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On the relationship between occlusion times and in-car glance durations in simulated driving

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ABSTRACT

Drivers have spare visual capacity in driving, and often this capacity is used for engaging in secondary in-car tasks. Previous research has suggested that the spare visual capacity could be estimated with the occlusion method. However, the relationship between drivers' occlusion times and in-car glance duration preferences has not been sufficiently investigated for granting occlusion times the role of an estimate of spare visual capacity. We conducted a driving simulator experiment ($N = 30$) and investigated if there is an association between drivers' occlusion times and in-car glance durations in a given driving scenario. Furthermore, we explored which factors and variables could explain the strength of the association. The findings suggest an association between occlusion time preferences and in-car glance durations in visually and cognitively low demanding unstructured tasks but that this association is lost if the in-car task is more demanding. The findings might be explained by the inability to utilize peripheral vision for lane-keeping when conducting in-car tasks and/or by in-car task structures that override drivers' preferences for the in-car glance durations. It seems that the occlusion technique could be utilized as an estimate of drivers' spare visual capacity in research – but with caution. It is strongly recommended to use occlusion times in combination with driving performance metrics. There is less spare visual capacity if this capacity is used for secondary tasks that interfere with the driver's ability to utilize peripheral vision for driving or preferences for the in-car glance durations. However, we suggest that the occlusion method can be a valid method to control for inter-individual differences in in-car glance duration preferences when investigating the visual distraction potential of, for instance, in-vehicle infotainment systems.

1. Introduction

Drivers have a variable amount of time at their disposal to look away from the forward road scene and still be able to drive safely. In other words, drivers have *spare visual capacity* in driving (Ahlstrom et al., 2022). Often, this spare visual capacity is used for engaging in secondary visual tasks (Kircher and Ahlström, 2018), and it can be increased by driving automation (e.g., Hoedemaeker and Kopf, 2001; Mars et al., 2014). The spare visual capacity in driving can be estimated by the visual occlusion method, where the visual field of the driver is intermittently blocked (Kujala et al., 2021; Senders et al., 1967). The self-selected lengths of the occluded intervals are assumed to indicate the spare visual capacity in driving. The longer the occluded intervals, the lower the demands of the driving task and the higher the spare visual capacity in driving. It has been proposed that – regardless of their subjective nature – self-selected occlusion times in attentive driving by experienced drivers could be used as baselines for acceptable situational in-car glance durations, that is, glances directed inside the vehicle and associated with secondary tasks (Kujala et al., 2016b). However, the relationship between drivers' occlusion time and in-car glance duration preferences has not been sufficiently investigated for granting occlusion times the role of an estimate of spare visual capacity in driving.

At least two general factors have been shown to affect drivers' preferred occlusion lengths; variable situational demands of the driving task and drivers' individual preferences for the occluded intervals (Kujala et al., 2021). If the driving task demands plenty of visual attention, the occluded intervals are more likely shorter since the driver needs to glance more at the road environment to drive safely. High visual demands might arise from fast changes in the driving environment associated with high levels of uncertainty (e.g., due to higher speeds,

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varying curvature, traffic density, poor visibility). Likewise, if the driving task demands low levels of visual attention, then the occluded intervals are more likely longer since the driver needs to glance at the sources of driving-relevant information less often and for shorter times to drive safely. Low level of demands refer to situations where the driving conditions change slowly and, hence, are more predictable (e.g., low curvatures, modest speeds, little traffic, good weather).

Even it seems that all the drivers adapt their occlusion intervals based on the changes in the general driving task demands in a similar fashion, they do not seem to prefer similar lengths for the occluded intervals in even the exactly same driving scenario (Kujala et al., 2016). Instead, there seems to be an individual preferred coefficient for the length of the occluded interval, which is consistent over different scenarios (e.g., suburban vs highway driving: Kujala et al., 2016) and can vary over three times between drivers in a given scenario. It would be rational to expect that these two factors also affect the lengths of in-car glance durations. However, there might also be other mechanisms in play.

For instance, drivers may be able to maintain their lane position with peripheral vision while conducting secondary tasks on in-car displays (e.g., Summala et al., 1996). However, during full occlusion, drivers are not able to use peripheral vision for lane-keeping since their whole visual field is blocked. This raises a question, are occlusion times a fair benchmark of spare visual capacity in driving if the driver cannot utilize peripheral vision for lane-keeping or for detecting brake lights and looming of a lead vehicle under occlusion?

Previously, a study examining the visual distraction potential of multimodal (i.e., auditory and visual) route guidance identified an association between drivers' occlusion distances (i.e., distance in meters driven during an occluded period) and in-car glance lengths (i.e., distance in meters driven during an in-car glance) (Kujala et al., 2016a). In the study, the secondary task was a visually and cognitively low-demanding task where drivers were asked to follow audio-visual navigation instructions without requiring any manual input. This finding suggests a connection between drivers' visual in-car sampling preferences in both conditions. However, in later studies in the same driving scenario, this association has not been found when the secondary in-car task has been visually and cognitively more complicated (e.g., typing a street address to a navigation software) and required manual input (e.g., Kujala and Grahn, 2017). It has remained unclear why the association between occlusion distances and in-car glance lengths was found in one study but could not be later reproduced. Hypothetically, a possible reason could have been the structure or complexity of the in-car task, which could have affected drivers' preferred visual in-car sampling strategies (cf. the individual coefficient in occlusion interval lengths, Kujala et al., 2016). For instance, the in-car task structure could have been such that the task steps could be completed with very brief glances. On the other hand, more complex steps of the task might have encouraged prolonging the glances over preferred durations. The driving scenarios used in these previous studies were the same, including relatively realistic suburban driving scenarios with speed management, junctions, turns, motion, sound, and no other traffic. These variable driving demands and information sources at the self-selected in-car glance initiation points may also have hindered the association between occlusion and in-car glance lengths.

Since it is unclear if the occlusion technique can be used for estimating a baseline of spare visual capacity in attentive driving, we should better understand driving during occlusion as well as driving during an in-car glance and how these two are associated. It should be clarified why there are inconsistencies in the results regarding the association between preferred occlusion times and in-car glance durations. This better understanding could provide evidence if the occlusion method is a valid method to assess spare visual capacity and visual demands in driving – and further, visual distraction – and how various factors and variables affect occlusion times and in-car glance durations.

With this line of thought, this paper aims to understand more profoundly driving during occlusion and driving during an in-car glance and their relationship, as well as the mechanisms that may affect this relationship. Thereby, we study the association between occlusion times and in-car glance durations by varying demand levels of in-car tasks in a simplistic driving scenario with fixed speed. The possible role of peripheral vision in this association should become visible in a simple lane-keeping task on a mildly curving road. Further, to focus purely on the drivers' visual behavior, we will omit the motion and audio cues of the driving simulator since drivers may have different abilities to utilize these cues, which could further affect their glancing behavior. Thus, we have posited the following research questions:

1) Is there an association between drivers' occlusion times and in-car glance durations in the same driving scenario?
2) Which factors and variables can explain the strength of this association?

Additionally, we tested the following hypotheses based on the rationale and research questions provided above:

H1. There is a positive association between occlusion time preference and in-car glance durations in a fixed driving scenario but only with simple in-car tasks. Here, a simple in-car task refers to a task with no task structure and thereby it allows self-paced glances.

H2. Lane-keeping performance is better in simple than in more complex in-car tasks during in-car glances of the same length or under occlusion intervals of the same length. This would suggest a better ability to utilize peripheral vision for lane-keeping in the simple than in the more complex in-car tasks.

H3. Lane-keeping performance decreases and in-car glance durations increase by increasing the complexity of the in-car task (here: number of search items per screen). This would suggest that the in-car task complexity or structure affects both glancing behavior and the ability to utilize peripheral vision for lateral vehicle control.

H4. There is a positive association between steering amplitude during an in-car glance and in-car glance duration. This would indicate steering effort and ability during the in-car glances, enabling longer in-car glance durations.

Further, we explored the effects of other possible factors and variables found in the literature that could explain variabilities in in-car glance durations and occlusion times, such as in-car task structure (e.g., items encoded per glance) and time-to-line-crossing at the start of the occlusion.

