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Posted Date: 22 May 2023

doi: 10.20944/preprints202305.1456.v1

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Article

Distraction and Visual Search Characteristics of Young Drivers When Using Navigation System Displays

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Abstract: Navigation systems are considered as a fast and efficient source of road information to drivers. However, they can distract drivers with more potential accidents on the road. This study examined the effect of navigation systems on driver distraction and visual search while driving in different driving conditions. An eye-tracking system was used to collect visual search data from twenty young drivers while using a driving simulator. Several factors were investigated, including the driving environment (urban and rural), the illumination level (day and night), and the display of the navigation system (large and small) as well as their interactions. Several measures related to eye movements were used in this experiment, including percentage of total Global Positioning System (GPS) fixation duration, average duration of GPS fixation, GPS fixation frequency, the percentage of total dwell duration for the road ahead, the frequency of dwelling on the mirrors and driver's right and left side windows, and the percentage of dwellings on the mirrors and driver's right and left side windows. Statistical analysis of the collected data was performed with repeated measures analysis of variance (ANOVA). The experiment revealed that the small GPS display creates more distraction in terms of average gaze duration and total gaze duration. Moreover, daytime driving conditions increase distraction. Regarding the driver's visual search, the study showed that the visual search area is wider and more spread out during the day, which leads to better driving performance. This study will compare small and large navigation displays to determine which one is more effective in reducing driver distractions, and contribute to understanding driver distraction and visual search while using the navigation system display.

Keywords: navigation system display; distracted driving; visual search behavior; fixation; dwell; eye-tracking; young drivers; night driving; driving safety

1. Introduction

Conventional navigation systems and smartphone navigation have been shown to be better than paper maps due to the shorter reaction time and lower mental workload required [1]. Smartphone navigation has begun to replace conventional navigation systems [2, 3]. Some of the factors that make smartphone navigation preferred by users over other methods include efficiency, less distraction, lower workload, better performance, portability and affordability [4]. In the market, the most common small display smartphones are 4-in diagonal; whereas standard navigation systems, in-vehicle information systems (IVIS), large display smartphones and tablets are usually between 6-in and 10-in diagonal. Making a smartphone display size larger affects portability; for this reason, it is unlikely to see smartphones produced in larger sizes that exceed approximately 6-in [5].

The limited visual display size of smartphones causes a problem when used for navigation while driving due to increased distraction and workload [6]. This problem is more common with smartphones with smaller displays because they take longer time to read (longer glances, which means more time away from viewing the road) and are harder to read and comprehend, which leads to a higher mental workload [6]. A subjective evaluation using NASA-TLX (The NASA Task Load

Index) showed that large navigation displays are better than small navigation displays in terms of driver workload [7]. Moreover, this problem negatively affects the driver's visual search [6], driving performance, and safety [8], and increases the likelihood of road accidents.

1.1. Young Drivers

Drivers between the age of 18 and 29 years have the highest number of crashes and driver fatalities, where this age group recorded 1,831 driver fatalities and 310,691 crashes in 2021 in Texas, representing 28.4% and 30.9% of all driver fatalities and all crashes, respectively [9]. Several studies have been conducted on driving performance and safety for this age group. It has been observed that young, inexperienced drivers perceive potential hazards and the traffic environment differently from experienced drivers [10, 11]. Moreover, novice drivers perceive hazards more slowly and less efficiently [11], and they overestimate their driving skills and underestimate the risk of accidents [11, 12]. Furthermore, young drivers are more willing to take risks than experienced drivers [11]. In [13] they found that experienced drivers have better performance than inexperienced drivers when using different types of head-up displays. Other factors such as consumption of alcoholic beverages, being distracted more easily than other age groups, driving without a seat belt, tiredness and preference for certain vehicle models may also affect the performance of young drivers negatively [12].

1.2. Night Driving

Driving at night is one of the conditions that may have a negative impact on the driver's visual search, and may lead to an increased risk of accidents. In most cases, there is less traffic at night, however, driving at night is riskier and has more fatal crashes than daytime [9]. This can be explained by several factors, including driver drowsiness, driving in a dark environment [14], and consumption of alcoholic beverages [15]. In addition, several studies have shown that driving in a dark environment is associated with poor visibility, degraded visual search [16], a higher driver reaction time, and a higher severity of accidents [17].

1.3. Visual Fixation and Saccades

The human eye has three movement states including visual fixation, saccade, and smooth pursuit. In most cases, the eyes alternate between visual fixations and saccades. According to [18], visual fixation can be defined as "the maintaining of the visual gaze on a single location." Fixation can also refer to the visual input that occurs at a particular gaze point between any two saccades [19]. Saccades are the "rapid refixation movements of the eyes from one point of fixation to another in a series of jerky steps"; all these rapid eye movements should occur in the same visual field [20]. Another term associated with eye movement is dwell, which is defined as the total duration that a subject fixates or glances within a specific area of interest (AOI) [21]. Visual fixations and saccades data can be collected using an eye-tracking system.

