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The Static and Dynamic Analyses of Drivers' Gaze Movement Using VR Driving Simulator

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Abstract: Drivers collect information of road and traffic conditions through a visual search while driving to avoid any potential hazards they perceive. Novice drivers with lack of driving experience may be involved in a car accident as they misjudge the information obtained by insufficient visual search with a narrower field of vision than experienced drivers do. In this regard, the current study compared and identified the gap between novice and experienced drivers in regard to the information they obtained in a visual search of gaze movement and visual attention. A combination of a static analysis, based on the dwell time, fixation duration, the number of fixations and stationary gaze entropy in visual search, and a dynamic analysis using gaze transition entropy was applied. The static analysis on gaze indicated that the group of novice drivers showed a longer dwell time on the traffic lights, pedestrians, and passing vehicles, and a longer fixation duration on the navigation system and the dashboard than the experienced ones. Also, the novice had their eyes fixed on the area of interests straight ahead more frequently while driving at an intersection. In addition, the novice group demonstrated less information at 2.60 bits out of the maximum stationary gaze entropy of 3.32 bits that a driver can exhibit, which indicated that their gaze fixations were concentrated. Meanwhile, the experienced group displayed approx. 3.09 bits, showing that their gaze was not narrowed on a certain area of interests, but was relatively evenly distributed. The dynamic analysis results showed that the novice group conducted the most gaze transitions between traffic lights, pedestrians and passing vehicles, whereas experienced drivers displayed the most transitions between the right- and left-side mirrors, passing vehicles, pedestrians, and traffic lights to find more out about the surrounding traffic conditions. In addition, the experienced group (3.04 bits) showed a higher gaze transition entropy than the novice group (2.21 bits). This indicated that a larger entropy was required to understand the visual search data because visual search strategies changed depending on the situations.

Keywords: visual search; dwell time; fixation duration; number of fixations; stationary gaze entropy; gaze transition entropy

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1. Introduction

According to the World Health Organization's report on road safety highlights that the number of road traffic deaths has reached 1.35 million annually, and road traffic injuries are now the leading killer of people aged 15–29 years [1]. The causes of their traffic accidents have been identified to affect driving behaviors such as driving experience, distraction, gender and cognitive, in particularly, driver's inexperience is one of the most frequently reported towards traffic accidents [2,3]. Moreover, Novice drivers with lack of driving experience were prone to insufficient the ability to properly cope with multiple sudden situations that occur of driving and overconfident their driving ability or afraid of driving [4]. It is known that this tendency increases the risk of accidents and that traffic accidents occur frequently [5]. Therefore, various studies are being conducted according to their driving experience, for instance Macenzie and Harris in 2017 reported that just shown ten-minute driving videos with expert driver's eye movements overlaid lead to increased novice driver's horizontal scanning of the road and larger saccade sizes [6]. In addition, McKnight in 2014 analyzed 1000 collisions related to young novice drivers and stated that attention and visual search failures contribute to more than 65% of vehicle collisions, and it indicates that the increased risk of collisions for young drivers can be largely due to cognitive factors such as attention and decision making [7,8].

However, as reported earlier, such behavior in the novice drivers is due to different reason, which is that the novice drivers are not able to judge other drivers' path or speed or accurately identify the risk factors even though their cognitive skills are not reduced [9]. To note, the most frequently reported contributing factor of road traffic collisions by at-risk drivers, such as novice and older drivers, was "failure to look properly", and recently, 39% of collisions have been reported to occur due to this factor [10,11]. For this reason, given that most of the information is obtained through vision by the driver to control the vehicle, information acquisition through visual scanning, and accurate judgement and processing of that information will enable safer road driving by preventing collisions.

Typically, for safe driving, drivers obtain the necessary information through visual scanning of roads and the adjacent areas. They then classify all traffic-related information, maintain alertness against potential hazards derived from the visual scanning, and ignore the unnecessary information from the complicated visual scenes. A more experienced driver is more likely to drive safely as they collect and employ not only the lateral information of a wide range but also the vertical one of a long distance, covering a wide area during their visual search for detailed information. However, the older drivers with low cognitive ability and novice drivers with insufficient driving experience are involved in car accident mainly because of misjudgment due to their narrow field of vision or insufficient visual search, respectively [12,13]. In a prior study comparing the difference in visual search according to driving experience, there are similar patterns between novice and expert drivers in the strategy of visual search on rural or suburban routes in the lateral direction, but expert drivers used the strategy of visual search in wider lateral on road types with more complex layouts [14]. Therefore, the information obtained from such visual searches can be used as indicators to differentiate the at-risk driver population who are significantly correlated to car accidents.

To note, visual search involves an eye tracking technique—a technique that tracks drivers' gaze to find out their concentration on objects and screens and where they are staring, and studies human reactions and interactions to stimuli [15]. Accordingly, it is possible to quantify the driver's gaze information in regard to visual attributes such as dwell tine, fixation duration, and number of fixations. The values of the visual properties vary depending on the number and type of target objects that a driver scans and judges its potential hazards [16,17]. One of the characteristics of the visual properties is that they involve various stimuli related to vehicles or pedestrians and are well demonstrated at intersections where there are a large number of visual stimuli [18]. In addition, it is possible to generate probabilities for all areas viewed during driving using the generated distributions by fixing the gaze to the position of the stimulus at intersections, and this can be quantified based on 'Stationary Gaze Entropy'. The Stationary Gaze Entropy (SGE) is used as an indicator for estimating the level of complexity or randomness of visual search, and is used in fields such as flight simulators, surgical simulation, and pattern recognition [19,20]. Through this static analysis of gaze, it will be possible to compare the difference between the novice drivers and experienced drivers in visual search because the inexperienced novice drivers cannot recognize potential hazards on the road or do not know where to look at while driving unlike the experienced drivers.