2. Related work

2.1. Occlusion as a measure of visual attentional demand and spare visual capacity

The visual occlusion technique was initially introduced by Senders et al. (1967) to estimate the attentional demand of driving. It should be noted that Senders et al.'s (1967) original occlusion technique differs from the methods published by ISO (2017) and the National Highway Traffic Safety Administration (2013), where participants complete in-car tasks in a series of 1.5-second forced glances in a stationary vehicle. Senders et al.'s (1967) visual occlusion technique refers to driving with vision intermittently blocked (i.e., occluded), and the duration of the self-selected occlusion is measured as an estimate of the visual attentional demand. Since Senders et al.'s (1967) first occlusion studies, the occlusion technique has been used in various driving studies – for a more comprehensive review of the occlusion technique, see Kujala et al. (2021). In the original technique, the driver's vision is occluded (i.e., driving blind without any visual information), and when needed, the driver can observe the driving scene for 500 ms at a time. During the occluded period, the time driven blinded is measured (i.e., occlusion time). According to Milgram (1987), with the occlusion technique, it is possible to evaluate the attentional demand, or information processing workload, that is imposed on a driver by recording the situation and the rate the driver samples the information. Similarly, according to Kujala et al. (2021), the visual attentional demand of driving can be estimated as the fraction of the time when the driver's eyesight is unoccluded (i.e., a driver is able to see the forward road scene). Self-paced occlusion drive with an unoccluded state as a default is similar to a situation where the driver chooses to conduct a visual secondary in-car task while driving by intermittent in-car glances (Kujala et al., 2021).

As the opposite to attentional demand of driving, Safford (1971) and Kircher and Ahlström (2018) suggest that the occlusion technique can measure drivers' spare visual capacity, too. Safford (1971) justifies the existence of the spare visual capacity in driving by the visual occlusion technique: the experiments suggest that a portion of drivers' visual sampling behavior in attentive driving is unnecessary and can be removed without serious effects on the driving performance – the part that could be removed is called spare visual capacity. Spare visual capacity refers to the fraction of time the driver's visual field is occluded, and these fractions can provide information on the required sampling frequency in driving (Kujala et al., 2021; Safford, 1971). Safford (1971) also noticed that spare visual capacity is sensitive to driving task difficulty and that the spare visual capacity differs between drivers. Additionally, Liu et al. (2020) suggest that spare visual capacity depends on the driving scenario and driven speed. Measuring driving performance together with occlusion may provide a more precise measure of spare visual capacity in (attentive) driving (Kujala et al., 2021).

2.2. Driving during occlusion

According to Senders et al. (1967), the time driven without vision is dependent on the information decay on the forward road scene. This implies that the occlusion time depends on the driver's ability to hold some kind of static picture of the driving scene in mind. However, the capacity of visual short-term memory – which is connected to keeping visual images in mind – seems not to be associated with occlusion times or distances (Kujala and Grahn, 2017). Alternatively, Liu et al. (2020) suggest that some personality trait or driving experience could have an effect on occlusion time preferences. According to Kujala et al.'s (2016b) study with 97 drivers, driving experience was not a major factor in explaining preferred occlusion times or distances, although it seemed to moderate the effect of occlusion distance on driving performance. However, the age of the driver seems to have a strong association with preferred occlusion times or distances: the occlusion time and distance decrease when the age of the driver increases (e.g., Grahn and Kujala, 2018; Kujala et al., 2016a; Kujala and Grahn, 2017; Mourant and Mourant, 1979; Rackoff, 1975; Tsimhoni and Green, 1999).

Previous studies propose that driving during occlusion is dependent on drivers' ability to predict the development of the road scene. Kujala et al. (2021) suggest that in occlusion drive, drivers can focus on the latest observed scene of the driving scenario, which makes it possible for the driver to predict the scenario's development. Also, Liu et al. (2021) studied driving with vision occluded, instructing participants to occlude their vision when they have good situational awareness. Liu et al. (2021) concluded that drivers try to sample "enough" driving-related information to create an adequate mental model before occluding themselves in order to be able to drive without vision by predicting the unfolding situations.

The referred situation awareness (Endsley, 1995), which deals with attentive task conduction in dynamic systems, consists of three levels: perception of the elements in the environment, comprehension of the current situation, and projection of its future status. The third level, the projection of the current situation's future status, shares similarities with Kujala et al.'s (2021) suggestion of how drivers predict the road scene during occlusion. Additionally, Chen and Milgram (2022) studied the human operator's ability to predict the status of a dynamic system during occlusion and concluded that humans are able to predict a dynamic system's progress without visual information – to an extent. Drivers are able to do this also in driving without occlusion, as humans cannot process the whole visual field continuously but have to sample with foveal vision and the view is blocked during saccades and blinks (Kujala and Lappi, 2021; Land, 2006). However, one's ability to drive a car under occlusion may also depend on motor control noise (Godthelp, 1986). A driver might remember exactly where the road is but one's inaccurate motor control might lead the car off the planned trajectory. After a situation-dependent time threshold affected by, for instance, the road curvature, this noise makes even a perfect memory of the road useless and requires a glance to see where the noisy control input has led the car.

2.3. Possible factors affecting visual sampling while driving

2.3.1. Ambient and peripheral vision

One significant factor affecting visual sampling while driving could be the use of ambient vision or peripheral vision, which serve several functions in the driving task. Shortly, in visual processing, there are two aspects: focal and ambient vision (Wickens, 2002). All that is not focal (i.e., visual field of the current point of gaze, foveal and parafoveal) is considered peripheral (Larson and Loschky, 2009) or ambient (Wickens, 2002). Focal vision is needed for details and pattern recognition (Wickens, 2002) since foveal acuity is greatly better than ambient or peripheral acuity (Anstis, 1998). According to Trevarthen (1968), ambient vision determines "space at a large around the body". Ambient vision involves peripheral vision and is used for orientation and ego motion sensing and is "pre-attentive" or "automated" (Wickens, 2002). Overall, peripheral vision provides information from across the field of view and makes planning the shifts of attention and gaze possible (e.g., Wolfe et al., 2020) and it enables a quick perception of the gist of a scene (i.e., catching the meaning at a glance, e.g., in 100 ms, Greene and Oliva, 2009). According to Vater et al. (2022), peripheral vision also makes it possible for drivers to compare their own vehicle to other vehicles and objects in the driving environment. In driving, peripheral vision also plays an important role in hazard perception (e.g., Crundall et al., 1999) since hazardous events are often noticed with peripheral vision. This can mean, for instance, rapid triggering of the looming of a lead car in peripheral vision and, thereby, a gaze shift towards the car for more accurate information on its deceleration pace (Nilsson et al., 2018). Additionally, Summala et al. (1996) found that experienced drivers are able to maintain their lane position using only peripheral vision. However, this ability may be negatively affected by cognitive and visual load by in-car tasks. In our study with a mildly curving road, the ability to steer with peripheral vision during in-car glances should be reflected in improved lane-keeping performance during these glances as compared to occluded driving and, consequently, as a positive association between steering amplitude and in-car glance durations if the participants become aware of this ability (hypotheses H2-H4).

2.3.2. Glancing strategies and task structures

According to Wierwille's (1993) visual sampling model, drivers use a glancing strategy where they do not allow their in-car glance times to exceed 1.6 s (on average) when conducting an in-car task. Additionally, the type of task and the demands of the driving scenario can affect the glancing behavior (e.g., the higher the demands, the shorter the glance durations). Besides these findings, inter-individual differences in glance strategies while conducting secondary tasks can be another factor affecting visual sampling (e.g., Broström et al., 2016, 2013; Donmez et al., 2010; Kujala and Grahn, 2017; Yang et al., 2020). Nevertheless, it is still unknown which factors are associated with the differences in drivers' in-car glance durations. One factor affecting could be visual processing speed. Visual processing speed can be determined as "the amount of time needed to make a correct judgment about a visual stimulus" (Owsley, 2013). According to Shinar et al. (1978), visual search time is also associated with occlusion times.

