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Design System of Driving Scenario by Applying Static and Dynamic Stimuli in VR Driving Simulator Based on Text Network Analysis

Ho-Sang Moon[1], Hyeok-Min Lee[1], Sung-Taek Chung[2]

[1] Department of IT Semiconductor Convergence Engineering, Korea Polytechnic University, Korea
[2] Department of Computer Engineering, Korea Polytechnic University, Korea

unitaek@kpu.ac.kr

Abstract. The aim of the present study is to create driving environments and scenarios for a VR-based driving simulator to quantitatively evaluate visual behavior of elderly drivers as response against a static or dynamic visual stimulus. To this end, a driving simulator was developed to collect relevant publications which contained complete analysis of driving characteristics of elderly drivers. Centrality was analyzed between the keywords of the driving environments and scenarios used in this study. Furthermore, the scenarios were recategorized as visual behavior, visual detection, visual perception, and visuomotor function by establishing a text network upon a static or dynamic visual stimulus, resulting in total 12 scenarios of the final publications collected after the removal and merging process. The 12 driving simulation contents implemented based on the study results included intersections with or without traffic signals and driving environments of the two-lane and four-lane roads, which were employed to assess the visual behavior of the drivers against a targeted stimulus using quantitative assessment indicators, such as number of gaze fixations, the time taken for the saccade, and behavioral response time. The method presented in this study is expected to predict the possibility of dangerous driving behavior of elderly drivers induced by a visual stimulus and can be used as a basis to establish an environment for driving stimulators with a view to identifying at-risk drivers well ahead.

Keywords: Driving simulator, elderly driver, static and dynamic stimuli, text network, visual behavior

1. Introduction

Due to low physical strength and narrow range of vision, elderly drivers find difficulty in making quick, accurate decisions and responding accordingly while driving. This leads to frequent traffic accidents and the number of such accidents are increasing worldwide with increasing number of elderly drivers (Bernadette A. et. el., 2021). To address this issue, the US has different sets of aptitude test procedures and driver's license renewal frequencies for elderly drivers in every state, while Australia requires the elderly drivers aged more than 80 years submit their visual and hearing test results every year to the license supervisory authority. On the other hard, New Zealand revokes the license of those who are older than 80 years, whereas Japan has a mandatory traffic safety training session operated by each city or province for the elderly aged 75 or more during their license renewal (Anu Siren, Sonja Haustein, 2015). In South Korea, an older driver voluntarily returns his driver's license when he experiences cognitive decline or fails to meet the aptitude test criteria, such as visual acuity, that are mandatory requirements for license renewal. The common objective of the above-mentioned systems of different countries is to enable the elderly drivers to renew or return their drivers' license without any objective assessment of their driving capability. This automatically calls for a system which would have an objective evaluation on various factors contributing to the driving capability of the elderly drivers.

Generally, processing of drivers' information on driving environment consists of four stages, viz. detection and perception, confirmation, decision, and response. Especially, older drivers are more likely to experience a traffic accident as they need more time to perceive and decide due to their physical deterioration (Theodore J. Post, et al., 1981). Most of the information related to driving is visual data, which in turn are closely related to attention, executive function, and visual perception (Cynthia Owsley, Gerald McGwin Jr., 2010)-(Nicole A. Matas, Ted Nettelbeck, Nicholas R. Burns, 2014). A decline in visual perception, important for quick detection and response to an object or other vehicles while driving, is one of the major reasons for traffic accidents by elderly drivers. Visual perception refers to the visual behavior exhibited by a driver after he perceives any information coming from a visual stimulus, and is categorized as visual detection, visual perception and visuomotor function (Qian Chayn Sun et. el., 2018). Visual detection refers to the step in which a driver collects various sets of information via visual inspection while driving. In this regard, the elderly drivers show a narrow area of interest and tend to rescan the same area more frequently (Shan Bao, Linda Ng Boyle, 2009). Visual perception signifies the step in which a driver perceives, analyzes and assesses an external stimulus to properly respond to it. In this respect, the older drivers have weak cognitive functions and thus displays a declined visual perception. This makes them slow in processing the information from the stimulus, and therefore, they take longer time than the younger drivers to respond (Marcin Piotr Biernacki, Rafal Lewkowicz, 2021). Visuomotor function refers to the step where a driver properly controls the vehicle after the perception step and can be measured by the driver's maneuvering of steering wheel and brakes as a response to a stimulus. After the vehicle is controlled accordingly, the driver repeats observing the surrounding area and gathering visual information, and this sequence of actions is continuously repeated while driving. Studies of visual behavior reported so far have been done using virtual driving simulation guaranteeing relatively better safety for the target involved in an experiment than the use of vehicles on an actual road and offering a controlled environment with fewer practical restrictions, such as time-related or spatial costs required for establishing an environment for the experiment. Especially, an eye tracking device is widely used which can analyze driving capabilities against both static visual stimuli of fixed objects (e.g. traffic signals, traffic signs, and stopped vehicles) and dynamic ones of moving objects (e.g. pedestrians, animals, or moving vehicles) (David B. Carr, Prateek Grover, 2020) (Qian Chayn Sun et. el., 2018).