However, a static analysis on gaze is not enough to identify the mobility related characteristics, such as movement, direction and speed of a driver's gaze of their visual search around their surroundings. Under such circumstances, a dynamic analysis is additionally required to process the complexity and quantity of the information manifested in the sequential pattern of visual search as well as dispersion of gaze across the area of interest (AOI) using gaze transition entropy (GTE) based on gaze transition between the AOIs [21,22]. It estimates uncertainty in predicting the next fixation location given the current position of the eyes. This is used in research to analyze the order of visual search and pattern recognition strategies in overall stimuli [23,24]. In particular, studies of visual search in driving have shown that experienced drivers have higher entropy because they make more gaze changes to identify potential risks which in turn increases the entropy, whereas for novice drivers, showing the lower entropy due to gaze changes between near and far spaces with simple visual search patterns [25,26]. Since most of results that mainly analyzed the visual search process for the direction, location, and distance at which drivers gaze, this study purposed to analyze which objects (e.g., Pedestrian, traffic light, cars etc.) the drivers stare at on the road. Even if novice and experienced drivers stare at the same road scene with the same visual field of view, there may be differences in the object and order to be searched, so the study should be conducted to analyze entropy acquired based on the objects that the drivers searched [27].

Actually, driving performance is evaluated using an actual vehicle. However, in the current research, a Virtual Reality (VR) driving simulator has been used to repeat the experiment process and to ensure safety for novice drivers from any potentially dangerous situations. Typically, a driving simulator using a virtual reality environment can evaluate drivers as if they are driving in real situations. Among these driving simulators, a Head Mounted Display (HMD)-based VR driving simulator provides higher concentration, immersion, and interest than the existing 3D (Full HD, Smart TV etc.) environment [28]. The driving simulation has other advantages, such as regulating the levels of difficulty posed by the chosen path and traffic jam, enabling an assessment of drivers' reaction to a life-threatening situation, which cannot be materialized on an actual road [29].

The current study aimed to explore whether the information obtained from the driver staring at traffic-related areas to prevent collisions while driving in a VR-based intersection scenario differs according to the driving experience, and the research questions are as follows.

RQ 1 Are there any differences in time, number, and distribution of areas at which the beginner and skilled drivers stare while driving.

RQ 2 Is there any difference in the entropy obtained by the movement and transition of gaze between the areas at which the novice and skilled drivers stare while driving.

Finally, this study would like to be contribution to prior studies that have researched quantitative indicators of visual search as a method for evaluating driving performance and habits. Furthermore, to be used as a pilot study to identify hazardous drivers by evaluating their visual recognition abilities of novice and elderly.

2. Materials and Methods

The present study adopted a HMD-VR driving simulator with an eye tracker attached and obtained visual search information based on the movements of drivers' gaze and their alertness at an intersection, a road type deemed most suitable to represent the visual properties. First, a static analysis of gaze was carried out on the frequency of additional visual searches in the AOIs and on the time required to recognize a change in the AOIs, based on the dwell time, number of fixations, and fixation duration of gaze on the areas that were observed while driving. The gaze dispersion was then calculated based on SGE, followed by analysis of the distribution density of gaze to compare the quantity of information acquired depending on the levels of driving experience. In addition, upon completion of the analysis of GTE based on the transition probability matrix, a dynamic analysis was implemented on the complexity of visual search patterns shown in AOIs and the quantity of information to identify the difference between the novice and experienced drivers.

2.1. Participants

An experiment was conducted after classifying 23 participants consisted of males aged 20 to 40 (mean age: 28.7 ± 4.6 years), and it is 6.2 ± 4.1 years since the driver's license was obtained. In addition, following two groups per frequency and duration of driving: the first group consisted of novice drivers who drove once a week on an irregular basis and the other group was made of experienced drivers who drove regularly more than once a week. Generally, novice driver means a driver licensed for the first time and has been licensed for less than two years as per Road Traffic Act of Korea. However, it was deemed inadequate to classify those without any driving experience as experienced drivers, even if they held license for more than two years [30]. In this regard, those with the driver's license who drove relatively less frequently on an irregular basis were categorized as novice drivers. Experienced drivers refer to those who own a vehicle and drive on a regular basis. Furthermore, novice drivers are the drivers whose annual mileage is relatively short(mean distance: 7704 ± 1388 km) and experienced not only car-to-car accident but also single car accidents(e.g., impact with a fixed object, rollover etc.). On the other side, experienced drivers are the drivers whose annual mileage is more than 10,000 km (mean distance: 28,330 ± 4899 km) and haven't had any accident in the last year. Table 1 lists up the frequency of driving per month and per week and the duration of driving in one trip, annual mileage and number of accidents in the last year for each group of the drivers.

Table 1. Classification of the participants.