Yet another affecting factor could be the design of the secondary in-car tasks (i.e., task structure). Task structure refers to "how a task breaks down into smaller subtasks" (Salvucci and Kujala, 2016). Often, drivers have a tendency to switch tasks at subtask boundaries (e.g., Janssen et al., 2012; Lee et al., 2015; Lee and Lee, 2019), such as dialing a phone number in chunks. Switching tasks at subtask boundaries (i.e., "natural breakpoints") has advantages: when the subtask is completed, mental workload decreases because there is no need to actively maintain the information in the working memory (Bailey and Iqbal, 2008), and the task resumption lags are shorter when the subtask is completed before the task switch (Altmann and Trafton, 2002). However, when conducting secondary in-car tasks, drivers may be forced to glance away from the forward road scene for longer periods than would be safe if the secondary task is not easily interruptible (e.g., Brumby et al., 2009; Salvucci and Kujala, 2016). One reason for a task not being easily interruptible could be the structure of the task and, hence, the task may cause longer glances than the driver would prefer. On the contrary, in-car tasks that can be divided into small subtasks may be beneficial in diminishing drivers' individual in-car glance durations (Grahn and Kujala, 2020).

In the current study, our aim is to study the relationship between occlusion times and in-car glance durations in the same driving scenario while manipulating the in-car task structure. Further, this experimental design can shed light on how the reviewed factors affect the strength of the association between occlusion times and in-car glance durations.

3. Method

3.1. Experimental design, driving scenario, and tasks

The experimental design was within-subjects with glance duration (or occlusion time) as the dependent variable. The driving scenario for each task was the same: a seemingly straight three-lane road with mild curvature to the right (about 38.20 degrees/km or 0.67 rad/km). The speed was fixed with cruise control to 100 km per hour. Time-to-line-crossing (TLC) from the center of the lane while keeping the steering wheel straight was approximately-two seconds. There was no road crown and no other traffic or other perturbations in the scenario, such as wind gusts.

For the self-paced occlusion trial, intended to estimate participants' (preferred) maximum spare visual capacities, the simulator's screens were blank to start with, and the participants were able to reveal the driving scene for 500 ms (as in Senders et al., 1967) at a time by pulling a lever attached behind the steering wheel. In addition, for instance, Kujala et al. (2016b) found out that 500 ms is sufficient visual sampling time to drive safely. If the participants pulled the lever continuously within 500 ms time windows, the driving scene remained continuously visible. Without that fixed time component, there is a chance that the occlusion task can turn into a satisfying task including lots of redundant sampling – which would not measure the maximum spare visual capacity (cf. Kircher et al., 2020). See the detailed instructions for the occlusion trial in Procedure. As a visually and cognitively low-demanding in-car task, we had a task where participants were instructed to glance at a letter "X" on the tablet screen (see Fig. 1) next to the steering wheel for as long as possible (see detailed instructions in Procedure). This task was done twice during the experiment, as a second trial and as a last trial at the end.

As a more complex in-car task, we had visual search tasks. In the visual search tasks (see Fig. 2), the task was to find a desired 3-letter combination (later target) from a page containing either 10, 15, or 20 letter combinations (later items). In reality, only two pages contained the target item, but participants did not know this (for a more detailed description, see Procedure). The first page containing the target item was at the beginning of the task (either on page 1, 2, or 3, depending on the task), and the second was at the end of the task (either on page 12, 13, or 14 depending on the task). This was done because we wanted to keep the participant alert and searching for the target item. Each visual search task (either with 10, 15, or 20 items) had 15 pages of letter combinations, and between each page, a page reminding what the desired letter combination was. To be completed, each task needed 31 screen tappings (start, tap the correct combination or next if not found, next, tap the correct combination or next if not found, next, etc.). The 3-letter combinations with 10, 15, and 20 items were IKJ, IJL, and IJK, respectively. Each participant completed all three visual search tasks, both driving and when the driving simulator was stationary. The stationary condition was added to measure the participants' visual search time when they were concentrating only on the search task.

Each visual search task had two alternative versions with differing randomized order of the items and the desired combination (e.g., 10 items A, 10 items B), which were counterbalanced across the driving and

Fig. 1. The setup of the X trial.

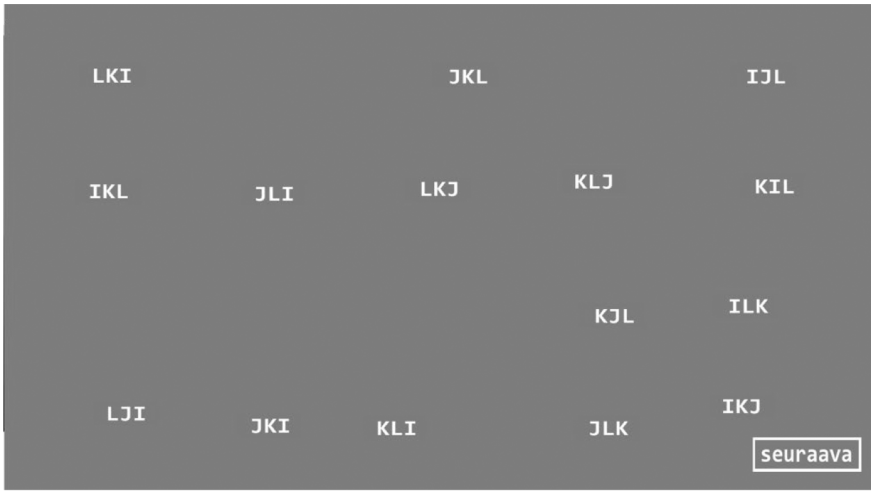

Fig. 2. Example of a visual search task with 15 items (seuraava: next in Finnish). The task was to find a desired 3-letter combination from a page either containing 10, 15, or 20 items. The desired item may or may not be present on the page.

stationary conditions. See detailed instructions for these tasks in Procedure.

3.2. Apparatus

We conducted the experiments in the University of Jyväskylä's driving simulator laboratory. The medium-fidelity driving simulator had a CKAS Mechatronics 2-DOF motion platform, a longitudinally adjustable seat, Logitech G27 force-feedback steering wheel, and pedals. In the simulator, there were three 40″ LED screens (95.6 cm × 57.4 cm) with a resolution of 1440x900 pixels per screen. The middle screen displayed a rear-view mirror, a HUD tachometer, and a HUD speedometer. The side screens displayed side mirrors (see Fig. 3). Automatic transmission and cruise control were used during the testing. Eepsoft (https://eepsoft.fi/) provided the simulator software, which saved the driving log data at 10 Hz. For the occlusion trial, the steering wheel was equipped with a lever that displayed the driving scene for 500 ms when pulled; otherwise, the screens were blank. The motion platform was not applied in this study, the participants had to rely on their vision for the lane-keeping task. This was done since the participants may have different abilities to utilize motion and sound cues which could have differential effects on the glancing behavior, and we wanted to focus purely on their visual behavior. The steering wheel gave force feedback by resisting movements by a small force. We used 10.1″ Samsung Galaxy Note 10.1 (2014 edition, Android version 5.1.1) tablet to display the X task and visual search tasks to participants. The tablet was in a holder on the right side of the steering wheel. The visual angle from the center of the in-car display to the vanishing point of the forward roadway (about 35 cm) varied between 24.98 and 33.58 degrees, depending on the participant's seat position. Our visual search tasks were constructed with PsychoPy (Peirce et al., 2019), a Python library for implementing different behavioral experiments. After we created our tasks, they were run in Pavlovia (https://pavlovia.org/).

We used Ergoneers' Dikablis Glasses 3 head-mounted eye-tracking system in the experiment to record participants' eye movements. To synchronize the driving simulator data and eye-tracking data, we used a LAN bridge and custom-built open access synchronizing software (Syncster 1.0.0). D-Lab 3.55 was used to manually inspect the accuracies of the recorded eye movements and the automated area-of-interest encodings by the software. We used Rstudio for data preparation and

Fig. 3. The driving simulator and the study setup.

the statistical analyses were performed with IBM SPSS Statistic 28 and Rstudio.

3.3. Participants

In total, 30 participants were recruited by convenience sampling using the university's mailing list. Nineteen of the participants were male, ten were females, and one not disclosing gender. Other relevant demographics of the participants are presented in Table 1.

Each participant had a valid driver's license. All participants had a normal or corrected-to-normal vision and were generally healthy. The duration of the experiment was approximately 1.5 h. After the experiment, participants were rewarded with a gift certificate worth 30 EUR. We conducted the research following the guidelines of the Finnish National Board on Research Integrity, the ethical principles of our university, the ethical principles of research in human, social, and behavioral sciences, as well as good scientific practice and valid legislation. Ethical approval was not required for the study based on the regulations of the university's ethics committee.