1.4. Literature Review

Visual fixations and saccades have been used in several studies to assess driver distraction. In [6] glance frequency, glance time and total glance time as a percentage of total driving time to find the safest position and display size for navigation systems inside vehicles. The study found that positioning a navigation system with a small visual angle can shorten glance time but increase glance frequency. In addition, small navigation systems increased glance time. In [22] they found that larger text on visual displays encourages more frequent and relatively short glances when driving, while smaller text leads to less frequent and longer glances. In [23] they used the number of GPS glances and glance duration of young drivers to investigate the difference between 2D and 3D e-map formats when combined or not with sub-windows in terms of driver performance and glance behavior. The study revealed that the 3D e-map has a significantly higher glance frequency than the 2D e-map, which imposes a greater workload on the driver. In [24] they used the percentage of dwell time of driver on the road ahead to assess a young driver's performance and visual attention to differentiate between a paper map, a standard navigation system with visual and audio directions, and a standard navigation system with only audio directions. The study found that the use of paper maps significantly increased visual distraction compared to the standard navigation system, whether that navigation system includes visual and audio directions or only audio directions. In addition, the use of only spoken directions mode on the standard navigation system significantly reduced driver visual distraction. Furthermore, in [25] they investigated two In-Vehicle Information Systems interface layouts (checkerboard and hierarchical) on driving safety and usability. The checkerboard required more time to flip the pages, however, the information presentation was clear and simple, revealing that driving was easier and with fewer errors. On the other hand, the hierarchical was not efficient timewise and increased driver errors due to increased physical and mental demands.

Another study in [26] compared the dwell time of young driver on the road ahead of a standard graphical display navigator with a graphical display and spoken directions with the navigator with spoken directions only. The study revealed that using the navigator with only spoken directions increases the time spent looking at the road ahead compared to a standard navigator with both visual and audio mode. Moreover, in [27] they studied young driver visual attention through percentage of dwell time on four locations while driving using augmented reality GPS and a conventional 2D head-down GPS display. The four locations included the surrounding environment, the augmented reality GPS display, the conventional GPS display, and others. The study showed that the augmented reality GPS improves the visual attention of young drivers compared to conventional navigation devices. Furthermore, in [28] they compared the distraction of young and old drivers through the total distance a driver's eyes travel, mean eye movement speed, the number of times they look away from the road, and the time spent looking away from the road. They used these metrics to evaluate the difference between an augmented reality navigation system and a 2D conventional navigation system. The study revealed that the augmented reality navigation system is significantly better than the conventional navigation system in terms of visual attention. Moreover, in [29] they compared young and old drivers' eye movements distribution for three different GPS display positions and driving without a GPS to assess the driver's visual search and safety for these display positions. The study revealed that the range of eye movements of older drivers is limited to the car's navigation system and the center of the field of view, unlike younger drivers who have a wider range of eye movements.

Furthermore, in [30] they studied the visual exploration behavior for young and old drivers through eye fixation data to determine the difference between daytime and night driving. The study revealed that night driving led both age groups to make fewer fixations on mirrors. In addition, there was a significant effect of age and lighting conditions on visual exploration behavior, as old drivers had a narrow visual exploration behavior, especially at night. In [16] they measured the number of fixations, fixation durations, and standard deviations of fixation locations in the X and Y coordinates of experienced and novice drivers during day, night, and rainy conditions to investigate the causes of accidents. The study concluded that experienced drivers had more frequent and shorter fixations and a broader scanning of the road. Moreover, poor visibility while driving, specifically driving in a rainy environment, significantly reduces the driver's visual search.

In this study, we used driving environment (urban and rural), GPS display size (large and small) and illumination level (daytime and night) as factors to investigate young drivers' visual fixations, collected by an eye-tracking system. In the past, eye-tracking technology has been used to investigate some of the mentioned factors separately. Yet, the interaction effects of the above-mentioned factors have not been investigated. The effect of the mentioned factors on the driver's visual search during night driving should be investigated using accurate technology. Moreover, night driving with different sizes of bright GPS display has not been studied. To our knowledge, the effect of these factors on urban and rural driving has not been investigated. An eye-tracking system was used to collect visual fixation data to investigate the effect of the above-mentioned factors and their interactions on the driver's visual search behavior and distraction while driving with the help of a navigation system. A driving simulator was used to conduct this study.

1.5. Hypotheses

Six measures of driver distraction and visual search were tested (section 2.4). Since the main effect of some factors on driver distraction and visual search, such as GPS display size and driving environment, have been investigated before [6], our hypotheses regarding the separate effect of these factors investigates the validity of the previous findings. For the other factor, environmental illumination, our hypotheses investigate its effect on driver distraction and visual search, where they have not been investigated before. Our study also investigates the hypotheses that the interactions between the investigated factors have a significant effect on driver distraction and visual search, as these hypotheses have not been investigated before.