Against such backdrop, the present study collected literatures on driving capabilities of elderly drivers using a driving stimulator that had been completed by June, 2020, and analyzed the relevance by type of accidents, driving environments, and visual behavior using a text network algorithm. A text-network-based analysis is analysis of relations between the keywords composing the text to produce and visualize a network. The analysis also gives the frequency of a word appearing in the text and their individual attributes (Youngji Kim, Soong-nang Jang, 2018). It further provides information on relative influence of each text, which cannot be found from the information on the frequency, by recombining or reanalyzing keywords in the text after processing and refining them (Eileen Kowler, 2011). Scenarios reflecting different driving environments from the collected set of literatures that shared similar contents or exhibited similar types were merged and the visual stimuli were categorized into static and dynamic objects to be expressed in text network regarding visual behavior categorized as visual detection, visual perception, and visuomotor function. Lastly, a virtual driving simulator equipped with a gaze tracking device was constructed to generate various driving environments and quantitatively analyze each driver's response to the static and dynamic stimuli. The results of this study are expected to be used as a fundamental tool to identify and quantitatively assess at-risk elderly drivers and at the same time encourage them to voluntarily return their driver's license.

2. Methods and materials

2.1. Apparatus

In the current study, driving simulation contents were applied using a gaze-trackable pro eye model of Vive that featured a 3.5-inch screen having 1440 × 1600px resolution and 90Hz regeneration ratio. This enabled collection of information relevant to users' gaze, such as gaze tracking up to a viewing angle of 110˚ and gaze direction, location and size of the pupils, and eye blinking. To apply the simulation contents, Logitech's Driving Force G29 was employed to enable the drivers to control the steering wheel, a lever with an H-type shift pattern, an accelerator and a brake pedal. The entire content-based scenarios were produced through an Unity3D engine attached to a system equipped with a CPU (4.2GHz), a 16-gigabyte memory, and a GPU (1.58GHz). Using this system, the drivers were asked to drive through a virtual road and their responses to static and dynamic visual stimuli were captured and evaluated.

2.2. Searching methods of published papers

To collect the relevant published papers, the most frequently-used academic database were chosen and the relevant ones on recent study trends were selected, rejecting the overlapped ones. The academic databased used were PubMed(NCBI), EMBASE, PsyINFO, Web of Science, and Science Direct, and the period chosen for the analysis was up to June, 2020. The literature search was done using the following filters: types of research, types of participants, types of interventions, and types of experiment results.

The filter– type of research involved studies from Science Citation Index (SCI) that used a driving simulator to evaluate the driving capabilities of elderly drivers and the dangerous driving situations they faced. Literatures on quality vehicle systems, such as autonomous driving systems and Head Mounted Display (HMD) systems, or government systems regarding road design or traffic issues and road environments were deemed irrelevant and excluded from the study.

For the type of participants, studies with more than ten participants or with statistically significant classifications between men and women were considered for verification of statistical significance as the participants' driving capabilities might have been compromised due to age-related decline in their physical and cognitive skills. However, literatures with participants aged 60 or older on average and suffering from trauma or diseases such as heart diseases, muscular atrophy, or optical diseases including glaucoma, were deemed unable to drive and were excluded. In addition, studies which involved participants without a driver's license or with history of driving under the influences (DUIs) or of driving while asleep due to drug abuse or fatigue were excluded as they were less relevant to driving problems caused due to decline in physical and cognitive capabilities because of aging.

For the filter– type of interventions, studies that used a driving simulator or compared driving with an actual car using a simulator were included, whereas those which used a simulator of two wheelers, such as motorcycles or bicycles, were excluded as they were of different physical characteristics. In addition, the following research studies were excluded as they did not share the purpose of this study: Besides the above-mentioned studies, work which focused on R&D efforts on function maneuvering and capabilities of a driving simulator; and literatures which did not present any details of collision and dangerous driving situations; or dealt with cases of driving an actual vehicle were not considered.

For studies filtered by experiment result, those that evaluated the level of attention, concentration, and response time in the face of an accident or a dangerous situation were included. On the other hand, the studies which compared the capabilities of drivers before and after driving training, or the ones which focused on improving the design of traffic systems and road environments as a way to resolve issues triggered by physical and cognitive decline, or those that investigated ways to enhance the design of vehicle structure and system for safer driving were all ignored and not included.

2.3. Keyword classification and literature identification

The keywords used to search different published papers are listed in Table 1. The search was done within five academic databases which resulted in a collection of 1453 papers in total, with 243 studies from EMBASE, 281 from PsyINFO, 206 from PubMed, 487 from Science Direct, and 236 from Web of Science. Among these, 263 studies came up in more than one database either with the same title or the same name of authors. They were counted as duplicate, making the total number of collected studies as 1190. Next, the title and abstract of these papers were reviewed to exclude those which did not satisfy the criteria for inclusion based on the literature search strategies, and 197 studies were chosen which targeted older drivers and used a driving simulator to assess the correlations with traffic accidents. Among them, the following studies were excluded– 68 literatures that did not share the purpose of the study, 2 which were not reported in English, 4 that did not provide access to the entire article, 63 with participants aged less than 60 on average, 23 that focused on comparative analysis of the diseases that the group of drivers had, 5 that compared driving done in an actual car versus in a simulator, and 3 that did not specify the collision and driving situations. After all exclusions, the final total number of studies selected was 29.