3.4. Procedure

Demographic data we collected beforehand via email. Upon arrival, participants read and signed the informed consent form and were informed about the setup and the purpose of the study. This experiment was a part of a two-experiment series, being the latter one. In the first experiment (not reported here), participants familiarized themselves with driving the simulator, both vision unoccluded and occluded. Here, driving occluded means driving with the driving scene intermittently blocked by blanking the simulator's screens. Since the participants were already familiar with driving the simulator after the first experiment, as a practice in the experiment reported in this paper, the participants' first task was to practice the occlusion trial as long as they wanted. The driving scenario for the occlusion trial – as well as in all other trials – was a seemingly straight three-lane road with mild curvature to the right. There was no other traffic, and the speed was fixed to 100 km/h. The average practice time for the occlusion trial was 1.7 min. It should be noted that participants conducted several occlusion trials in the first experiment, and hence the practice time was kept relatively short.

The first actual trial was the visual occlusion trial. During the trial, the screens of the simulator were blank by default, and participants were able to reveal the scenery for 500 ms (following Senders et al., 1967) by pulling a lever behind the steering wheel. Cruise control was used during the experiment, which was adjusted to 100 km/h. The instructions were to try to stay in the middle lane but at the same time to try to maximize the time driven without vision (i.e., screens blank). A lane deviation occurred if an edge of the HUD meters exceeded a lane marking (see Fig. 3). In order to get the participants to concentrate on the driving task but still try to maximize their occlusion time to their preference, an extra gift certificate of 10 EUR was promised and given to those who had the longest occlusion times while being accurate on the lane-keeping. The length of the occlusion drive was three minutes. After the occlusion trial, participants put on the eye-tracking system, which was then adjusted and calibrated.

Table 1
Demographics of the participants.

	N	Range	Mean	Standard deviation	Median
Age	30	19–42	25.1	4.74	24
Driving experience in years	30	0.9–24	6.8	4.63	5.8
Self-estimated kilometers per year	30	100–30000	6172	7191	3000
Self-estimated lifetime driving experience in kilometers	30	1000–400000	61,982	81,435	37,500

The second trial of the experiment consisted of a visually and cognitively low-demanding task where participants glanced at a letter X on the screen next to the steering wheel (the X1 trial, see Fig. 1). The instruction for the task was "Try to stay in the middle lane as accurately as possible. At the same time, glance the letter X on the screen as long as you feel it is possible for the sake of staying in the middle lane". The duration of the trial was three minutes. The driving scenario and speed were the same as in the occlusion trial.

The visual search task trials, which followed next, were counterbalanced across the total sample. First, the tasks were practiced in two ways: with visual search tasks having a target item on every page and with visual search tasks similar to the actual tasks (i.e., no target on each page). Both practices were done while driving and when being stationary. The actual tasks were instructed as follows: "Your task is to drive and stay in the middle lane and to find the desired 3-letter combination as quickly as possible. In the beginning, you will see the desired letter combination on the tablet's screen, and the task starts when you tap the screen. After tapping, you will see multiple 3-letter combinations, and your task is to find the desired combination as quickly as possible *while still staying* in the middle lane. After finding the combination, tap it, and the next page shows you the same desired 3-letter combination as a reminder. Tap the screen, and you will see another page with multiple 3-letter combinations. Repeat until the task ends. However, the searched target item might not be present on the page, and in a case like that, you should tap "next" to see the next page of letter combinations". During the actual experiment, the visual search tasks were conducted twice: while driving and while being stationary. When the task was conducted in a stationary simulator, the instructions regarding driving were excluded. The driving scenario and speed were the same as in the occlusion and X trials.

After the visual search tasks, participants repeated the first visually and cognitively low-demanding task (the X2 trial) with the same instructions. Finally, participants were thanked and rewarded with a gift certificate.

3.5. Data preparation and analysis

For measuring the occlusion times, we used the driving simulator's log data and an R script to calculate the time driven occluded. For calculating the in-car glance durations in the visually and cognitively low demanding task as well as in the visual search tasks, we used D-Lab's automated area-of-interest (AOI) analysis. We also used D-Lab to manually inspect each in-car glance from eye-tracking videos (25 frames per second) and manually corrected the found inaccuracies in the AOI data frame by frame following the SAE-J2396 definition (Society of Automotive Engineers, 2000). With the manual inspection we also made sure that all the in-car glances were directed to the secondary task at hand.

As outlier handling, we excluded all glances exceeding eight seconds from the data. That procedure filtered 58 glances or occlusion times from the data. In total, nine different participants produced these over eight-second glances or occlusions. The eight-second threshold was selected because an inspection of the data indicated that glances above this threshold were outliers four standard deviations above the mean. We did not want to lower this duration threshold further since the instructions for the X trials and occlusion trials were to try to maximize the time participants were able either to look at the X or drive occluded. Another filtering was done for the occlusion times: only those occlusions that start when the participant is in the lane are included in this data. In this filtering process, 538 occlusions were discarded which left us 1596 occlusions. This procedure made the occlusions more comparable with in-car glances that are usually initiated when in one's own lane.

For testing the hypotheses H1–H4 and for analyzing the possible effects of other relevant factors found in the literature, four stepwise multilevel models (Hox, 1998) were created. Multilevel models are used when data have a hierarchical or clustered structure, for example, students nested in schools (Hox, 1998), or for more comparable example, reading time studies where read sentences are nested within persons (Richter, 2006). Here, glances and occlusions are nested within persons. To construct multilevel models, we organized the glance and occlusion data in a longitudinal format. According to the 30/30 rule of thumb, Level 1 in the multilevel model should contain at least 30 observations, and those observations should be nested within 30 units on Level 2 for sufficient statistical power (Richter, 2006). In our data, there are in total 10,613 in-car glances or occlusions (Level 1) nested within 30 participants (Level 2). The glance and occlusion numbers per trial can be seen in Table 2.

Models 1 and 2 were targeted at predicting in-car glance durations for the in-car tasks (one for X and one for the visual search tasks) and Model 3 for predicting occlusion times in the occlusion trial (i.e., one model per type of trial). Models 1 and 2 served in testing H1 and H4. The independent variables in the X model were participant's mean occlusion time (fixed factor), trial number (X1 vs X2, fixed), and steering amplitude (covariate). For the visual search task model, the independent variables were participant's mean occlusion time (fixed), number of search items (fixed), participant's visual search speed (covariate), and steering amplitude (covariate). Model 3 was created for exploration of the significant predictors of occlusion time. The independent variables in this model were time-to-line-crossing (TLC) at the beginning of occlusion (covariate) and steering amplitude (covariate). Two versions of each model were created, one with intercepts and another with slopes for participants as a random factor. Model 4 was created for predicting lane deviations in the trials and, thereby, testing the hypotheses H2 and H3. The independent variables in this multilevel binary logistic regression model were trial (fixed) and occlusion time or glance duration (as a covariate for control).

Models 1, 2, 3, and 4 were constructed using IBM SPSS Statistics 28. The random slope models were constructed using a lme4 package in R. As an effect size, both marginal R^2, which describes the proportion of variance explained by the fixed factors alone, and conditional R^2, which describes the proportion explained by the fixed and random factors, are reported. Due to the possible suppressor effects in forward modeling, we created the models also by backward stepwise selection. The resulting significant effects did not differ between these two modeling approaches.

Table 2

Descriptive statistics. The statistics are calculated across all the glances (or occlusions) in a particular trial.

Trial	Number of glances (or occlusions)	Mean duration	Median duration	Standard deviation	Lane deviation percentage
X1	1658	1.80	1.57	1.15	9.47
X2	1523	1.95	1.74	1.21	9.00
Occlusion	1596	2.12	2.03	1.08	19.55
Visual search task, 10 items	1744	1.49	1.33	0.97	12.79
Visual search task, 15 items	1981	1.56	1.40	0.99	15.04
Visual search task, 20 items	2111	1.66	1.53	0.98	16.06

4. Results

4.1. Descriptive statistics and distributions

Table 2 presents the relevant descriptive statistics of each trial in the experiment. Lane deviation percentages were calculated using the lateral offset data provided by the driving simulator. We calculated the instances when the drivers were "in lane" and "off lane" during an in-car glance or occlusion. If the offset to the lane center was < -1.1 m or $>$ 1.1 m at least once per instance, a lane deviation occurred ("off lane"). Then we divided the "off lane" instances by the total number of the instances (i.e., glances or occlusions).