2. Materials and Methods

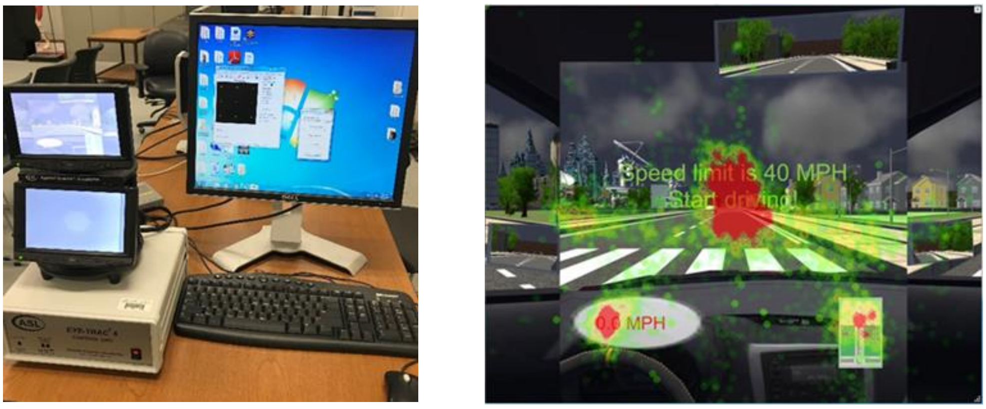
2.1. Participants

Ten males and ten females were paid to participate in a simulated driving experiment. The study protocol was approved by the Texas Tech University Human Research Protection Program (STUDY #: IRB2018-208). Participants were recruited by word of mouth, recruitment fliers and official announcements websites. Their age ranged from 18 to 29 years (mean age = 24.3 years, SD = 2.74 years). The mean age of female participants was 23.9 years (SD = 2.96 years), while the mean age of male participants was 24.7 years (SD = 2.58 years). All participants hold a driver's license. Moreover, they stated that their visual acuity was at least 20/40, and they were allowed to use lenses or eyeglasses to correct vision as long as it did not interfere with the collection of eye tracking data. The driving experience of the participants ranged from 1 to 14 years (mean years of experience = 5.5 years, SD = 3.4 years).

2.2. Apparatus

2.2.1. Eye tracking system (Figure 1 (a))

The visual search behavior of the participants while on a driving simulator was evaluated by analyzing the visual fixation (points of gaze) and saccade data. The driver's visual fixation and saccade data were accurately collected using an eye-tracking system [31]. This experiment utilized the ASL Eye-Trac 6 – desktop optics with a video head tracker, which uses an Eye-Trac 6 model D6 pan/tilt camera and a video head tracker VHT3 [31]. The eye-tracking camera was placed below the driving simulator screen. All data was digitally recorded on the eye tracker interface PC as real-time serial data. The data collection frequency of the eye-tracking camera was 60 Hz [31].



(**a**) (**b**)

Figure 1. (a) Eye tracking system, (b) An example of a heat map for one of the driving tasks.

2.2.2. Driving simulator

The used driving simulator included a steering wheel and pedals (Logitech, Driving Force GT) with driving simulator software developed to serve the purpose of the experiment. The driving simulator software was developed as close as possible to the real driving environment with Unity 3D [32]. In the game interface, the car interiors included a GPS system, which can be changed to different sizes according to the requirements of the task. The driver's visual field in the driving simulator interface also included the speedometer, the road ahead, the driver's left side window, the driver's right side window, the left mirror, the right mirror, and the rear-view mirror. The GPS was positioned on the dashboard on the driver's right side with a viewing angle of 17 degrees to the right to provide directions and route information (Figure 2). According to [33], short glance distance is associated with this location. Two sizes of GPS displays were used in the simulation software; small display (4-in) similar to a smartphone, and large display (6.95-in) similar to the conventional GPS system or the built-in vehicle IVIS.

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Figure 2. The driving simulator interface.

2.3. Independent variables

The study investigated three independent variables with two levels for each. These variables are driving environment including urban and rural area, GPS display size including small display size (4-in) and large display size (6.95-in), and environmental illumination including night driving (dark environment) and daytime driving. The driving tasks were carried out on two-way two-lane roads. The urban area has shorter road segments (20 – 50 m) compared to the rural area (60 – 90 m). Furthermore, the urban driving scenarios involve navigating through heavy traffic where vehicles are making various maneuvers, and there are also many pedestrians and objects like traffic signs, high buildings, stores and trees. As a result, the driver's visual field becomes crowded and requires a lot of attention from them. While rural driving scenarios involve navigating through light traffic where you see few vehicles, pedestrians, buildings, trees and traffic signs. The GPS interface was designed to be similar for the two GPS display sizes to avoid any variation in the collected data coming from a factor other than the display size. To simulate day and night driving, the room illumination level was controlled, with the daytime illumination level between 350 and 450 lux, and the nighttime illumination level between 10 and 30 lux. Moreover, the simulated tasks for daytime driving were developed by providing sufficient lighting in the driving scene, while the tasks for night driving were simulated by reducing the illumination in the driving scene to a level similar to the nighttime illumination. In the study, all combinations of the three factors were examined, resulting in eight different driving scenarios for each participant.

2.4. Dependent variables

The dependent variables in this study assessed driver distraction caused by the navigation system, and the driver's visual search behavior while looking at different locations in the visual field. Six metrics of driver distraction and visual search were used to assess distraction by the GPS and driver visual search behavior. These metrics were: percentage of total GPS fixation duration [34, 6], average duration of GPS fixation [35, 6, 23, 16], GPS fixation frequency [36, 6], the percentage of total dwell duration for the road ahead, the frequency of dwelling on the mirrors and driver's right and left side windows [34, 24, 27], and the percentage of dwellings on the mirrors and driver's right and left side windows [37]. These metrics are defined in Table 1.

Table 1. The definition of the driving distraction and visual search metrics, including the fixation metrics [18, 19], and the dwell metrics [21].

Driver distraction and visual search metrics	
Fixation metrics (driver distraction)	
Percentage of total GPS fixation duration	Ratio of the total of GPS fixation durations to the total fixation durations at all points of gaze in the visual field.
Average duration of GPS fixation	Average GPS fixation durations over a single driving task.
GPS fixation frequency	GPS fixation frequency in one minute.
Dwell metrics (visual search)	

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Percentage of total dwells duration for the road ahead	Ratio of the total durations of dwell on the road ahead to the total durations of dwell in all AOIs in the visual field for a single driving task.
Frequency of dwelling on the mirrors and side windows	Dwelling frequency on the mirrors and driver's right and left side windows in one minute.
Percentage of dwelling on the mirrors and side windows	Ratio of the number of dwells on the mirrors and driver's right and left side windows to the total number of dwells across all AOIs in the visual field.