			Novice (n = 11)	**Experienced (n = 12)**
Gender (male/female)			11/-	12/-
Mean age (years)			25.7 ± 3.0	31.3 ± 4.5
License (years)			2.7 ± 1.1	9.4 ± 3.1
Driving frequency	**Month**	Less than 3 times (<3)	8	-
		3 to 5 times (3∼5)	3	-
		More than 5 times (>5)	-	12
	Week	Less than 1 times (<1)	9	-
		1 to 2 times (1∼2)	2	3
		More than 3 times (>3)	-	9
	Time	Less than 30 min (<30)	10	-
		30 to 60 min (30∼60)	1	6
		More than 60 min (>60)	-	6
Driving mileage (last 12 months)	5000 to 10,000 km		10	-
	10,000 to 20,000 km		1	2
	20,000 to 30,000 km		-	3
	More than 30,000 km		-	7
Accident experience (last 12 months)	Accident free		-	12
	1 to 2 times (1∼2)		7	-
	More than times (>3)		4	-

2.2. VR Driving Simulator and Data Pre-Processing

In this study, Logitech G29 Driving Force was adopted as the VR driving simulator to accommodate a testing environment. The G29 driving force consisted of a steering wheel capable of rotating up to 900°, an accelerator, a brake, a clutch pedal and a shiftable gearbox with four gears, viz. Drive (D), Neutral (N), Reverse (R), and Park (P), as shown in Figure 1. The participants wore HMD of HTC-VIVE PRO EYE (Resolution: 1440 × 1600 pixels per eye, screen refresh rate 90 Hz) while driving the car simulator to obtain their gaze tracking data (Sampling frequency: 30 Hz) with the eye tracking function offered by the device.

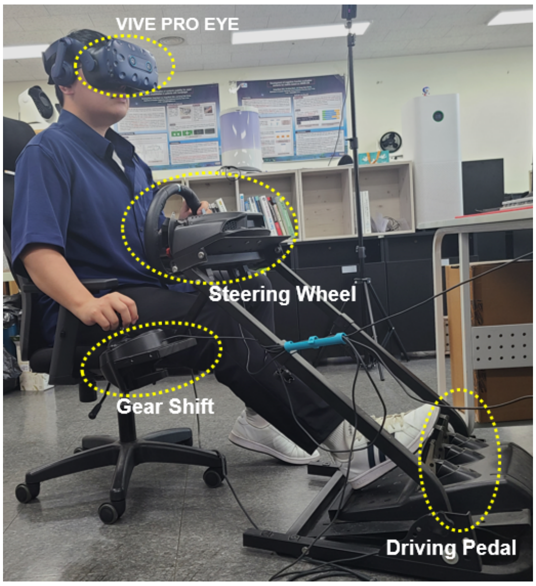
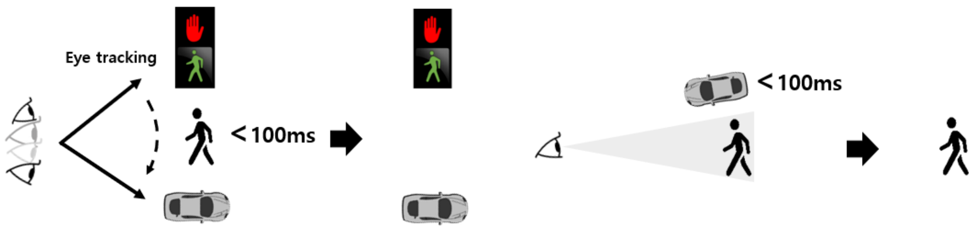


Figure 1. The virtual reality driving simulator.

The obtained gaze tracking data shows the information and status (e.g., red traffic light or pedestrian on the move) of an object applied to the Hitmap, whose coordinates coincide with those (x, y) of the direction that the participant is gazing in virtual reality. The final data were produced after pre-processing two sets of data—the one gathered when the participants shifted the gaze, while the other obtained when they looked at the boundary space between objects. Figure 2a illustrates how data less than 100 ms secured in the gaze shifting process were eliminated because these data indicated that the participants did not look at the pertinent object. Figure 2b shows the pre-processing of removing data less than 100 ms achieved when the participant gazed at the boundary between the objects [31].



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

Figure 2. Schematic of pre-processing of gaze tracking data. (**a**) the gathered data when the participants shifted the gaze; (**b**) the gathered data when the participants looked at the boundary space between objects.

2.3. Driving Scenarios

The participants drove the simulator for approx. three minutes according to the driving scenarios after they were explained about how to maneuver the machine. They were given a chance to practice for ten minutes (straight drive, left and right turns, and stop) before actual evaluation of their driving performance. The scenario involved driving on a four-lane road and at an intersection where the most active visual search was required. The scenario was simulated with Logitech G29 Driving Force and VIVE PRO EYE connected to the simulator using Unity (ver. 2019.4.7.f1) engine based SteamVR plug-in. As shown in Figure 3, the scenario went as follows: drives straight and stops at an intersection with traffic lights, turns left to face an event that causes him or her to sudden braking, and turns right after changing lanes. When they arrived at the destination or could not drive any further because of a car crash, the scenario ended, prompting the driving performance evaluation to begin.

