods we tested had a significantly higher level of acceptance than both GUI-based ones. Even though our ambient light-based navigation methods are novel, our participants did not experience difficulties getting accustomed to this mode of output. Moreover, based on our Likert-based results, the factor *demand* showed that GUI-based navigation displays were significantly more demanding in comparison with ambient light displays, despite that GUIs are well-known and often used today as personal navigation devices. This finding can be in part explained by the slight head movements towards a GUI-display required from drivers, since the display was placed on the side of the steering wheel. As far as drivers do not have this navigation aid in focus, they have to repeatedly check the distance left before the next maneuver. In case of the GUI navigation display in the front, the *demand* factor was significantly lower, which involves less head movements towards the navigation device.

Furthermore, during the interviews participants wished to have a combination of ambient light with other modalities for more complicated traffic situations, such as highways with multiple lanes, roundabouts with multiple exits, and so on. A combination with an aural feedback that provides additional assistance under more complicated situations could be a reasonable addition to ambient light navigation. Aural navigation aid do not increase neither the number nor duration of glances at the navigation devices, but provide an additional feedback about the upcoming maneuver [8]. However, in so far as our goal was to evaluate the effectiveness of ambient light as an unobtrusive modality for presenting turn-by-turn instructions, other modalities are outside the scope of our current work.

Together, the results of both the exploratory study and the experiment showed that participants had a low *error rate* using ambient light as a navigation method, which was comparable to the error rate of the standard GUI navigation device. This leads us to the conclusion that ambient light is an effective means of displaying turn-by-turn navigation instructions, and is applicable under simple driving situations with the following maneuvers: turn left, right and make a U-turn.

Color Set and Brightness Progression

We conclude that the combination of green and white colors form a suitable color set for encoding the remaining distance before an upcoming turn – essentially, encoding *progress* information. In general, participants perceived this color combination to be the most suitable, where this was consistently observed across our studies. Green color was overall perceived as a signal for allowance to make a turn, and white (seen as a neutral color) as appropriate for preparing for an upcoming turn. A few participants suggested that the decision of which color combinations are to be used should be left up to the driver (or user), so that the user can select his favorite color combination. However, leaving this choice up to the user may pose risks, especially if users were to use color combinations that are initially well perceived, but lead to heavy distractions or are not perceivable when driving. Furthermore, previous research has shown that the more distant the colors are on the color wheel [5], the easier they can be distinguished when presented on the periphery of human vision. However, this currently remains an assumption and not a generalized outcome about all cold-warm color combinations, because in our experiments we ended up testing only yellow-green (warm-cold) and white-green (neutral-cold) color combinations given the user-centric approach we adopted.

Concerning brightness, the distinct change of the brightness behavior of LEDs helps us to make a driver aware of the upcoming turn. From our experiments, we derived that the brightness progression – static-blinking-static (SBS) – is the best way to indicate the *progress* information for approaching a turn, and moderate blinking is the best to give a hint for a driver. In comparison with static-blinking-blinking (SBB), SBS involves less blinking light and therefore less distraction from the driving process. The important point is to indicate the shift from one navigation stage to another, e.g. from *get ready for a turn* to *turn now*, where the green-white color combination together with SBS brightness progression provided the best awareness cue about an upcoming turn. Also we interviewed participants regarding the number of navigation phases and 18 of them showed their preference for three phases: approaching, get ready, and turn now. They mentioned that having a blinking light spontaneously during the first or third phase is too distracting, and they preferred having a static light as a mental preparation for an upcoming maneuver.

Ambient Display Position

As we did not observe a significant effect for the *position* of the ambient light navigation display, we reject our second hypothesis H2 that stated the position of the display would have an effect on the time spent looking at it. We expected that showing ambient light in the front of a driver on the steering wheel will involve significantly less glancing at the light display, because of the differences for the angle of view. However, this was not the case. Even though there was no significant difference between these two positions of light displays, on average (Table 2) the participants were indeed spending less time looking at the ambient light navigation display on the steering wheel. Participants were also glancing at the light-based navigation aids on the steering wheel less frequently than on the light-based navigation aid next to the steering wheel. However, we did not reveal a significant difference for this dependent variable for these two conditions. From the foregoing, at least for ambient light displays, the position of the display matters less. We believe this to be an important finding, as it provides car designers more freedom to vary the location of these light displays, which can be additionally used for aesthetic purposes.

Study Limitations

One limitation of both our exploratory study and our experiment is that drivers were tested in a driving simulator. This meant that drivers did not encounter heavy traffic nor pedestrians, and the driving routes had a relatively straightforward block structure. However, for our proof-of-concept approach, our goal was not to test whether this system could support drivers under heavy traffic conditions, but rather to empirically validate whether ambient light displays, that beam light unobtrusively and to the periphery of a user's attention, can provide basic turn-by-turn instructions without incurring further processing costs, such as glance frequency and dwelling.

Another potential limitation concerns whether the subjective responses concerning color preference can be generalized to other studies, given the sample size of study participants. Given the subjective nature of color preferences, we would need to test different color combinations with hundreds of experienced drivers that use navigation assistance systems to arrive at concrete design recommendations. Our goal in this paper was not to identify the ideal color combinations, but to validate the effectiveness of ambient displays, where color is inseparable from the encoding of certain parameters. Nevertheless, we based our final decision on a combination of related work and two exploratory studies (focus groups and online questionnaire) to systematically tease out appropriate color preferences.

As far as the study was conducted in the driving simulator we admit that the color perception of light patterns might change depending on the external light conditions, e.g. driving in the bright day or a nighttime. An association of colors with their semantic meaning might vary depending on the social and cultural background of a driver. However, our studies showed that learning of the derived light patterns is intuitive and did not take a long time, because all of the participants could immediately use an ambient-light navigation in the driving simulator right after a short explanation of the experimenter. Also a proposed color-based navigation is limited to the population without visual impairments or color blindness.

CONCLUSIONS & FUTURE WORK

In this paper we investigate ambient light displays and their effectiveness as a navigation aid in an automotive context. We propose a novel ambient light-based navigation patterns and investigated them in comparison to a baseline GUI navigation display. We compared different positions for ambient light navigation displays to ensure this was not a confound.

The color combination of white-white-green together with the brightness progression static-blinking-static was determined to be the best encoding for three navigation phases: approaching, get ready, and turn now. The results of our experiments show that people spend on average less time glancing at navigation aids using ambient light in comparison with a graphical user interface navigation aid. Moreover, people check their navigation devices less often using ambient light navigation than with a graphical user interface. Based on these results we conclude that the usage of ambient light as a navigation aid can significantly reduce driver distraction levels in an automotive context.

Our outcomes, however, leave open questions for the future exploration and investigation of ambient light as a navigation method in the car. For example, the participants were driving in a simulated city without traffic and pedestrians. Thus, their focus was mainly on the road, navigation aids and a speedometer. This raises the question of whether the performance of ambient light navigation displays would differ under varying traffic conditions. Another interesting aspect for future exploration is assessing the mental load of participants while using ambient light, which has so far not been studied. Additionally, we want to investigate ambient light-based navigation methods for more complicated situations, such as the rapid succession of turns, navigation at the roundabout with multiple exits, and highways with multiple lanes. Moreover, we aim to compare light navigation encoding for turning left and gearing left. We also want to explore the combinations of our proposed ambient light navigation patterns with other modalities, such as auditory cues. We believe that additional assistance to ambient light in car navigation tasks, such as aural feedback, will help drivers to concentrate more on situations on the road and make driving a less demanding activity.

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