2.5. Experimental protocol

In this experiment, all participants had to read and sign a consent form before beginning the driving tasks. Then, participants answered screening questions about their age, sex, driving experience, driver's license, experience with navigation systems, and visual acuity through a short survey. Next, the participants proceeded to the driving simulator station where they performed training tasks and actual recorded tasks. The training tasks took approximately one hour, and consisted of three sessions of 20 minutes each. The first training session included four tasks of 5 minutes each, the aim of which was to familiarize the participants with the driving simulator. The second and third training sessions also lasted 20 minutes each, with four tasks of 5 minutes each. Unlike the first session, which was done without a navigation system, participants used navigation systems with different display sizes. The aim of the second and third training sessions was to familiarize the participants with driving with the aid of a navigation system. Each of the three training sessions included all combinations of illumination conditions (daytime and night driving) and driving environment (urban area and rural area).

Once the participants finished the training sessions, they proceeded to the actual driving tasks, in which eye movement data were recorded and saved to the eye tracker operator's PC. The actual tasks included four different routes for urban areas and four different routes for rural areas. The routes in each set (i.e. urban set and rural set) were developed with the same length, traffic, complexity, and number of left and right turns [6]. The different routes were developed to avoid having a participant drive the same route twice (i.e. to control the effect of learning the routes and directions by the participant). The urban area routes were 2.71 miles each with a speed limit of 40 MPH, while the rural area routes were 2.8 miles each with a speed limit of 60 MPH. During the driving tasks, the participants only received directions from the GPS display, and no audio information was provided to avoid the effect of receiving audio directions on the driver's visual search behavior. In the event of a wrong turn, the simulation software displays a warning message asking the participant to correct the route.

The actual recorded tasks included all combinations of one of two GPS display sizes (large and small) and one of two illumination conditions (daytime and night) for each set of routes (urban and rural) for each participant. The participants had to follow traffic rules and speed limits as much as possible. The sequence of performing the eight driving tasks was randomized for each participant before starting. Each participant needed one three-hour session to complete the experiment including the training and the actual recorded driving tasks.

2.6. Theory/calculation

A repeated-measures analysis of variance (ANOVA) model was used [38]. This model compared different driving conditions in terms of the participant's visual search behavior and the level of distraction from the navigation system display while driving. This model was used to compare eight driving conditions in terms of three distraction metrics and three visual search metrics, including percentage of total GPS fixation duration, average duration of GPS fixation, GPS fixation frequency, percentage of total dwell duration for the road ahead, frequency of dwelling on the mirrors and driver's left and right side windows, and percentage of dwellings on the mirrors and driver's left and right side windows. The eight driving conditions were all combinations of two driving environments (urban and rural), two GPS display sizes (large and small), and two illumination conditions (daytime and night). The main effects and interaction effects of the three factors were tested. Additionally, an investigation into the difference between males and females was conducted, revealing no significant

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difference. As a result, the investigation of the sex factor was not pursued any further. The statistical analysis of the collected eye-tracking data was performed using Minitab [39], and the validity of the repeated measures analysis of variance model was evaluated by examining various assumptions, such as normality, homogeneity of variance and independence.

3. Results

The results of the statistical analysis of the driver distraction measures are presented below.

3.1. Fixations on the GPS

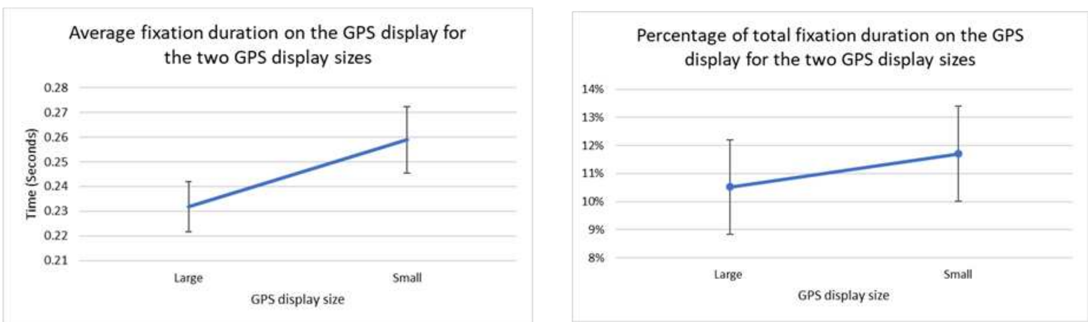
Table 2 shows the results of the repeated-measures ANOVA on the average duration of fixation, GPS fixation frequency, and percentage of total GPS fixation duration.

Table 2. Results of the GPS fixation measures tested with the repeated-measures ANOVA model.

	Average fixation duration		*Fixation frequency*		*Percentage of total fixation duration*	
Tested Factor	**F-Value**	**P-Value**	F-Value	P-Value	F-Value	P-Value
Driving environment	0.27	0.604	0.96	0.328	0.30	0.584
GPS display size	59.21	0.000*	0.38	0.536	9.25	0.003*
Environmental illumination	9.71	0.002*	18.54	0.000*	31.00	0.000*
Driving environment X GPS display size	0.87	0.353	0.30	0.584	0.06	0.805
Driving environment X Environmental illumination	1.09	0.298	0.37	0.546	1.69	0.196
GPS display size X Environmental illumination	2.00	0.159	0.00	0.957	0.00	0.981