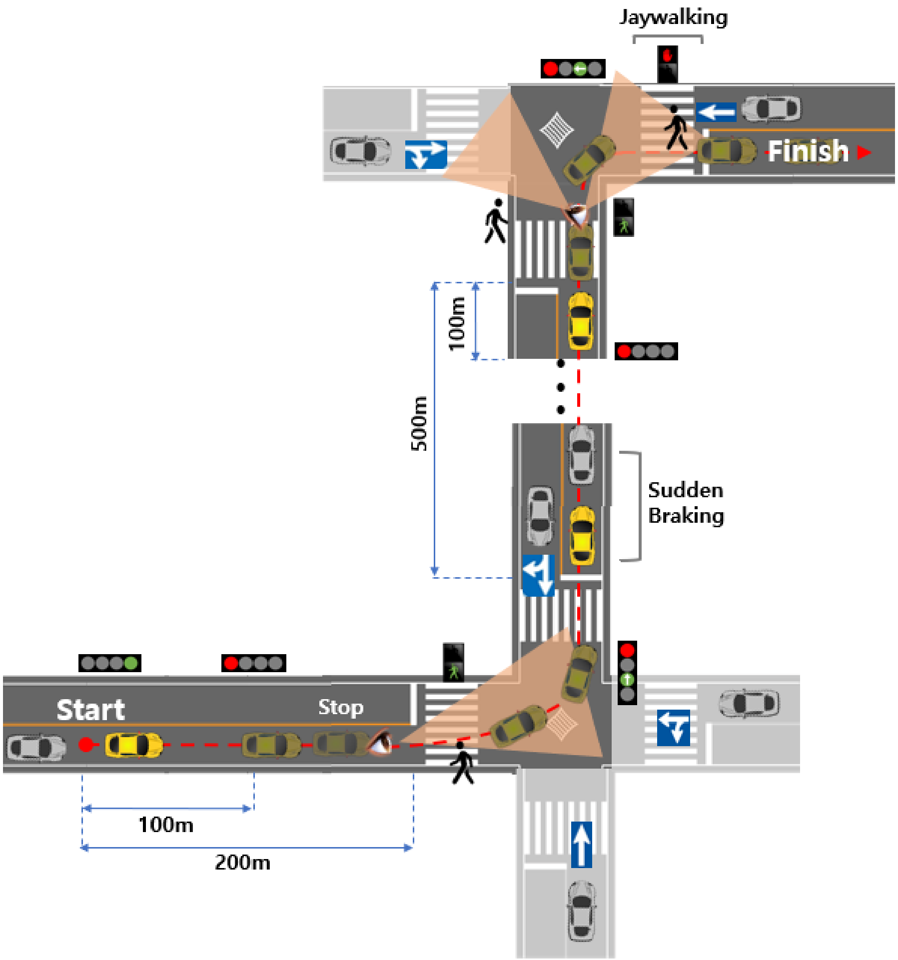


Figure 3. Schematic representation of the driving scenario.

Once the participants started the scenario, the navigation system displayed the map as shown in Figure 4a to lead them to drive straight for 200 m and then turn left. When the vehicle arrived 100 m away from the intersection, the traffic light turned from green to red, making them slow down and stop at the intersection. Then they could see the situations at the intersection as displayed in Figure 4b. When they turned left after surveying the road situations and surroundings according to the traffic light signal, the road situations as shown in Figure 4c were played out for them to move straight for 500 m and turn right. The situation in Figure 4d was to see whether they apply brakes or change lanes when they had to stop abruptly. The scene in Figure 4e tells us whether they observed the surroundings to see if there were other vehicles on the left lanes or pedestrians before they turned right. In case the participants tried to turn right without sufficiently surveying the surroundings, the scenario was designed to make them get into a crash with other driving cars or pedestrian(s). When there was a crash or if the participants made a right turn safely, the test was completed.

(**a**)

(**b**)

(**c**)

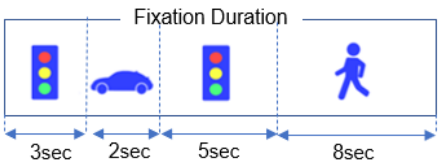
(**d**)

(**e**)

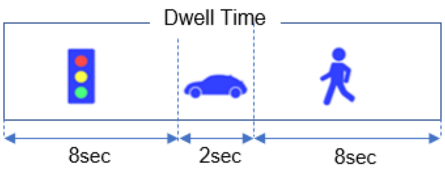
Figure 4. Display by scenario shown to the participants. (**a**) navigation system; (**b**) intersection; (**c**) navigation system; (**d**) sudden brake; (**e**) intersection.

2.4. Static and Dynamic Analysis of Gaze

As shown in Figure 5, a static analysis was carried out based on visual properties, such as gaze fixation duration, dwell time, and the number of fixations. Fixation duration means the time required for a driver to gaze at each object and assess the situations while driving. For instance, Figure 5a suggests that a driver held his or her gaze at the traffic lights for three seconds on the vehicle. Figure 5b indicates the sum of fixation duration of each object which was used to analyze the dispersion and density of the drivers' gaze. Figure 5c demonstrates the number of fixations, which means how many times a driver gazed at a certain object, translating into the frequency of checks in its status.



(**a**)



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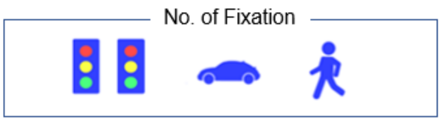


(**c**)

Figure 5. The visual properties for static analysis. (**a**) fixation duration; (**b**) dwell time; (**c**) Number of fixation.