Table1: Searching strategy and keywords

<table>
<tr><td colspan="4">DB : EMBASE, PsycINFO, PubMed, Science Direct, Web of Science
Years of research searched : ~ 2020.06
Limits : English Language, SCI
Search Equation : (A (NOT B) AND C AND D)</td></tr>
<tr><td>A(Participants)</td><td>B(Diseases)</td><td>C(Interventions)</td><td>D(Outcomes)</td></tr>
<tr><td>aged/
aging/
drivers/
elderly/
older/
senior/</td><td>chronic disease/
drunk/
drug/
heart attack/
underlying disease/</td><td>computer/
simulation/
simulator/
video/
vr/</td><td>accident/
cognitive/
crash/
hazard/
scenario/
traffic
unsafe/</td></tr>
</table>

2.4. scenario design from analysis of text network using r

In general, density, average distance, and centrality are the 3 mostly used indicators in an analysis to figure out the characteristics of the keywords correlated with one another in a text network, but again among these, centrality is the most popular one. Centrality is an indicator which expresses the level of importance of a major keyword in the entire network, which includes degree centrality and betweenness centrality.

Degree centrality is measured as the number of all edges that are connected to one node in the network. In other words, it signifies the level of connection between one keyword and the others; so, higher the size of a keyword, the more connective relationships the keyword has. The degree centrality C_{d_i} of a random node i can be calculated from equation (1), where d_{ij} refers to the number of edges connected to another node j other than the node i itself, N is the total number of nodes in the network.

$$C_{d_i} = \sum_{j=1}^{N-1} d_{ij} \quad \begin{cases} i \neq j \\ i = 1, 2, \cdots, N \end{cases} \tag{1}$$

Betweenness centrality signifies how intermediary a node is to other nodes in the network, indicating the level of its involvement in expanding the flow of meaning among other keywords or in controlling the network structure. Betweenness centrality C_{b_i} of a random node i can be estimated from equation (2), where g_{jk} refers to the number of shortest routes between node j and node k, and N is the total number of nodes in the network. $g_{jk}(i)$ signifies the number of cases where the shortest routes between node j and node k go through node i.

$$C_{b_i} = \sum_{j=1}^{N-1} \frac{g_{jk}(i)}{g_{jk}} \quad \begin{cases} i \neq j < k \\ i = 1, 2, \cdots, N \end{cases} \tag{2}$$

The 29 selected literatures were analyzed in terms of both degree centrality and betweenness centrality of driving environments per accident type of the driving simulation contents and scenarios reflecting such environments. The visualized results are depicted in Fig. 1. The keywords and relations between them are expressed as circles and lines, respectively as visual representations, and here is how to interpret them– the higher the degree centrality, the larger the size of a circle, and the higher the betweenness centrality, the thicker the lines drawn.

Among the accident types classified as Single-Car, Car to Car, Car to Pedestrian, and Car to Animal (see Fig. 1), the Car to Car accident type had the largest degree centrality and betweenness centrality (largest circle, thickest line). Also, among the 3 driving environments, classified as intersection, road, and highway, the intersection and the highway showed relatively high degrees of centrality, whereas in regard to betweenness centrality, the highway associated with the Car to Pedestrian accident type and the intersection and road connected to the Single-car accident type were relatively high. In the scenarios reflecting the driving environments, degree centrality was the highest for ‘Turning Left’ and ‘Cross-Traffic Collision’ at the intersection, and in particular, the case with a traffic light (controlled) was higher than the case without a traffic light (uncontrolled). The betweenness centrality was found to be high for two lane and four lane roads connected to the highway and for intersection without a traffic signal. The scenarios associated with driving environments of ordinary roads also demonstrated similar results.

From the text network analysis results in Fig. 1, scenarios of different driving environments, such as a signal-controlled intersection, signal-uncontrolled intersection, two-lane one-way roads, four-lane two-way road, and three-lane one-way road, have been shown in Table 2. Based on these results, we implemented our driving simulations so that a driver's visual behavior can be evaluated meaningfully against certain static and dynamic visual stimuli in an urban driving environment.

In this context, certain scenarios such as appearance of an animal, driving in a one-way lane, evaluation of the driver's specific cognitive domain (e.g. peripheral detection while driving, visual and auditory reaction, visual memory, etc.), and evaluation of the ability to control vehicle functions (e.g., selecting or finding a road, just driving, and following and overtaking a car in front) have been excluded and shown in bold in Table 2.