Table 3 presents the relevant descriptive statistics of the number of glances participants made during the visual search task trials per page. This data is informative for indicating differences in the structures of the different self-paced tasks based on the number of items. Due to technical problems with two participants, visual search task 10 and visual search task 20 are missing data from one participant.

Due to the non-Gaussian distributions, we performed Friedman's test to investigate if there were differences between the trials on the number of glances per page. According to the test, the glance number was statistically significantly different at different visual search tasks, $\chi^2(2) = 24.14, p < .001$. Pairwise comparisons were performed with a Bonferroni correction for multiple comparisons. Glance numbers per page in visual search tasks were statistically significantly different between the visual search task with 10 items and the visual search task with 20 items ($p < .001$), as well as the visual search task with 15 items and the visual search task with 20 items ($p = .002$).

Figs. 4 and 5 present the distributions of the glance durations and occlusion times (s) in the trials.

4.2. Multilevel models

4.2.1. Model 1: The X trials

In Model 1 (the X trials, see Table 4), there were 3181 glances, and the dependent variable was in-car glance duration. We started the construction of the model by exploring the intraclass correlation (ICC), which was 27.72 % for the intercept only model. This justifies the use of a multilevel model since the value of ICC is different from zero (Peugh, 2010). Next, we added fixed factors one by one and inspected the -2 Log-Likelihood Ratio for the fit of the model, and tested with a chi-squared test (χ^2) to assess whether the added fixed factor improved the fit of the model significantly ($p < .005$). If the model fit did not significantly improve, the fixed factor was removed from the model. For Model 1, we entered as fixed factors the trial (X1 and X2), mean occlusion time per participant, and steering amplitude during the glance, all of them increasing the fit of the model significantly, and as a random factor, we had intercepts for participants (i.e., drivers). Mean occlusion

Table 3

Glances per page in visual search task trials. Means are calculated first per participant and then averaged across the sample.

Trial	Mean	Median	Standard deviation	Range	Items encoded per glance (average)
Visual search task, 10 items, $N = 29$	4.01	4.13	0.89	2.73–5.73	2.49
Visual search task, 15 items, $N = 30$	4.56	4.37	1.40	1.80–8.40	3.29
Visual search task, 20 items, $N = 29$	6.13	5.73	2.38	3.27–16.00	3.26

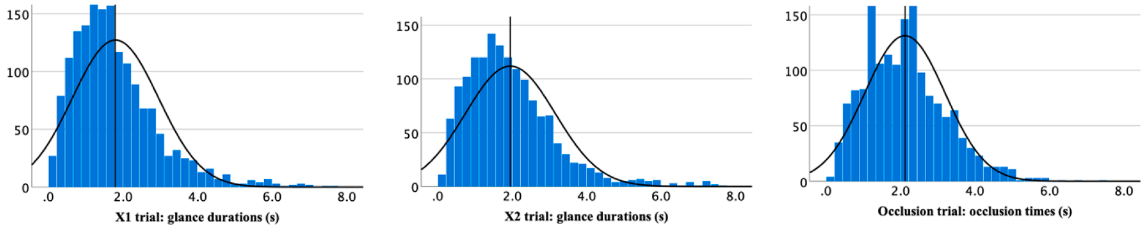

Fig. 4. Glance duration distributions in the X1 and X2 trials, and the occlusion time distribution (s), reference line at mean.

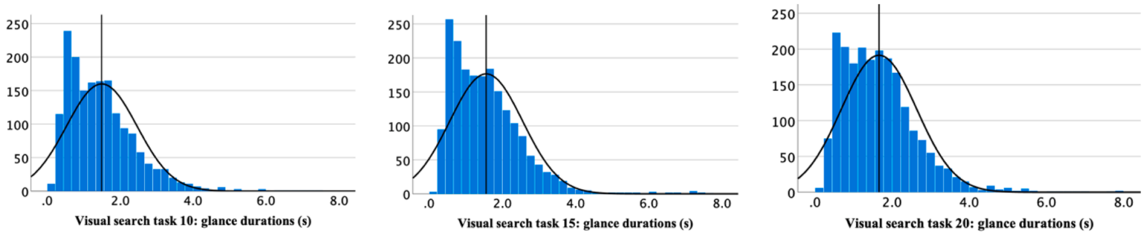

Fig. 5. Glance duration distributions in the visual search task trials with 10, 15, and 20 items (s), reference line at mean.

Table 4
Model 1, the X trials. Dependent variable (DV): in-car glance duration.

Fixed effects	Estimate	Standard error	p	95 % confidence interval lower bound	95 % confidence interval upper bound
Intercept	0.70	0.44	0.125	−0.21	1.61
Drive X1	−0.19	0.04	<0.001	−0.26	−0.12
Drive X2*	0	0			
Mean occlusion time	0.51	0.21	0.019	0.09	0.94
Steering amplitude	0.14	0.01	<0.001	0.12	0.15
Random effects	σ^2				
Intercept (participant)	0.26	0.07	<0.001	0.13	0.40
Residual	1.00	0.03	<0.001	0.95	1.05
Intraclass correlation (ICC)					
Participant	0.18				
Model fit (-2RLL)	9143.90				

*The factor above is compared to the factor that gets the value of zero (i.e., intercept).

time refers to a participant's mean occlusion time (time driven without visual information) in the occlusion trial and is interpreted as an estimate of one's individual occlusion time preference or tendency (cf. Grahn, 2021; Grahn and Taipalus, 2021; Kujala et al., 2016a; Kujala and Grahn, 2017). Finally, we visually inspected the residual plots, and they indicated a normal distribution of residuals but with some deviations from normality for the longer glances in the Q-Q plot. This should be considered when interpreting the results of the model.

The model's total explanatory power is notable (conditional $R^2 = 0.30$ and marginal $R^2 = 0.14$). The intercept for the in-car glance in the latter X2 trial (grand mean) is 0.70 s. When the trial is X1 (the first X trial), the in-car glance duration decreases by 0.19 s. The model also indicates that when the mean occlusion time increases by one second, the glance duration increases by 0.51 s and when the steering wheel amplitude during a glance increases by one degree, the glance duration increases by 0.14 s. The ICC for Model 1 with the predictors decreases to 18.40 %.

We also constructed a random slope model for Model 1, which allows individual differences in slopes between the drives. Results from the slope model are similar to the intercept model, which only allows individual differences in intercepts. As we only modified the random effect (participant), marginal R^2 is the same (0.14), but conditional R^2 is slightly increased to 0.32 from 0.30. Overall patterns of each main effect are consistent compared to the intercept model: Drivers' in-car glance duration is significantly increased in X2 compared to X1, $t(3173) = 2.84$, $p < .001$. Also, the steering amplitude is positively associated with in-car glance duration, $t(3173) = 17.95$, $p < .001$ and the effect of mean occlusion time is positively associated with in-car glance duration, $t(3173) = 2.41$, $p < .05$.

4.2.2. *Model 2: The visual search task trials*

In Model 2 (Table 5), the data consisted of 5836 in-car glances, and the dependent variable was again glance duration. The construction procedure of the model was identical to Model 1 but with the addition of another predictor candidate for visual search tasks, the visual search speed of a participant. Visual search speed refers to a mean sum variable (Cronbach's $\alpha = 0.720$) constructed of total times it took the participant to conduct the three visual search tasks when not driving. The intraclass correlation (ICC) was 17.91 % for the intercept only model. The inspection of the model revealed that mean occlusion time was not a significant predictor in this model. It also revealed that visual search speed was a significant predictor affecting glance duration. The longer duration in finishing the visual search tasks in the stationary condition predicts a longer glance duration in visual search tasks completed in the driving condition. However, visual search speed did not significantly improve the model fit and was therefore removed from the model. Finally, in Model 2, we entered as fixed factors trial (visual search task with 10, 15, or 20 items) and steering amplitude, both increasing the fit of the model significantly. As a random factor, we had intercepts for participants (i.e., drivers). Finally, we visually inspected the residual plots indicated a normal distribution of residuals but with some deviations from normality for long glances in the Q-Q plot.