In addition, SGE, the quantity of information generated from the driver's gaze dispersed across AOIs while driving, was calculated to estimate the amount of information to initiate a visual search. Here, as SGE signified the probability distribution of an object that the driver observed while driving or of the one that was overlooked, gaze dispersion across the whole areas can be quantified using Shannon's Entropy, which is expressed by Equation (1) [32].

$$\text{SGE} = -\sum_{i=1}^{n}(p_i)\log_2(p_i) \quad (1)$$

Here, p_i refers to the probability of gaze at AOIs for the ith time, and in case the driver focused only on a certain object, it led to a low probability distribution, resulting in a low entropy value. This is because their gaze density was measured higher than that of the other drivers who inspected all the objects involved [33]. In other words, the higher the entropy value of a driver was, the more evenly were distributed their gaze points in visual search, signaling lesser dispersion. As mentioned before, a static analysis did not reflect the visual search patterns that could indicate how the driver controls the vehicle and assesses the situations by continuously shifting or moving their gaze while driving on a road. Therefore, we also carried out GTE, which is a dynamic analysis on gaze, to quantify the dependency of objects that exist subsequently to the object that the driver's gaze is currently on [34]. Here, GTE refers to an indicator of complexity of a gaze transition pattern with a transition matrix based on the conditional probability of shifting the gaze from one location to the next, as expressed by Equation (2) [35].

$$\text{GTE} = -\sum_{i=1}^{n} p_i \sum_{i,j=1}^{n}(p_{i,j})\log_2(p_{i,j}) \quad \begin{cases} i,\, j = & 1, 2, 3, \cdots n \\ & i \neq j \end{cases} \quad (2)$$

GTE literally means the transition entropy of a driver's gaze, i signifies an AOI that the driver looks at first, and j refers to an AOI that is currently observed. A higher GTE makes it more difficult to predict precisely where the eyes are looking as the sequence of gaze shifts was not predefined. For instance, at a place where there are many stimuli involved, such as intersection, drivers may engage in a visual search in a more complicated pattern than they do on an ordinary road to avoid any collision, possibly resulting in a higher GTE [36]. In this case, the search pattern of the generated gaze may differ depending upon the driving experience, and the difference between the groups according to driving experience was analyzed using t-test (α = 0.05).

3. Results

3.1. Static Analysis of Gaze

For the static analysis of drivers' gaze in visual search, four indicators, viz. dwell time, number of fixations, fixation duration, and SGE were adopted, and the average dwell time of each group on each AOIs is shown in Figure 6. The indicated error bars represent the minimum and maximum values of dwell time measured for each group, having the largest deviation in ambient environment (Others) for the novice driver group and the left side mirror for the experienced driver group. The novice drivers had a long stay in AOIs of vehicle controls, namely traffic lights, vehicles, navigation system, and dashboard, whereas the experienced drivers had equal stay times in all the areas of interest. The novice group spent a relatively long time in observing traffic lights (24.52 s), passing vehicles (24.67 s), navigation system (27.91 s), and the dashboard (28.18 s), except for others in the surrounding environment, but overlooked the pedestrian signal lights and the right-side mirror. On the other hand, the experienced group not only checked the right- and left-side mirrors (21.33 s and 18.53 s) and pedestrian signal lights (18.47 s), but spent a similar amount of time on surveying each of the entire AOIs while driving.

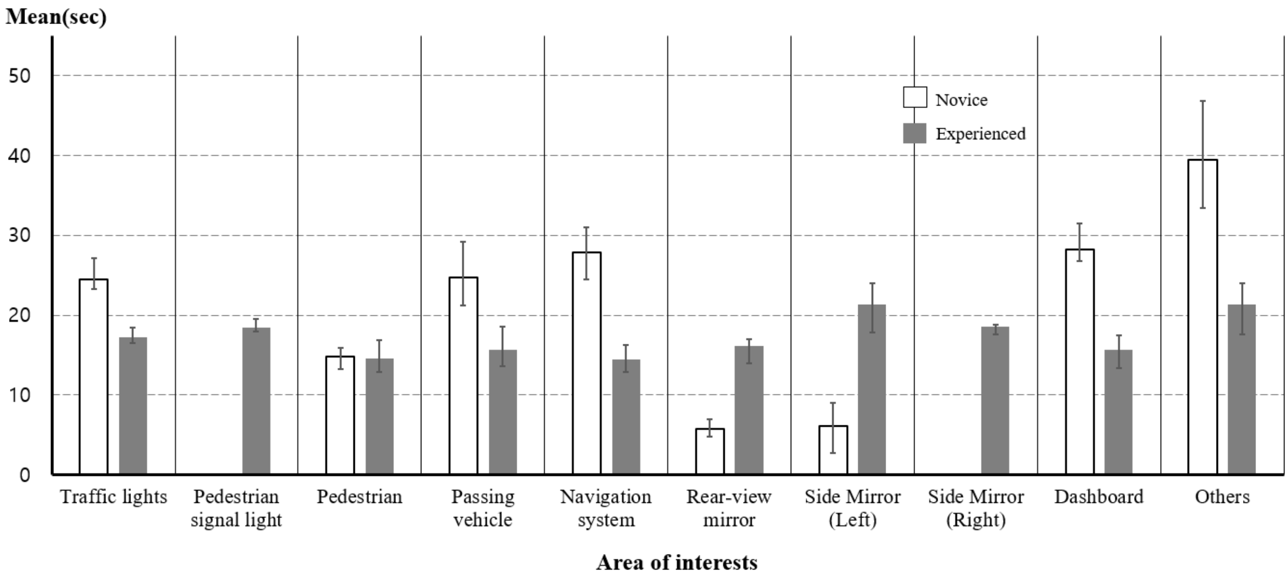


Figure 6. Average dwell time by area of interest for each group.