Table 2: Scenarios according to driving environments of 29 literatures

Road Type	Driving Scenario		Description	Road Type	Driving Scenario		Description
Controlled intersection	1	Stop or go	Stop by traffic light red light	Uncontrolled intersection	1	Turning left/right	Turning scenario with an emergency situation
	2	Following the front car	Evaluate whether the distance is maintained while driving following the leading vehicle		2	Sudden brake	Check and react to the sudden brake of front car
					3	Cross-traffic collision	Recognize and react to oncoming vehicle during turning left
	3	Sudden brake	Recognize and react to the sudden brake of front car		4	Checking stalled car	Avoiding stalled car on the shoulder after exiting the intersection
	4	Jaywalk	Pedestrian collision scenario		5	Cut in line	Changing lanes after vehicles have passed

	5	Cross-traffic collision	Recognize and react to oncoming vehicle during turning left	2-lane highway	1	Turning left	Evaluate visual detection during driving without unexpected event
	6	Reversing vehicle collision	Recognize and react to oncoming vehicle while going straight		2	Sudden brake	Check and react to the sudden brake of front car
	7	Avoiding stalled car	Avoiding stalled car on the shoulder after exiting the intersection		3	Jaywalk	Pedestrian collision scenario
	8	Turning left/right	Evaluate visual detection during driving without unexpected event		4	Crosswalk	Same as jaywalk
	9	Way finding	Evaluate whether driver is recognizing traffic signs and driving in the right direction		5	Reversing vehicle collision	Recognize and react to oncoming vehicle while going straight
	10	Peripheral detection task	Gathering gaze distraction for peripheral detection during driving		6	Avoiding stalled car	Avoiding stalled car on the shoulder after exiting the intersection
	11	Auditory reaction task	Response to auditory stimuli presented during driving		7	Following the front car	Evaluate whether the distance is maintained while driving following the leading vehicle
	12	Visual reaction task	Response to visual stimuli		8	Overtaking	Same as following the front car

			presented during driving				
4-lane highway	1	Turning left/right	Evaluate visual detection during driving without unexpected event		9	Periphera l detection task	Gathering gaze distraction for peripheral detection during driving
					10	Auditory reaction task	Response to auditory stimuli presented during driving
	2	Sudden brake	Check and react to the sudden brake of front car		11	Visual reaction task	Response to visual stimuli presented during driving
	3	Jaywalk	Pedestrian collision scenario		12	Visual memory task	Memory of visual stimuli presented during driving
	4	Avoidin g stalled car	Avoiding stalled car on the shoulder after exiting the intersection		13	Cut in line	Changing lanes after vehicles have passed
	5	Followin g the front car	Evaluate whether the distance is maintained while driving following the leading vehicle		14	Lane change	Changing lanes after detecting surroundings
	6	Overtaki ng	Same as following the front car		15	Speed limit	Recognize traffic signs and slow down
	7	Peripher al detection task	Gathering gaze distraction for peripheral detection during driving		16	Traffic lights	Reaction to the red light of a traffic light
	8	Auditory reaction task	Response to auditory stimuli		17	Dog emergen ce	A scenario in which an animal

			presented during driving				suddenly appears
	9	Cut in line	Changing lanes after vehicles have passed		18	Water deer emergence	A scenario in which an animal suddenly appears
	10	Lane change	Changing lanes after detecting surroundings		19	Just driving	Driving without unexpected event
	11	Lane change to secondary road	Same as Lane change	3-lane highway	1	Avoiding stalled car	Avoiding stalled car on the shoulder after exiting the intersection
	12	Just driving	Driving without unexpected event		2	Following the front car	Evaluate whether the head distance is maintained while driving following the leading vehicle