*** p< 0.1 Marginal significance, ** p<0.05 Significant at 5%, and * p<0.01 significant at 1%.

From Table 2, the interactions between the investigated factors have no significant effect for any of the metrics. However, the main effect of GPS display size and environmental illumination have a significant effect on the Average fixation duration (p< 0.01), and the percentage of total GPS fixation duration (p< 0.01). This indicates that the average GPS fixation duration and the percentage of total GPS fixation duration varies with GPS display size and time of day (daytime and night). Driving with the aid of a small GPS display had a higher average fixation duration and a higher percentage of total GPS fixation duration compared to a large GPS display (Figure 3 (a, b)). The mean of the average fixation duration for the small GPS display was 0.256 seconds, and the percentage of total GPS fixation duration was 11.73%; while the mean of the average fixation duration for the large GPS display was 0.232 seconds, and the percentage of total GPS fixation duration was 10.65%. Moreover, driving during daytime created a higher average fixation duration and a higher percentage of total GPS fixation duration compared to driving at night (Figure 3 (c, d)). The mean of the average fixation duration for daytime driving was 0.249 seconds, and the percentage of total GPS fixations duration was 12.18%; while the mean of the average fixation duration night driving was 0.239 seconds, and the percentage of total GPS fixation duration was 10.20%. For GPS fixation frequency, only environmental illumination had a significant effect (p< 0.01), with daytime driving having a higher GPS fixation frequency compared to nighttime driving (Figure 3 (e)). The mean fixation frequency for daytime was 18.7 fixations/minute, while nighttime driving had a mean of 16.4 fixations/minute. For these metrics, the other main effects did not show any significance.



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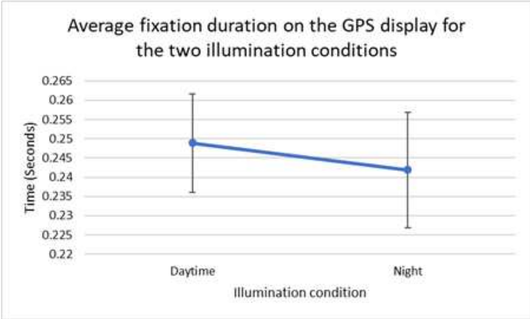
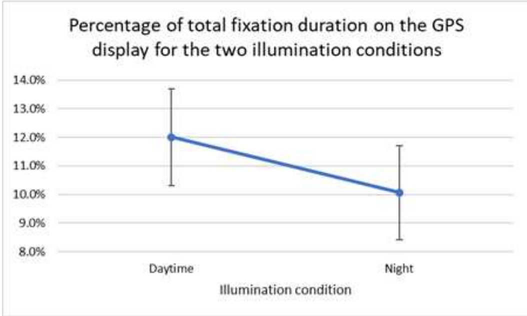
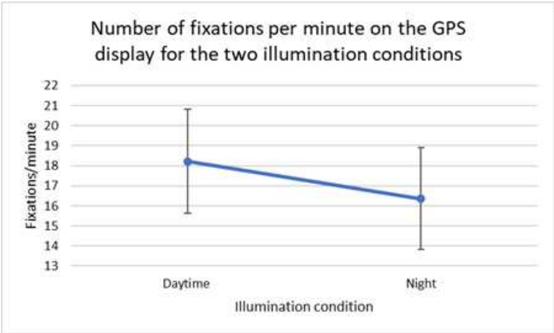
(a) (b)





(c) (d)



(e)

Figure 3. Main effect plots for fixations on GPS metrics; (a) average fixation duration for the two GPS display sizes, (b) percentage of total fixation duration for the two GPS display sizes, (c) average fixation duration for the two illumination conditions, (d) percentage of total fixation duration for the two illumination conditions, (e) fixation frequency for the two illumination conditions. (Note: the bars represent the standard error (SE)).

3.2. Driver Visual Search

To understand the driver's visual search, the percentage of dwells at each AOI in the driver's visual field was examined in terms of number and total duration. Table 3 shows the percentages of the number of dwells for each AOI in the visual field for the different factor combinations. Furthermore, the grand averages of the percentage of the number of dwells for each AOI in the visual field are shown in Figure 4. Table 4 shows the percentages of dwells duration for each AOI in the visual field for the different factor combinations. While the grand averages for the percentage of dwells duration are shown in Figure 5.

Table 3. Percentages of the total number of dwells for each AOI in the visual field.

Factors of interest			**Locations in the visual field**			
Driving environment	***GPS display size***	***Illumination condition***	***GPS display***	***Speedometer***	***The road ahead***	***Mirrors and sides***
Urban	Large	Daytime	29.67%	15.83%	46.93%	7.58%
		Night	27.67%	19.76%	47.00%	5.58%
	Small	Daytime	29.91%	16.00%	46.83%	7.27%
		Night	30.03%	17.83%	47.08%	5.06%
Rural	Large	Daytime	28.58%	17.91%	47.08%	6.43%
		Night	29.19%	18.91%	47.38%	4.54%
	Small	Daytime	28.96%	18.02%	47.40%	5.62%
		Night	29.36%	18.77%	47.04%	4.85%

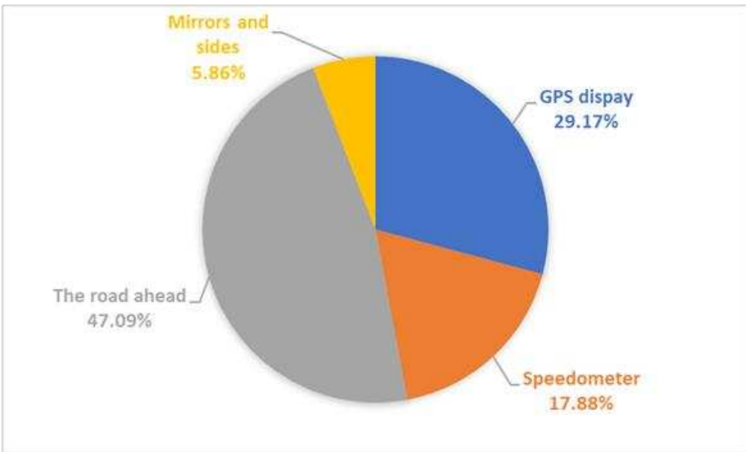


Figure 4. Grand averages of the percentage of the total number of dwells for each AOI in the visual field for all conditions.