Table 5
Model 2, the visual search task trials. DV: in-car glance duration.

Fixed effects	Estimate	Standard error	*p*	95 % confidence interval lower bound	95 % confidence interval upper bound
Intercept	1.42	0.09	<0.001	1.25	1.59
Visual search task 10 items	−0.11	0.03	<0.001	−0.17	−0.06
Visual search task 15 items	−0.03	0.03	0.341	−0.08	0.03
Visual search task 20 items*	0	0			
Steering amplitude	0.08	0.00	<0.001	0.07	0.08
Random effects	σ^2				
Intercept (participant)	0.20	0.05	<0.001	0.11	0.34
Residual	0.77	0.01	<0.001	0.75	0.80
Intraclass correlation (ICC)					
Participant	0.20				
Model fit (-2RLL)	15199.78				

*The factor above is compared to the factor that gets the value of zero (i.e., intercept).

The model's conditional $R^2 = 0.26$ and marginal $R^2 = 0.07$. The grand mean duration of the in-car glance in the visual search task with 20 items is 1.42 s. When the trial is the visual search task with 15 items, it decreases the glance duration by 0.03 s but the difference to the grand mean is not significant. When the trial is the visual search task with 10 items, it decreases the glance duration by 0.11 s, and this difference is significant. When the steering wheel amplitude during a glance increases by one degree, the glance duration increases by 0.07 s. The ICC for Model 2 with predictors increases to 20.10 %, which is understandable as there were no such fixed factors in the final model which would have explained the individual variability in glance durations.

Again, we constructed a random slope model for Model 2. Compared to the intercept model, the random slope model slightly increases conditional R^2 to 0.27 and the patterns of the main effect are consistent. Drivers' in-car glance duration is significantly increased in the visual search task with 15 items compared to 10 items, $t(5830) = 2.14$, $p < .05$. Also, drivers' in-car glance duration is significantly increased in the visual search task with 20 items compared to 10 items, $t(5830) = 2.57$, $p < .05$. Additionally, the steering amplitude is positively associated with in-car glance duration, $t(5830) = 19.15$, $p < .001$.

4.2.3. *Model 3: The occlusion trial*

Model 3 (Table 6) consisted of 1596 occlusions, and the dependent variable was occlusion time. The construction procedure of the model was identical to Model 1 with the exception that mean occlusion time was removed and time-to-line-crossing (TLC) was added as a new relevant predictor candidate. TLC (Godthelp et al., 1984) refers to how long it would take for the participant without steering to cross the lane marking from the point of measurement (here: start of occlusion) and provides here an estimate of the driver's last representation of the car's trajectory before the occlusion (and of driver's "spare visual capacity" at that point). Further, we inspected the correlation between TLC and steering amplitude in the occlusion trials and we found an association ($r = -0.352$, $p < .001$). This suggests that there is a moderate negative correlation but no collinearity problem. The negative correlation implies that the lower the TLC was in the beginning of an occlusion, the more the participant steered during the occlusion. The interclass correlation (ICC) for the intercept only model was 15.89 %. In Model 3, we entered as fixed factors TLC at the beginning of occlusion and steering amplitude, both increasing the fit of the model significantly. As a random factor, we had intercepts for participants (i.e., drivers). Again, some deviations of the residuals from normality in the longer end of glances in the Q-Q plot should be considered when interpreting the results of the model.

The model's total conditional $R^2 = 0.24$ and marginal $R^2 = 0.10$. The grand mean duration in Model 3 for occlusion time is 2.00 s. One second increase in time-to-line-crossing from the beginning of the occlusion increases the occlusion time by 0.05 s. In this model, the effect of steering is opposite than in the previous models: when the steering wheel amplitude during the occlusion increases by one degree, the occlusion duration decreases by 0.04 s. The ICC for Model 3 with predictors is 15.90 %.

Compared to the intercept model, the random slope model increases conditional R^2 to 0.29 from 0.24 and the patterns of the main effect are consistent: time-to-line-crossing is positively associated with drivers' in-car glance duration, $t(1589) = 5.95$, $p < .001$; and steering amplitude is negatively associated with the in-car glance duration, $t(1589) = -4.68$, $p < .001$.

4.2.4. *Model 4: Lane deviations*

Model 4 (Table 7) is a multilevel binary logistic regression model, a type of multilevel model where the predicted variable is binomial, where 0 means that the simulated vehicle is in the lane (no lane crossing) and 1 means that the vehicle is off lane (lane crossing). Here, we model the relationship between the predictors and the probability that the predicted variable (i.e., lane crossing) is 1. In this data set, occlusions and glances were combined for investigating the lane crossing probabilities during the X trials, the visual search task trials, and the occlusion trial. Hence, Model 4 consists of 10,613 combined occlusions and

Table 6
Model 3, the occlusion trial. DV: occlusion time.

Fixed effects	Estimate	Standard error	*p*	95 % confidence interval lower bound	95 % confidence interval upper bound
Intercept	2.00	0.09	<0.001	1.81	2.19
Time-to-line-crossing (TLC) at the beginning of occlusion	0.05	0.01	<0.001	0.04	0.05
Steering amplitude	−0.04	0.01	<0.001	−0.06	−0.03
Random effects	σ^2				
Intercept (participant)	0.17	0.05	<0.001	0.10	0.30
Residual	0.90	0.03	<0.001	0.83	0.96
Intraclass correlation (ICC)					
Participant	0.16				
Model fit (-2RLL)	4439.98				

Table 7
Model 4, odds for lane deviations. DV: lane deviation (0/1).

Fixed effects	Coefficient	Standard error	p	Expected coefficient	95 % confidence interval lower bound	95 % confidence interval upper bound
Intercept	−2.15	0.23	<0.001	0.12	0.08	0.18
X1	−0.86	0.11	<0.001	0.42	0.34	0.53
X2	−0.97	0.12	<0.001	0.38	0.30	0.48
Visual search task 10 items	−0.47	0.11	<0.001	0.63	0.51	0.77
Visual search task 15 items	−0.22	0.10	0.026	0.81	0.67	0.97
Visual search task 20 items	−0.15	0.10	0.122	0.86	0.72	1.04
Occlusion trial*	0					
Occlusion time or glance duration	0.23	0.03	<0.001	1.26	1.20	1.33
Random effects	σ^2					
Intercept (participant)	1.28	0.37	<0.001			
Intraclass correlation (ICC)						
Participant	0.28					

*The factor above is compared to the factor that gets the value of zero (i.e., intercept).

glances. The intraclass correlation (ICC) in the intercept only model was 29.69 %. According to the intercept only model, the general expectation odds across the total data for lane crossing are 0.12, and the expected probability of lane crossing is 11.03 % (Crowson, 2020).

As fixed factors, we added trial and occlusion or glance duration, and as a random factor we had intercepts for participants (i.e., drivers). The occlusion or glance duration was added as a fixed factor because it can be expected that a lane deviation probability increases with an increasing glance or occlusion duration, and we wanted to study the possible additive effects of the trial on lane deviations. In Model 4, both tested fixed factors were significant: trial and occlusion or glance duration.

In the final model, the estimated odds for lane crossing are 0.12, and the expected probability of lane crossing is 10.47 % (Crowson, 2020). All regression slopes for trials are negative – decreasing estimates on trials indicate that the probability of lane crossing is decreasing. Hence, after the occlusion trial (set to zero), in the visual search task with 20 items, the probability of lane crossing is the highest (−0.15, no significant difference to the occlusion trial), and in the X2 trial the probability of lane crossing is the smallest (−0.97). Occlusion time or glance duration has a positive regression slope – this means that when occlusion time or glance duration increases by a second, the probability of lane crossing also increases (estimate: 0.23). The odds ratio (expected coefficients in Table 7) is the multiplicative change in odds per unit increase on the predicted lane crossing while holding the remaining predictors constant (Crowson, 2020). Hence, for every unit increase in coefficients, the odds for lane crossing change by a factor of expected coefficients. For instance, in the X2 trial, the odds for lane crossing change by 0.38. Since it is smaller than 1, the odds for lane crossing are decreasing compared to the occlusion trial. The ICC for Model 4 with predictors decreases slightly to 28.01 % from the model without the predictors.