Each group's fixation duration, listed in Table 2, shows that the novice group (0.78 s) had a longer fixation duration than the experienced drivers (0.51 s). The inexperienced group fixed their gaze at relatively closer AOIs (navigation system, rear-view mirror, left side mirrors, and dashboard) to the driver's seat for a longer time than they did on the distant ones (traffic lights, pedestrians, and passing vehicle). Especially, among the areas, other than the objects they overlooked and others, they held their gaze on the left-side mirror for the longest time, resulting in the largest difference with the experienced group. The fixation duration of the experienced drivers averaged at 0.51 s, but the one on the traffic lights for pedestrians was estimated to be 0.92 s, which was relatively longer than the average.

Table 2. Average fixation duration by area of interest for each group.

Area of Interests	Novices (s)	Experienced (s)
Traffic lights	0.71	0.31
Pedestrian signal light	0	0.92
Pedestrian	0.64	0.41
Passing vehicle	0.76	0.39
Navigation system	1.12	0.51
Rear-view mirror	0.97	0.37
Side mirror (Left)	1.14	0.48
Side mirror (Right)	0	0.52
Dashboard	1.02	0.37
Others	1.41	0.94
Average time	**0.78**	**0.51**

For the number of fixations, a heatmap was adopted to illustrate how many times the drivers repeatedly observed AOIs at random while making a right turn after stopping at an intersection, and is shown in Figure 7. Figure 7a depicts a screen which shows a driver turning around a corner after making a left turn, and the area and size (pixel) of AOI. Also, a heatmap shows the visualized outcome of the frequency of gaze at each AOI per group. The more frequent the gaze was fixed on a certain AOI, the color of the area turned red and less frequent it turned green. As displayed in Figure 7b, the heatmap of the novice drivers suggested that they re-inspected mostly the front AOIs, such as passing vehicles and traffic lights. By contrast, the experienced group in Figure 7c rechecked not only the front areas but also the AOIs reflected on the right- and left-side mirrors.

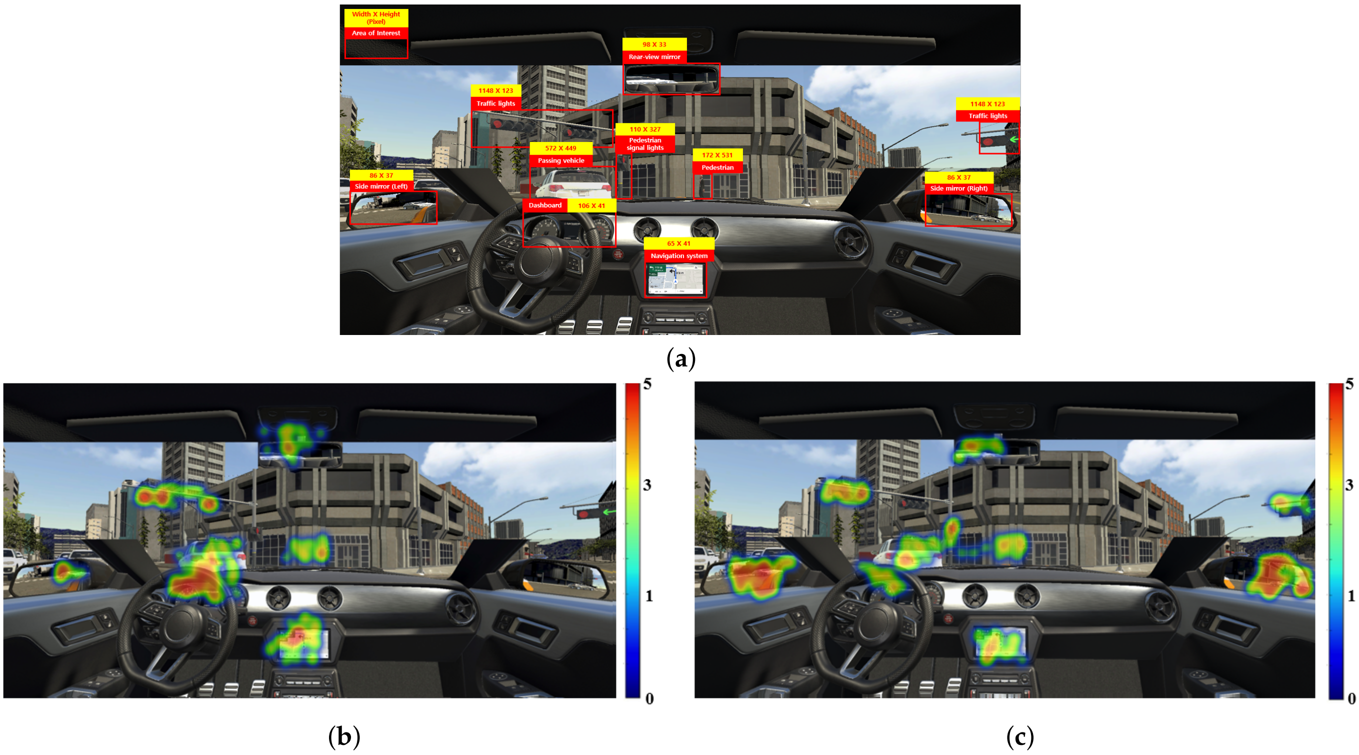


Figure 7. Number of fixations by AOI at intersection. (**a**) division and size of each AOI; (**b**) novice driver; (**c**) experienced driver.