Table 4. Percentages of total dwells duration for each AOI in the visual field.

Factors of interest			Locations in the visual field			
Driving environment	*GPS display size*	*Illumination condition*	*GPS display*	*Speedometer*	*The road ahead*	*Mirrors and sides*
Urban	Large	Daytime	9.39%	5.22%	82.97%	2.42%
		Night	8.28%	6.49%	84.29%	2.09%
	Small	Daytime	11.05%	5.38%	80.79%	3.10%
		Night	8.28%	5.43%	85.91%	1.85%
Rural	Large	Daytime	9.80%	6.60%	80.54%	2.30%
		Night	8.25%	6.13%	83.37%	1.39%
	Small	Daytime	9.64%	6.42%	80.56%	2.03%
		Night	9.40%	6.90%	81.42%	1.51%

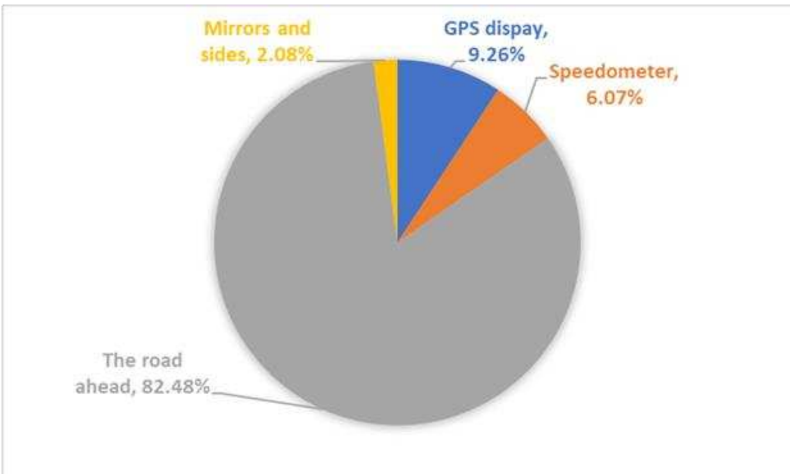


Figure 5. Grand averages of the percentage of total dwells duration for each AOI in the visual field for all conditions.

Figure 5. Grand averages of the percentage of total dwells duration for each AOI in the visual field for all conditions.

From Figures 4 and 5, the number of dwells on the road ahead represents 47.09% of all dwells, and the total dwell time on the road ahead represents 82.48% of the task time, which means that dwells on the road were longer compared to all dwells' average duration. The dwell count on the speedometer accounts for 17.88% of all dwells, while the total dwell time represents 6.07% of the task time, indicating that dwells on the speedometer were shorter compared to the average duration of all dwells. Moreover, the number of GPS dwells accounts for 29.17% of all dwells, while the total dwell duration accounts for 9.26% of the task time, which also means that dwells on GPS were shorter compared to the average duration of all dwells. Finally, the number of dwells on mirrors and side windows represents 5.86% of all dwells, while the total dwell duration represents 2.08% of the task time, showing that dwells on mirrors and side windows were shorter than all dwells' average duration.

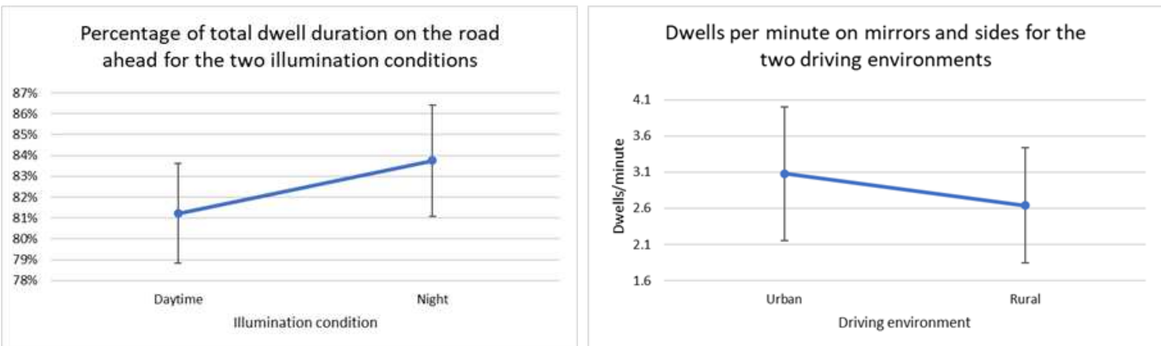
Using a repeated-measures ANOVA model, several metrics related to AOIs in the driver's visual field were investigated, including: the percentage of total dwell duration for the road ahead, the frequency of dwell on the mirrors and driver's left and right side windows, and the percentage of dwells on the mirrors and driver's left and right side windows. Table 5 shows the results of the aforementioned metrics.

Table 5. Results of the dwell metrics tested with the repeated-measures ANOVA model.