5. Discussion

In this paper, we conducted a driving simulator experiment ($N = 30$) and investigated if there is an association between drivers' occlusion times and in-car glance durations in a given driving scenario. Furthermore, we wanted to explore which factors and variables could explain the strength of the association. The findings suggest that there is an association between occlusion time preferences and in-car glance durations in visually and cognitively low demanding tasks but that this association is lost if the in-car task is a visual search task (H1 supported). The findings might be explained by the driver's inability to utilize peripheral vision for lane-keeping when conducting in-car tasks and/or by in-car task structures that override the driver's preferences for the in-car glance durations (H2-H4 supported).

5.1. *Occlusion times and in-car glance durations*

In the X trials (Model 1), driver's mean occlusion time (i.e., driver's individual preference in the occlusion trial) was a significant predictor of the glance duration. Both occlusion and the X trials were instructed in a similar way: try to drive occluded as long as possible or try to glance at the X as long as possible. Hence, in both tasks, drivers were able to adjust the durations of glances or occlusions according to their preferences, even if the participants may have been more cautious in the X trials. The significant association between occlusion time preference and in-car glance duration in the X trials is a similar finding as in Kujala et al.'s (2016a) study, and this may imply that drivers had similar visual sampling strategies in the visually and cognitively low demanding X trials as in the occlusion trial. The glance numbers and occlusion numbers (Table 2), as well as the similar distributions (Figs. 4 and 5) in the X trials and the occlusion trial support this interpretation. As a partial answer to Research Question 1, Model 1 showed a significant association between one's occlusion time preference and in-car glance duration when the in-car task was visually and cognitively low-demanding (H1 supported).

However, when investigating the association between the mean occlusion time and in-car glance duration in the visual search task trials, occlusion time was not a significant predictor (Model 2, further support for H1). This could imply that the drivers were not able to use similar visual sampling strategies as in the X trials, perhaps due to the structure of the in-car tasks and/or higher visual and cognitive load by the visual search tasks. The mean in-car glance durations were shorter in the visual search task trials than in the occlusion or X trials (Table 2), which is understandable as there was no instruction to maximize the glance durations in the visual search tasks. The participants received instructions to find the desired letter combination as fast as possible, so there was time pressure in these tasks, too. In this case, the best search strategy would have been to search as many of the 3-letter combinations as possible during each in-car glance. However, the participants seemed not to use this strategy, even if adding more search items per screen increased the number of search items encoded per glance. Yet, the probabilities of lane deviations were at a similar level between the 20-item visual search task trial and the occlusion trial, and much lower for the X trials than for any of the visual search task trials, when controlling for glance/occlusion durations (H2 supported). Altogether, these findings suggest that the in-car visual search tasks at least occasionally overrode the participants' visual sampling preferences and impacted lane-keeping performance, and that these negative impacts were moderated by the number of search items on the in-car display (H3 supported).

In comparison, the occlusion times (mean 2.12 s) were similar to Tsimhoni and Green's (2001) study, where the mean occlusion time on a straight road (i.e., simple driving scenario) was approximately 2.1 s. In more complex driving scenarios including suburban roads and intersections, the mean occlusion times have been much shorter (from 0.67 to 0.95 s, Kujala et al., 2016b). This kind of adjustment of occlusion times based on the driving task demands is well in line with Wierwille's (1993) visual sampling model based on real-world in-car glance data on different in-car tasks in various driving environments. The unnaturally simple driving task and the instruction to push to the limits that were used in the current study, as well as in Tsimhoni and Green's (2009) study may explain why the mean occlusion times were significantly longer than the upper limit of Wierwille's model (1.6 s). The mean in-car glance durations in the visual search task trials were well in line with the Wierwille's 1.6 s prediction, yet, there was a large portion of glances significantly longer than this (see Fig. 5).

5.2. Peripheral vision and lane-keeping performance

In Model 3, we set out to investigate how time-to-line-crossing (TLC) at the beginning of an occlusion and steering amplitude during an occlusion affect the occlusion time. When the TLC increased, the occlusion time increased. This seems natural: drivers probably estimated that they had more time to drive occluded when the TLC at the start was longer. A strong association has been found between TLC and occlusion time also in earlier research (e.g., Godthelp et al., 1984). However, the effect of steering was contrary to the other trials: when the steering wheel amplitude increased, the occlusion duration decreased. This could imply that because there was no feedback (visual or from the motion platform) available on the steering actions, the larger the steering wheel movements the participant made, the faster the participant's uncertainty about the lane position grew during the occlusion. For the occluded driving, keeping the steering wheel still and straight and unoccluding oneself on the TLC from the start of occlusion might have been a better strategy than making noisy steering movements.

Steering amplitude predicted the in-car glance durations in the X trials (Model 1): the in-car glance duration increased per each steering wheel angle (H4 supported). This suggests that the participants felt they could stare at the X longer the more they steered. Lane crossing percentages and odds were the lowest in the X trials compared to the other trials, which supports the interpretation that the drivers were able to use their peripheral vision successfully during this visually and cognitively low-demanding secondary task. Similarly to Summala et al.'s. (1996) study, it seems that the drivers were able to use their peripheral vision during the X trials and, hence, steer to maintain their lane position.

Also, in the visual search task trials (Model 2), larger steering movements during an in-car glance increased the glance duration, which suggests that maybe the drivers felt they could look longer at the in-car display the more they steered (H4 supported). However, based on the lane deviation percentages and odds, it seems that their lane-keeping performance with peripheral vision was much worse during the visual search tasks as compared to the X trials. Visual and cognitive load can affect peripheral vision by making the functional field of view smaller (Williams, 1982), which could explain this observation together with noise in motor control.

Model 4 was constructed to predict lane deviations (i.e., lane crossings) during the trials. The odds for lane deviations were the highest in the occlusion trial and the visual search task with 20 items (no significant difference between those two trials). This finding is similar to Tsimhoni and Green's (2001) study, where driving performance (SD of lateral position) was similar under occlusion and when conducting map reading tasks (i.e., visual search tasks). The odds for lane deviations decreased significantly when the trial was the visual search task with 15 or 10 items and yet more when the trial was X1or X2 – these two having the lowest odds for lane deviations even if their mean in-car glances were longer than in the visual search task trials. This result implies that the in-car task demands could hamper the use of peripheral vision for lane-keeping since the trial with 20 items did not differ from the occlusion trial – and the X2 trial had the lowest odds for lane deviations. The X2 trial had lower odds than X1, presumably due to a higher level of driving experience in the simulator at the end of the experiment. The high number of lane deviations in the occlusion trial is understandable, as the participants were instructed to push their occlusions to their limits without any real-time feedback on the lane position. In general, these findings are in line with Summala et al's. (1996) study that drivers are able to maintain their lane position during in-car tasks, and Vater et al.'s (2022) study that peripheral vision helps to compare own vehicle's position to other objects. They are also in line with Kountouriotis and Merat's (2016) study that conducting a visually distracting task causes a higher standard deviation of lateral position. Another explanation could be that visual distraction hampers processing and reacting to the information that peripheral vision provides, as Gaspar et al. (2016) suggest.

Overall, based on our results, drivers can utilize peripheral vision for lane-keeping if foveal vision is not needed for the secondary in-car task or if they are not experiencing a high cognitive workload. Visual search tasks seem to impair peripheral vision, and the impairment seems to increase together with the complexity or structure of the task.

5.3. Inter-individual preferences for occlusion times and in-car glance durations

Even though lane-keeping was more accurate and the odds for lane deviations were much lower in the X trials than in the occlusion trial (see Table 2 and Section 5.2), the occlusion times and glance durations were quite similar in all those three tasks. Why did drivers not glance longer at the X if they were seemingly able to maintain their lane position despite the additional staring task? This could again imply that drivers have preferred visual sampling strategies when they can freely and self-paced adjust their sampling – albeit that they were able to utilize peripheral vision in the X trials and not able to utilize it during the occlusion trial.