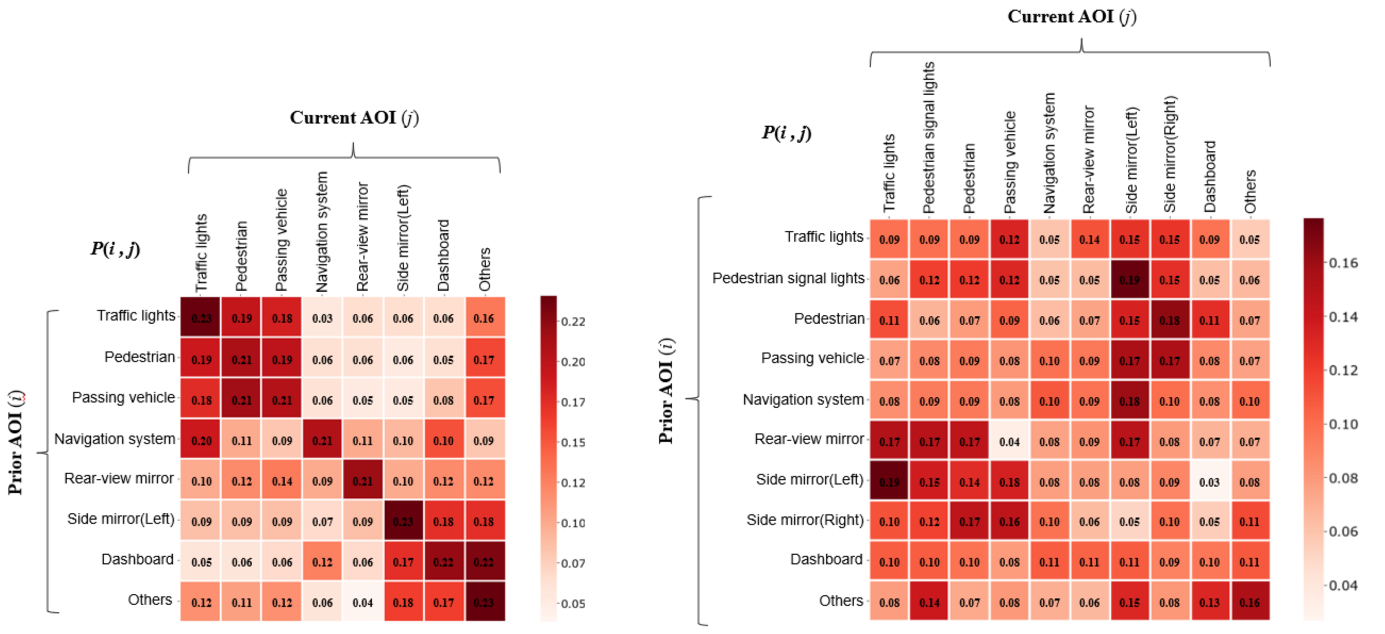
Each group's probability of gazing at each AOI and SGE were calculated using Equation (1), and the results are shown in Table 3. Here, the probability of gaze refers to a ratio of the frequency of gaze at each AOI at 30 Hz sampling rate to the frequency of gaze at all AOIs. In the present study, where ten AOIs were defined and the maximum SGE for a driver was set at 3.32 bits, the results showed that the novice driver group demonstrated each SGE of 2.60 bits, or 78 percent of the maximum value, whereas the experienced group displayed 3.09 bits, or 93 percent of the maximum. This suggests that the gaze of the experienced was relatively evenly distributed and not focused on a certain AOI, compared to the novice group.

3.2. Dynamic Analysis of Gaze

The dynamic analysis of the drivers' gaze used a transition matrix that showed a transition of their gaze from one AOI to the next one, as indicated in Figure 8. The Figure shows that as more transitions were made, the color turned darker. In Figure 8a, which suggests a transition matrix of the novice group, gaze transitions were observed in diagonal direction not only between the traffic-related AOIs (traffic lights, pedestrians, and passing vehicles) and the ones inside the vehicle (dashboard and side mirrors), but also between the two consecutive AOIs. In addition, the experienced group were engaged in more gaze transitions between the right- and left-side mirrors and the rear-view mirror to examine the surrounding road conditions, and Figure 8b suggests that the transitions were evenly made across the entire AOIs. In general, the novice group conducted a visual search in the physically close AOIs, whereas the experienced group carried out a visual search frequently to assess the traffic situations. For estimation of GTE that represents the amount of information indicating gaze transitions, Equation (2) was used, and the results showed that the novice group had a lower GTE (2.21 ± 0.19 bits) than the experienced group (3.04 ± 0.16 bits). In addition, independent sample *t*-tests on the novice and experienced driver groups revealed statistically significant differences (t(22) = 4.24, p = 0.02), and small effect size (Cohen's d = 0.51). This signified that the novice drivers were not as various as the experienced group in observing the surrounding objects.