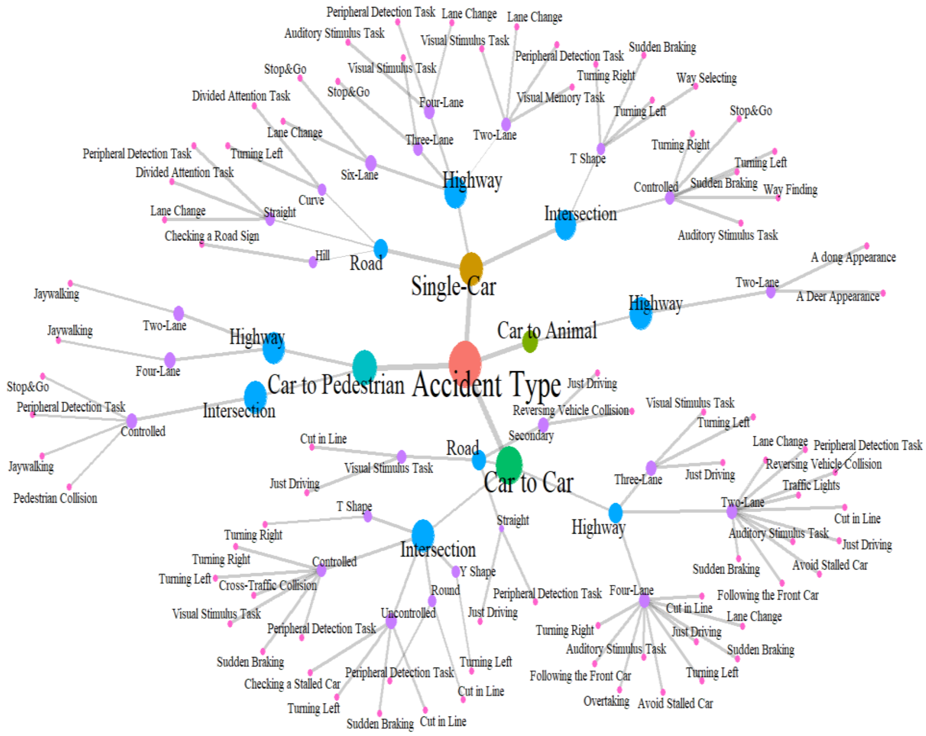
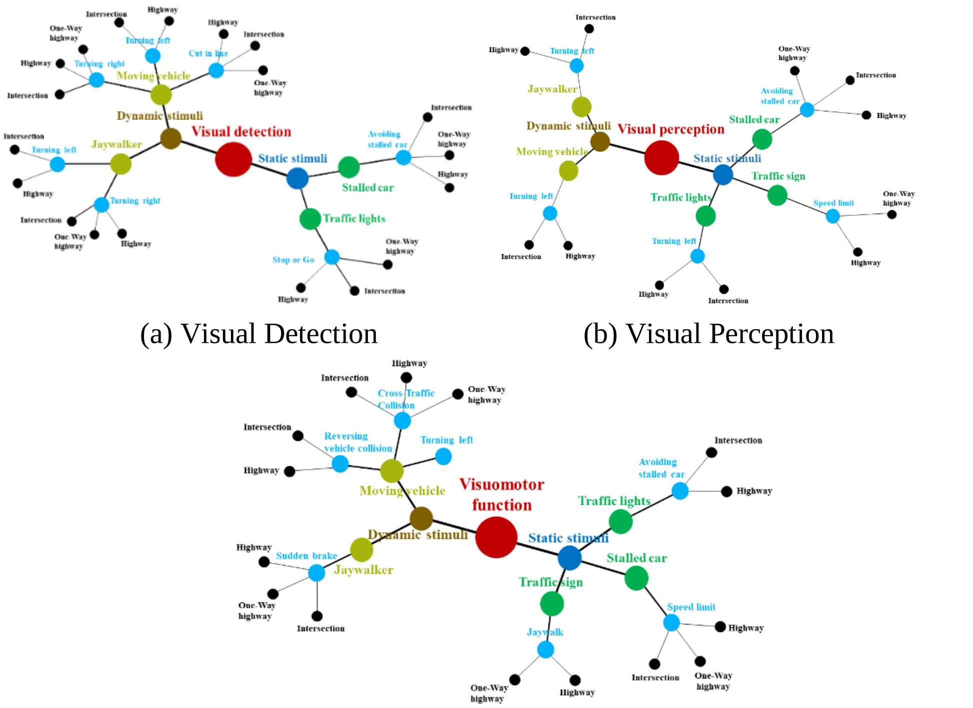


Fig. 1: Text network visualization of driving scenarios by accident type

Based on the newly classified scenarios, the text network was analyzed in terms of visual detection, visual perception, and visuomotor function against static and dynamic visual stimuli, and the visualized results of the recategorized driving environments and scenarios are summed up in Fig. 2. As shown in Fig. 2(a), for visual detection scenario against static visual stimuli, ‘Stop or Go,’ an action to detect a change in the traffic light that appears near the driver was selected, whereas for the ones against dynamic visual stimuli, ‘Cut in line’, ‘Turning Left’, and ‘Turning Right,’ actions requiring detection of a change in the surrounding environment of the driving vehicle were chosen. Visual perception assesses a driver’s response to an external stimulus after perceiving, analyzing and making a decision on what to do about it. As depicted in Fig. 2(b), ‘Speed Limit,’ a non-stimulating sign as a static visual stimulus involving no change unlike traffic lights or a taillight of a vehicle, and ‘Avoiding Stalled Car’ were selected to be integrated into the scenarios. Visuomotor function refers to perception and response to an external stimulus. Instead of a static visual stimuli, ‘Reversing vehicle collision’ from the dynamic visual stimulus scenario, which enables assessment of a behavioral response to an unpredictable situation and ‘Sudden Brake’ of a car in front, and ‘Jaywalk’ were adopted in the scenario(s), as shown in Fig. 2(c).



(a) Visual Detection (b) Visual Perception

(c) Visuomotor Function

Fig. 2: Text network analysis of static and dynamic visual stimuli by visual behavior

Overall, the scenarios designed to evaluate a driver's visual behavior against static and dynamic visual stimuli were merged together when they shared similar types and contents to establish more frequently occurring driving environments with more visual stimuli. For example, 'Reversing Vehicle Collision' occurs more frequently in two-lane one-way roads than at an intersection, so the two-lane one-way road condition was adopted for a scenario.

Table 3: Driving environments and scenarios finally selected

Road Type		Driving Scenario
Intersection	Controlled	Stop or go
		Sudden braking
		Jaywalking
	Uncontrolled	Turning left
		Turning right
Highway	Two-lane	Reversing vehicle collision
		Speed limit
		Stop or go
	Four-lane	Sudden braking
		Jaywalking
		Avoid stalled car
		Cut in line

Likewise, ‘Turning Left’ and ‘Turning Right’ were adopted in the signal-free intersection scenario, because for an interaction or a four-lane two-way road, visual detection while driving was assessed as they posed no unexpected elements and because an interaction without signals enabled evaluation of visual behavior against dynamic visual stimuli, such as moving vehicles and crossing pedestrians. Furthermore, since ‘Sudden Brake’, ‘Jaywalk’, or ‘Stop or Go’ are used to estimate a different aspects of driving environment and visual behavior, all three were reflected in two different driving environments. After the merging process, the finally chosen driving environments and 12 scenarios are listed in Table 3.