These sampling strategies endorse the idea that the occlusion method (or a similar visually and cognitively low-demanding task as our X trial), may be a valid method to add to the procedure for estimating and controlling individual differences in spare visual capacities when investigating the visual distraction potential of, for instance, in-vehicle infotainment systems. This is important since previous research has revealed that uncontrolled inter-individual differences in visual sampling can affect the results of distraction potential testing (e.g., Broström et al., 2016; Grahn and Taipalus, 2021; Lee and Lee, 2017; Ljung Aust et al., 2015).

5.4. Task complexity, task structures, and per page glancing strategies

In the visual search tasks (Model 2), when the number of items in the task decreased, the glance duration decreased as well. The number of search items also increased the number of glances per trial and the number of glances per page from 10 to 15 or 20 item-trials. One could argue that this means that the complexity of the in-car task increases glance numbers and duration, which would be a similar finding as in, for instance, studies by Large et al. (2015), Smith et al. (2016), and Victor et al. (2005). However, what does the increase in complexity by increasing the number of items refer to exactly in these kinds of search tasks?

Apart from the "next" presses, the visual search tasks did not have clear subtask boundaries by user interface design that would have reduced driver's mental workload (Bailey and Iqbal, 2008) or supported task resumption after interruptions by the driving task (Altmann and Trafton, 2002). When the number of search items increased from 10 to 15 or 20, the number of items encoded per glance also increased (see Table 3). If the drivers had used a similar searching strategy during the 15- and 20-item tasks as in the 10-item task, the mean number of glances per page should have increased. This self-selected strategy by encoding more items per glance on the 15- and 20-item pages (3.3 vs 2.5) could be due to bounded-rational optimization of sampling behavior (Jokinen et al., 2021) for limiting working memory load and/or to support inhibition of return (Klein, 2000) during the interruptions by driving. This is understandable from the perspective of minimizing cognitive load but can have negative consequences for driving performance. These kinds of task-specific glancing strategies may also be a reason for hiding the individual in-car glance duration preferences.

Thereby, another – or complementary – candidate for explaining the increased odds of lane deviations, besides the decreased ability to utilize peripheral vision for lane-keeping in the visual search task trials, could be the tails of the glance duration distributions. Thicker tails can be indicative of such instances where the in-car glance has been prolonged beyond the driver's preferences due to prolonged encoding of items, which is again a result of the task structure (i.e., user interface design). This is supported by the finding that the odds for lane deviations were significantly higher for the 15- and 20-item trials than for the 10-item trial but not between the 15- and 20-item trials, which had similar items-*per*-glance strategies and thicker tails of the glance duration distributions.

5.5. Limitations and future work

There are some limitations that should be considered. The visual search task used in this study was artificial, as it did not resemble any actual secondary in-car task as such. However, the task resembled a visual search task, a common part of a task among secondary tasks conducted while driving, such as searching for an address or a song. Additionally, for examining the drivers' visual behavior purely, the driving task was relatively straightforward (road with low curvature, fixed speed, no motion or audio cues, and no other traffic) which may hinder the generality of the findings. In future work, the observed association between occlusion times and in-car glance durations should also be examined in more complex driving scenarios to see if the findings are generalizable to such conditions. In our simple driving task, the only relevant source of information was the lateral position of the vehicle. In more realistic driving, there are other critical sources of off-forward information, such as speedometer, mirrors and crossing objects. Therefore, there is a critical difference between driving-relevant and irrelevant off-forward glances in more realistic scenarios, in that the driving-relevant off-forward glances can be indicative of the visual demands of driving and not of visual spare capacity (Kircher et al., 2020). Further, the absence of motion and auditory cues may have increased the visual demands of the lane-keeping task in the current study.

In addition, we suggest that occlusion times should always be used together with relevant driving performance metrics to validate that the driving during occlusions was safe (or attentive) as the occlusion times are always a subjective estimate of the spare visual capacity. This is crucial especially if one would like to utilize visual occlusion as a tool to estimate spare attentional capacity in more realistic driving, for the development of driver attention monitoring systems or similar. Here, we evidenced almost 20 % probability of a lane deviation per occlusion suggesting the participants aimed at maximizing their occlusion times as instructed. Further, we used occlusion as the default condition. This is in contrast to in-car glancing, where the driver is able to choose when to look off forward (Seppelt et al., 2017). On-road glance durations might have an effect on in-car glance durations, and in future studies, these effects should be taken into account. However, for mapping situational occlusion times or distances to specific driving environments or scenarios (e.g., Kujala and Mäkelä, 2015) occlusion as the default is the best option to enable sufficient spatial and temporal resolution of the visual demand estimates. Further, in our experiment the participant could keep the driving scene unoccluded by pulling the lever repeatedly.

Another limitation of the study is the reliability of the number of glances per page. The driven route was limited to approximately-three minutes. This was approximated to be a sufficient length in pilot studies. However, since some of the participants were slower to conduct the visual search tasks, the route ended before they were able to finish the task. When this happened, they were asked to pull over and finish the task. We identified these incidents afterward from the videos provided by the eye-tracking camera and calculated the mean glances per page based on how many pages participants were able to finish before pulling over. Further, there were two pages with targets in these numbers. There could be variability in how many glances the participants needed to find the targets on these pages. However, the means were averaged over 15 pages per participant and should provide reasonable estimates. Another possible limitation of the study are the residuals of the multilevel models. The Q-Q plots indicated deviations from normality in the longer ends of glances. This should be considered when interpreting the models.

Here, we had two types of in-car tasks: the X task and the visual search tasks. As a future work, other kinds of in-car tasks should also be studied to see which kind of in-car task features affect the association between occlusion times and in-car glance durations, perhaps by gradually adding the visual demand or complexity of the in-car task.

In the visual search task trials (Model 2), driver's visual search speed was a significant predictor of the in-car glance duration but was removed from the model since it did not improve the fit of the model significantly. However, it implied that a longer duration in finishing the visual search tasks in the stationary condition might increase the glance duration in visual search tasks completed while driving. As a future work, this phenomenon would be beneficial to investigate more profoundly if driver's visual search speed could affect the durations of in-car glances.

6. Conclusions

In this paper, we were able to find an association between occlusion time and in-car glance duration during driving in the same scenario when the in-car task was unstructured and visually and cognitively low-demanding (the X tasks). However, the association was lost when the in-car task was a visual search task. Hence, we suggest that drivers have similar individual visual sampling preferences or tendencies during driving under occlusion and when accomplishing visually and cognitively low-demanding unstructured secondary tasks – but that this preference is disturbed if the performed task is more demanding.

Possible explanatory mechanisms behind the findings include drivers' (in)ability to utilize peripheral vision for lane-keeping and the structure of the in-car task. According to our experiment, drivers can utilize peripheral vision for lane-keeping if their foveal vision is not needed for the secondary in-car task or if they are not experiencing cognitive workload due to an in-car task. The ability to use peripheral vision may improve lane-keeping performance with in-car glances over occlusions of the same length in a similar situation. However, higher visual and cognitive loads by in-car tasks seem to impair both the individual visual sampling preferences and the use of peripheral vision for lane-keeping while multitasking behind the wheel. During the secondary visual search tasks participants made shorter glances in-car but still more lane deviations. Furthermore, user interface design (here: number of search items per page) may encourage visual sampling strategies that overrun individual preferences for in-car glance durations and may also have negative safety consequences by increasing the frequency of very long glances. Interestingly, it seemed that the participants might have had inaccurate beliefs about the accuracy of their steering during the visual search tasks as compared to the visually and cognitively low-demanding secondary tasks.

It seems that the occlusion technique could be used to estimate drivers' spare visual capacity in research – but with caution. As the occlusion times are always subjective estimates of this capacity, it is strongly recommended to use these in combination with driving performance metrics. It seems that there is less spare visual capacity if this is used for secondary tasks that interfere with the driver's ability to utilize peripheral vision for driving and preferences for the in-car glance durations. However, we suggest that the occlusion method (or similar visually and cognitively low-demanding task as in our X trials), can be a valid method to control for relative inter-individual differences in in-car glance duration preferences when investigating the visual distraction potential of, for instance, in-vehicle infotainment systems.

CRediT authorship contribution statement

Hilkka Grahn: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – original draft. **Tuomo Kujala:** Conceptualization, Methodology, Writing – review & editing, Project administration. **Toni Taipalus:** Software, Writing – review & editing. **Joonbum Lee:** Formal analysis, Writing – review & editing. **John D. Lee:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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