Table 3. Probability distribution by area of interest and SGE.

Area of Interests (i)	Novice		Experienced	
	Freq. (n)	Probability (P_i)	Freq. (n)	Probability (P_i)
Traffic lights	572	0.12	484	0.10
Pedestrian signal light	0	0	683	0.13
Pedestrian	224	0.05	297	0.06
Passing vehicle	643	0.13	286	0.06
Navigation system	683	0.14	253	0.05
Rear-view mirror	143	0.03	637	0.12
Side mirror (Left)	167	0.31	727	0.15
Side mirror (Right)	0	0	344	0.07
Dashboard	794	0.16	290	0.06
Others	1747	0.35	980	0.20
Total	4973	1	4981	1
SGE	**2.60**		**3.09**	



(a) (b)

Figure 8. The transition matrix of drivers' gaze from one AOI to the next. (**a**) novice driver; (**b**) experienced driver.

4. Discussion

Generally, drivers engage in a visual search to find out the road conditions and traffic situations, and to avoid any potential hazards, but novice or older drivers with low cognitive ability may be involved in a car accident as they repeat the process of examining the same object to have an accurate assessment of it or an AOIs, or obtain insufficient information due to inadequate visual search. The current study aimed to propose a method to differentiate at-risk drivers who are highly likely to cause an accident by conducting static and dynamic analyses on gaze and comparing the information obtained from the visual search depending on the levels of driving experience. The indicators used for the static analysis on gaze included dwell time, fixation duration, and the number of fixation and SGE, whereas the dynamic analysis adopted GTE. The driving performance assessment was carried out using a VR driving simulator based on a scenario involving an intersection where visual properties were abundant.

The static analysis of gaze indicated that for the dwell time, the novice group tended to hold their gaze at a certain AOI for a long time, which means that they spent a long time on searching the driving route and dangerous elements. Meanwhile, the experienced group displayed a relatively even distribution, signaling that they spent time on surveying the overall surrounding traffic situations on the road they were on. In terms of fixation duration, the novice drivers displayed a longer duration than the experienced driver, spending the longest time on observing the left side and rear-view mirrors. In other words, they spent a long time on gauging the distance between their vehicle and those behind and on the sides. In addition, the experienced group had a short fixation duration on average, but they spent the longest time on the traffic lights for pedestrian, which could be understood as their attempt to predict the next traffic light signal. When it comes to the frequency of fixation, the most frequently checked AOIs by the novice group when they made a right turn at an intersection were the passing vehicles and pedestrians. By contrast, the experienced drivers looked at the right- and left-side mirrors more frequently than the others. In other words, the novice group tended to look what was before them repeatedly, while the experienced group was more likely to survey the AOIs on their right and left sides more frequently. The estimates of SGE indicated that the experienced group processed a larger amount of information than the novice and recorded a high entropy due to low gaze density as they drove while giving similar visual attention to the entire AOIs. Therefore, the static analysis illustrated that the novice group tended to spend a long time on collecting information by gazing at a certain object and to engage in more visual inspections in the front areas, whereas the experienced group showed a tendency to rapidly identify the entire objects and survey the surrounding objects related to traffic conditions. These results are supports that the novices scan the roadway less than experienced drivers tending to focus on the road directly ahead of them, as reported by Underwood. in 2007 [37].

In the transition matrix that represented the dynamic analysis of the novice group, the largest number of gaze transitions were made between traffic lights, pedestrian, and passing vehicles, while dynamic analysis of the experienced group suggested that the most transitions took place between the right- and left-side mirrors and traffic-related AOIs. In other words, the gaze transition of the novice driver group focused mainly on visual search between the areas of interest at close distance, and the gaze transition of the experienced driver group focused on visual search to check the surrounding traffic conditions for vehicle driving. Since the experienced drivers mainly search for objects around their own vehicle, the area which the driver gazes changes in every face-to-face situation, increasing randomness. Muela et al. in 2021 showed that experienced drivers anticipate dangerous situations more effectively by directing their attention towards areas of the traffic scene more likely to yield hazards and that these characteristics could effectively predict danger [38]. This means that a larger entropy is required to explain their visual search strategy.

5. Conclusions

The results of time and number of traffic-related objects that the drivers stare at while driving as well as the entropy from their gaze change can be used as basic data for indicator research to identify the drivers who need driving practice. However, since the participants in this study were only male drivers, additional experiments are needed to study the difference in visual search by gender, and precise data collection at sufficient sampling rates is required for more accurate measurements, as the sampling rates were set at 30 Hz. In future studies should be conducted to calculate the appropriate sample size by power analysis and analyze the magnitude of the effect of the driver's line-of-sight evaluation. In addition, it should be conducted to identify hazardous drivers by comparing and analyzing differences in gaze search patterns according to age and differences between them through more sample collection for elderly drivers and experiment on various driving situations other than intersections [39]. Then it will be possible to establish an objective standard for driver's license return policy focusing on the policy of voluntarily returning driver's licenses by judging the drivers themselves so far in Korea.

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