3. Results

3.1. Driving evaluation

The driving simulation contents created in the current work were used to assess the driving capabilities of aged drivers based on their visual behavior against static and dynamic visual stimuli in a VR environment. The information on a driver's gaze in response to various stimuli was acquired from the eye tracker mounted on an HMD, such as gaze fixation and saccades, and the one on behavioral response in controlling the vehicle they drive came from the steering wheel and pedal of a simulator. From all the information gathered from the above-mentioned tests we formed a set of indicators to assess the driver's driving ability, as shown in Table 4. Gaze fixation means that a driver stops temporarily at a location for more than 100~200ms to survey the surroundings, and saccade signifies the distance or a temporal interval created when the center of gaze shifts from one spot to another (Tania Dukic, Thomas Broberg, 2012). Visual detection, an evaluation indicator, was obtained from the ratio of stimuli detected by the driver to the total stimuli, while visual perception was measured by the response time taken from the appearance of a target object to the fixation of the gaze on the target. In addition, visuomotor function refers to the time taken from visual detection of the targeted stimulus to behavioral response, such as vehicle control.

Table 4. Measurement Methods and Evaluation Factors

Measurement	Tool	Description	Unit	Method
Visual Detection	Eye Tracker	Number of gaze fixations on static and dynamic visual stimulus targets	%	$\frac{b}{a} \times 100$
Visual Perception	Eye Tracker	Saccade time according to the change of static and dynamic visual stimulus target	ms	$d - c$
Visuomotor Function	Steering Wheel	Reaction time from saccade to steering wheel operation	ms	$e - d$
	Brake Pedal	Reaction time from saccade to brake pedal operation	ms	$f - d$

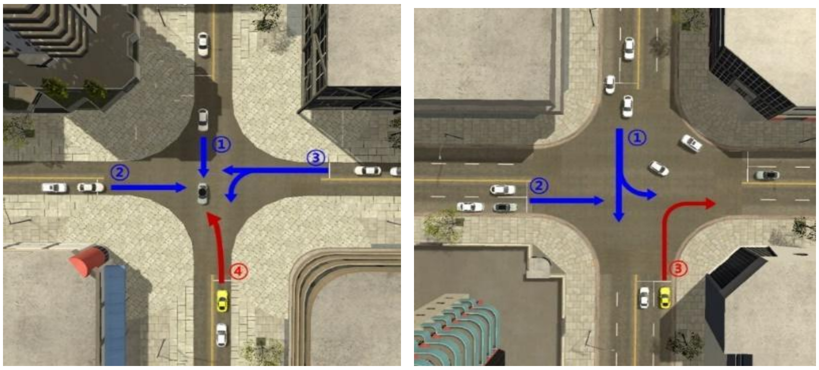
Note: **a** is number of presented target stimuli; **b** is number of target stimuli with gaze fixation; **c** is time at which the target stimulus was presented; **d** is gaze fixation time for target stimulus; **e** is time of the handle operation occurred; **f** is time of brake pedal worked;

3.2. Implemented contents: uncontrolled intersection

The contents regarding intersection without signals that rely on drivers' visual detection without any aid from the traffic system, such as traffic signals, consisted of 'Turning Left' and 'Turning Right' scenario(s), which were designed to assess the drivers' visual detection capability from the number of gaze fixations (***Note b*** in Table 4) against a presented target stimulus (***Note a*** in Table 4), i.e., the surrounding vehicles as a visual stimulus.

The stimuli presented for 'Turning Left' and 'Turning Right' are as follows– two vehicles on the other side, three vehicles on the right and left and five vehicles on the other side, and two vehicles on the left. The driver's gaze should be fixed on the target for more than 100~200ms to constitute a single gaze fixation. The ratio of the number of target stimuli presented here to the number of target stimuli on which the gaze is fixed served as an indicator of visual detection capability.

In Fig. 3(a), reflecting the 'Turning Left' scenario, vehicle ④ aims to turn left without any collision after sufficient visual detection of the driving route and speed of Vehicle ① on the other side and Vehicle ② and ③ on its right and left. Here, the numbers ①, ②, and ③ in Fig. 3(a) represent not only vehicles but also the sequence of their entry into the intersection. Likewise, Fig. 3(b) reflects the 'Turning Right' scenario, in which the driver aims to turn right without any collision with other vehicles nearby, same as the one for 'Turning Left.'