	Percentage of total dwell duration for the road ahead		*dwell frequency on mirrors and driver left & right side windows*		*Percentage of dwells count for mirrors and driver side windows*	
Tested Factor	**F-Value**	**P-Value**	F-Value	P-Value	F-Value	P-Value
Driving environment	2.52	0.115	5.49	0.021**	1.41	0.238
GPS display size	0.62	0.433	0.00	0.971	0.00	0.980
Environmental illumination	5.82	0.017**	22.51	0.000*	12.92	0.000*
Driving environment X GPS display size	0.01	0.913	0.00	0.945	0.03	0.873
Driving environment X Environmental illumination	0.01	0.911	0.01	0.931	0.39	0.531
GPS display size X Environmental illumination	0.09	0.764	0.11	0.735	0.60	0.438

*** p< 0.1 Marginal significance, ** p<0.05 Significant at 5%, and * p<0.01 significant at 1%.

From Table 5, there were no significant interactions. However, several main effects were significant. There was a significant effect of environmental illumination on the percentage of total dwell duration for the road ahead ($p < 0.05$). Night driving had a higher percentage of total dwell duration for the road ahead (83.9%) compared to daytime driving (81.4%), (Figure 6 (a)). Furthermore, the frequency of dwell on the mirrors and driver's left and right side windows was significantly affected by the driving environment ($p < 0.05$), and the environmental illumination ($p < 0.01$). The dwell frequency on the mirrors and driver's left and right side windows was 3.0 dwells/minute for urban area compared to 2.52 dwells/minute for rural area (Figure 6 (b)), and 3.25 dwells/minute for daytime driving compared to 2.28 dwells/minute for night driving (Figure 6 (c)). Moreover, by considering the percentage of dwells on the mirrors and driver's left and right side windows, the analysis showed a significant effect of environmental illumination ($p < 0.01$). Daytime driving was 6.4%, while night driving was 5.0% (Figure 6 (d)). The rest of the factors did not show any significant effect on the three above-mentioned metrics.



(**a**) (**b**)

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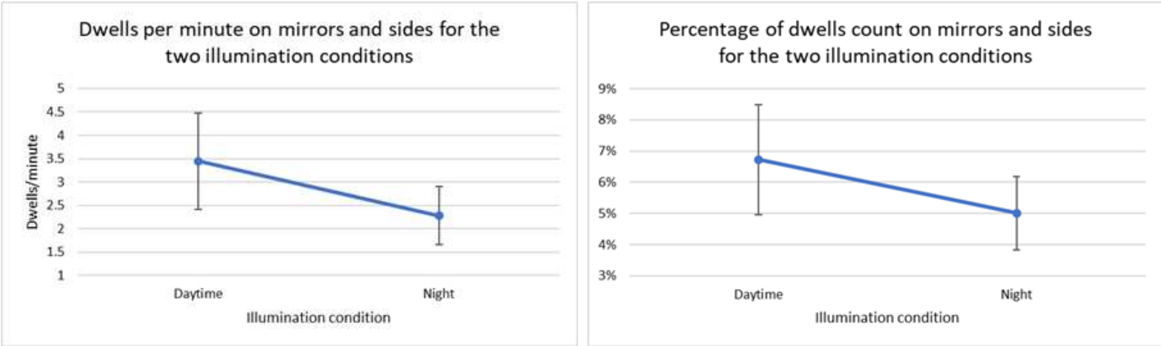

(c) (d)

Figure 6. Main effect plots of dwell metrics on different locations in the visual field; (a) percentage of total dwell duration for the road ahead for the two illumination conditions, (b) frequency of dwell on the mirrors and driver's left and right side windows for the two driving environments, (c) frequency of dwell on the mirrors and driver's left and right side windows for the two illumination conditions, (d) percentage of dwells on the mirrors and driver's left and right side windows for the two illumination conditions. (Note: the bars represent the standard error (SE)).

4. Discussion

The study hypotheses were supported for some of the tested factors, as at least one factor was significant for each of the metrics examined. However, the interactions between these factors were not significant for any of the investigated metrics.

4.1. Fixation on GPS

As the results showed, driving with the aid of a small GPS display had a higher average duration of GPS fixation and a higher percentage of total GPS fixation duration compared to a large GPS display, however, the GPS fixation frequency was similar for both display sizes. This indicates that driving with a small GPS display is more distracting in terms of the duration of each glance, and since the frequency of glancing is similar for both small and large displays, the driver spent more time of the total task time glancing at the small GPS. This might be a result of the small scale of the information displayed on the GPS, which makes it harder to read and comprehend by the driver, creating higher cognitive workload. When the driver takes his eyes off the road for a long time, it might lead to a safety issue as well as a higher probability of being involved in a traffic accident [6].

The results also revealed that driving during daytime created a higher average duration of GPS fixation, a higher percentage of total GPS fixation duration, and a higher GPS fixation frequency compared to driving at night. These results indicate that the driver's glances were longer and more frequent during daytime, what leads to more time glancing at the GPS display of the total task time. This might be explained by the driving conditions at daytime, which are less challenging and require less cognitive workload compared to night driving, what might lead to a feeling of safety and security by drivers, and a less urgent need to keep their attention on the road ahead [40, 41]. Another explanation can be the easiness of extracting information from the external environment during daytime due to sufficient lighting, which tolerates longer and more frequent glances on the GPS display without compromising safe driving.