(a) Turning Left (b) Turning Right

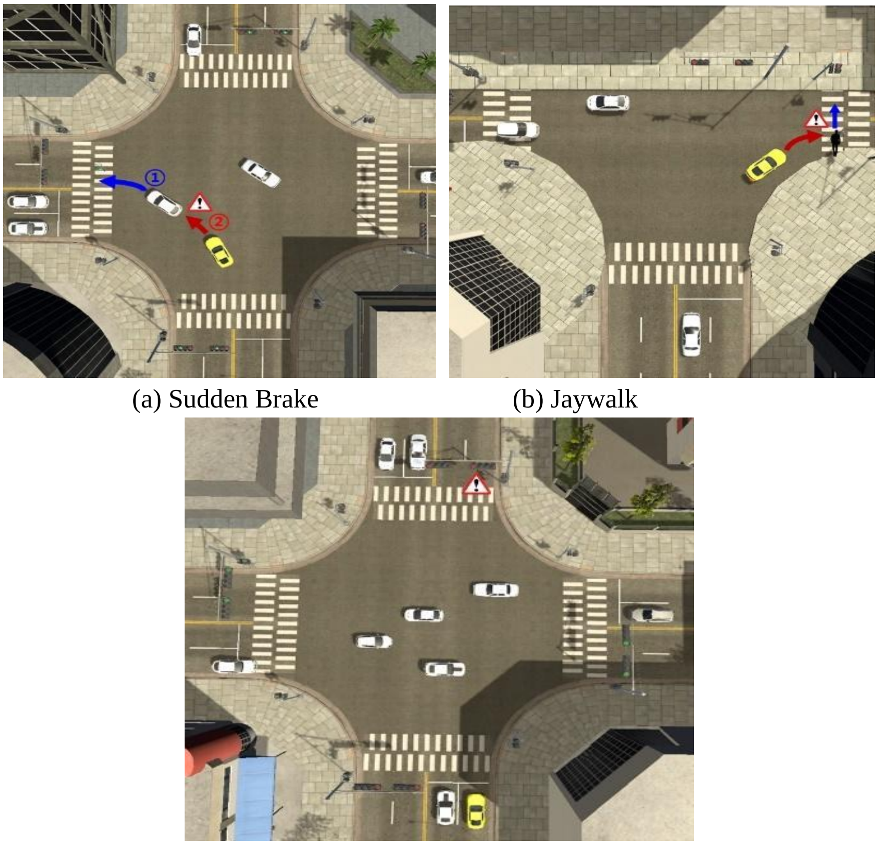
Fig. 3: Uncontrolled intersection scenario

3.3 implemented contents: controlled intersection

For intersections with signals, 'Sudden Brake', 'Jaywalk', and 'Stop or Go' were reflected in the scenarios. The scenarios associated with 'Sudden Brake' and 'Jaywalk' were used to evaluate the visuomotor function presented to the driver, such as cars in front or pedestrians, whereas scenarios with 'Stop or Go' was employed to assess the visual detection of a target stimulus coming from the traffic signals.

First, the 'Sudden Brake' scenario in Fig. 4(a) was aimed for Vehicle ② to turn left without any collision while surveying Vehicle ① in the front, the taillight of Vehicle ① serving as a major target stimulus. Here, the visuomotor function was evaluated by measuring the time taken from the moment of saccade to the behavioral response manifested in maneuvering of the steering wheel (***Note e*** in Table 4) and the use of the brake pedal (***Note f*** in Table 4). To note, the saccade signifies the difference between the moments when the taillight was on (***Note c*** in Table 4) and when it was perceived (***Note d*** in Table 4).

In the 'Jaywalk' scenario, a driver turned right and passed an intersection upon the perception of a jaywalking pedestrian without colliding with him, as shown in Fig. 4(b). Similar to the 'Sudden Brake' scenario, a pedestrian here appears all of a sudden from the pavement located on the right side of the driver's vehicle. The pedestrian served as a major target stimulus to measure the time taken to push down the brake pedal or maneuver the steering wheel after the saccade. The 'Stop or Go' scenario in Fig. 4(c) was designed to see if the driver perceived red light from the traffic signals by visual detection and stopped the car before it reached the stop line. Here, the four LED lights in green, yellow, and red, placed across the driver's vehicle, were presented as major target stimuli (***Note a*** in Table 4), and the number of gaze fixations on the flashing LED light (***Note b*** in Table 4) was measured to estimate the level of the driver's visual detection of the traffic signals.



(a) Sudden Brake (b) Jaywalk

(c) Stop or Go

Fig. 4: Controlled intersection scenario

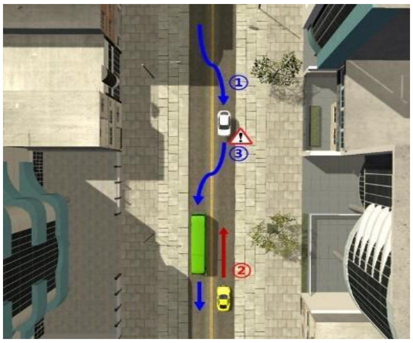
3.4. Implemented contents: two-lane highway