4.2. Driver Visual Search

In general, for all driving conditions, the driver spent most of the time dwelling on the road ahead, with the number and average dwell duration being the highest compared to the other AOIs. Basically, driving and monitoring the road ahead is the primary task and should take up most of the driving time. On the other hand, the dwells on the speedometer, GPS display, and mirrors and side windows were short. The GPS display had the highest number of dwells among these three AOIs, then the speedometer, and finally the mirrors and side windows. The quick dwells on these AOIs are to collect information to support the primary task of driving such as navigation information, vehicle speed, and side and rear vision. These dwells usually don't take much time. In our study, the GPS display appears to take the majority of dwells compared to the other AOIs except for the dwells on the road ahead. This can be explained by the amount of information presented by the GPS display

 doi:10.20944/preprints202305.1456.v1

and its frequent update while driving. In general, having a GPS competes with other AOIs, which essentially reduces the time dwelling on the road ahead, which can negatively affect driving safety.

The statistical analysis of the dwelling metrics using the repeated measures ANOVA showed a higher percentage of total dwell duration on the road ahead, a lower percentage of dwells on the mirrors and driver's left and right side windows, and a lower dwell frequency on the mirrors and driver's left and right side windows for night driving compared to daytime driving. These results indicate a wider and more spread visual search during daytime driving compared to nighttime driving [42]. According to [16], this negatively affects driving performance at night and can compromise safe driving and increase the potential of road accidents.

Moreover, driving in urban area showed a higher dwell frequency on mirrors and driver's left and right side windows than in the rural area. At the same time, the percentage of dwells on the mirrors and side windows, and the percentage of the total dwell duration on the road ahead were both similar in both urban and rural areas. This indicates that drivers spent in total the same amount of time dwelling at the GPS display, speedometer, and mirrors and side windows for both urban and rural areas, but with shorter and more frequent dwells in the urban area compared to the rural area. This finding is in line with the research conducted in [43], which asserts that with heavy traffic, drivers tend to take shorter glances away from the road ahead. This can be explained by the high density of traffic and pedestrians, and the increased amount of information and updates presented by the GPS in the urban area, which requires the driver to pay more attention to the surrounding environment through quick and frequent glances that do not affect the time allotted to the primary task of driving and dwelling at the road ahead.

4.3. Study limitations

The driving simulator has been developed to be as close as possible to real driving. However, participants do not feel the same risks as driving in a real environment. Furthermore, the study had some limitations, including the limited visual angle of the eye-tracking system which was 30 to 35 degrees in the vertical axis and 40 to 45 degrees in the horizontal axis. In the real driving environment, the driver's visual search angle is wider than that, especially for the horizontal axis. This limitation forced us to use a single monitor and include the driver's left and right sides in that monitor. Another limitation is the steering wheel and pedals used, which were joystick controllers for a PlayStation game box. These joystick controllers differ from real vehicle steering wheel and pedals in terms of weight and size.

After the participants completed the driving tasks, they were asked to rate the driving simulator with the following question: "How close is the driving simulator to real driving? (Rate out of 10)". The twenty participants gave an average rating of 7.5 out of 10, with scores ranging from 6 and 8.5.

5. Conclusions

Driver distraction and visual search were examined for different driving conditions using an eye-tracking system. Conditions tested in the study included driving environment, GPS display size, and illumination condition. None of the interactions between the investigated factors showed a significant effect. However, two factors showed a significant effect on driver distraction, including GPS display size and illumination. In conclusion, using a small GPS display leads to more distraction because of the associated long glances, which may compromise safe driving. Furthermore, daytime driving tends to have a lower cognitive workload which may result in the driver feeling safe and less urgent need to maintain attention on the road ahead. At the same time, the extraction of information by the driver from the external environment is easier during daytime due to sufficient lighting, which tolerates longer and more frequent glances at the GPS display without compromising safe driving.

For driver visual search, two factors showed a significant effect, including illumination condition and driving environment. In conclusion, the GPS display captured a significant amount of the driver's attention and visual search. Furthermore, daytime driving showed a wider and more spread visual search, which positively affects driving performance and safety. Moreover, drivers had shorter and more frequent dwells on the GPS display, speedometer, and mirrors and side windows in the urban area, which might be due to the higher density of traffic and pedestrians, and the increased amount of information and updates provided by the GPS in the urban area, which requires the driver to pay more attention to the surrounding environment through quick and frequent glances.

Finally, large GPS displays are recommended for navigation. Besides, being cautious while driving and never underestimate risks is essential to be safe on the road, even when driving in a less demanding environment. Moreover, it is suggested that manufacturers of navigation systems and smartphones provide warning massages about GPS distraction every time a user starts using it, especially for small display systems. The findings of this study should help improve navigation systems by choosing the appropriate display size. Furthermore, future research should be directed to examine more driving conditions to gain a better understanding of the driver distraction problem and to achieve the goal of reducing risks on the road.

In the future, more driving conditions can be investigated such as the position of the navigation system inside the vehicle, and different driving conditions such as driving in a rainy or snowy environment. Moreover, the interactions between these and other factors can be investigated. Furthermore, other age groups can be studied, such as elderly and middle-aged drivers, and drivers with vision or health issues.

Author Contributions: Conceptualization, T.Y. and P.P; Data curation, T.Y.; Formal analysis, T.Y.; Funding acquisition, T.Y. and P.P.; Investigation, T.Y. and A.M.; Methodology, T.Y.; Project administration, T.Y. and P.P.; Resources, T.Y. and P.P.; Software, T.Y.; Supervision, P.P.; Validation, T.Y. and A.M.; Visualization, T.Y.; Writing – original draft, T.Y. and P.P.; Writing – review & editing, T.Y., P.P. and A.M.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Texas Tech University Human Research Protection Program (STUDY #: IRB2018-208).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data are not publicly available.

Acknowledgments: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of Interest: The authors declare no conflict of interest.

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