For the two-lane one-way road, 'Reversing Vehicle Collision', 'Speed Limit' and 'Stop or Go' were presented as scenarios. First, the 'Reversing Vehicle Collision' scenario is depicted in Fig. 5(a) to assess the response time taken from the moment at which the driver in Vehicle ② recognizes Vehicle ① to cross the central line and move in the opposite direction, to the behavioral reaction of pushing down the brake pedal. The moment when Vehicle ① touched the central line (***Note c*** in Table 4) was deemed as the target stimulus was presented, and the time taken from the driver's gaze fixation (***Note d*** in Table 4) to the use of the brakes (***Note f*** in Table 4) was measured. This was designed to estimate the visuomotor function by estimating the time-gap between the driver's perception of the vehicle moving in the opposite direction as a target stimulus and his or her behavioral response against it. The 'Speed Limit' scenario in Fig. 5(b) was used to assess the visual perception by measuring the time from the recognition of the speed limit sign in the child protection zone to the physical response of pushing down the brake pedal. This was to measure the time taken for the driver to recognize the traffic sign based on the time-gap between the driver's entry into the road with the sign (***Note c*** in Table 4) and his or her gaze fixation (***Note d*** in Table 4). Whether he or she had the right perception can be easily identified from the speed of the vehicle in the section of red asphalt– if it moved at a speed less than 30km/h, it means that the sign was properly perceived. The 'Stop or Go' situation depicted in Fig. 5(c) on the two-lane one-way street was designed to see if the driver can rapidly recognize a change in the traffic signals by properly surveying the traffic lights, defined as a major target stimulus, which was measured by the number of driver's gaze fixation on the lights and the detection of the major target stimulus upon shift in the signals in the same way as the 'Stop or Go' scenario at the signal-controlled intersection did.

3.5. Implemented contents: four-lane highway

The scenarios involving a four-lane two-way road were created based on 'Sudden Brake', 'Jaywalk', 'Avoiding Stalled Car', and 'Cut in Line.' The 'Sudden Brake' scenario depicted in Fig. 6(a) was to see if the driver in Vehicle ① surveyed the taillight of Vehicle ② ahead of it and maintained a safe distance. Its evaluation criteria and major target stimulus were the same as those for the scenario of 'Sudden Brake' upon turning left at a signal-controlled intersection. Also, the 'Jaywalk' scenario was about a pedestrian jaywalking on a road as a major target stimulus, as illustrated in Fig. 6(b), and its evaluation was done using the same criteria as those used for the scenario 'Jaywalking' at an intersection.

The scenarios, 'Avoiding Stalled Car' and 'Cut in Line' in Fig. 6(c) were to see if the driver in Vehicle ① recognized and moved around the stalled vehicle ② on the right before it turned right and surveyed Vehicle ③ moving on the left side to cut in line without a collision. The 'Avoiding Stalled Car' scenario was employed to assess the driver's visual perception against a static target, such as a stalled vehicle, by measuring the time taken from the moment when the driver entered the same lane as the stalled vehicle was placed (***Note c*** in Table 4) to when he or she detected the emergency light on the stalled vehicle (***Note d*** in Table 4). The 'Cut in Line' scenario was utilized to evaluate the driver's visual detection of the surroundings to cut in front of other vehicle and change lanes based on the number of his or her gaze fixations (***Note b*** in Table 4) on the major target stimuli (***Note a*** in Table 4), which consisted of one stalled vehicle, one vehicle following behind on the left lane, and the left side mirror of his or her car.



(a) Reversing Vehicle Collision

(b) Speed Limit

(c) Stop or Go

Fig. 5: Two-lane highway scenario

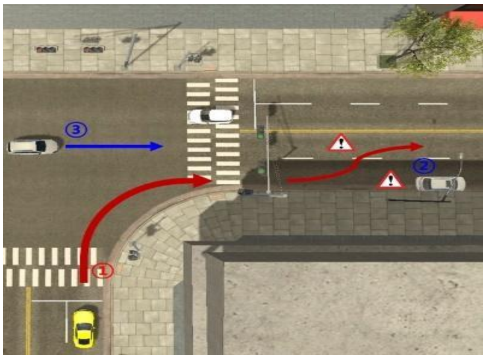
4. Discussion

Elderly drivers have a narrower range of vision required for surveying the surroundings while driving, and spend a longer time to perceive and respond to an external visual stimulus due to aging. As such driving characteristics of elderly drivers may cause major accidents on roads, it is necessary to objectively evaluate their driving capabilities by measuring their visual detection under various traffic conditions and visual behavior manifested in the form of a response to a visual stimulus (Aurenice Cruz Figueira, Ana Paula C. Larocca, 2020). To this end, the current study aimed to devised certain driving environments and scenarios for simulation, which can be employed to quantitatively estimate drivers' visual behavior against static and dynamic visual stimuli using HMD.

In this regard, published literatures which estimated the driving capabilities of elderly drivers using a simulator were searched using keywords, such as type of research, type of participants, type of interventions, and type of experiment result, and out of total 1,453 studies, 29 were chosen finally after the screening process based on the inclusion and exclusion criteria as they shared the same purpose of this study.

The type of accident most studied in the selected literature is a Car-to-Car accident, and the driving environment was frequently performed at controlled intersections and four-lane two-way road where the driver had to deal with various situations at the same time. This is also known from the study of Sun et. al. (2018) that the physical and mental workload is the highest at intersections, and the study of Figueira et. al. (2020) that the rate of crashes with the leading vehicle due to driving behavior such as overtaking is high in four-lane two-way road.

(a) Sudden Brake (b) Jaywalk



(c) Avoiding Stalled Car and Cut in Line

Fig. 6: Four-lane highway scenario

As a result of text network analysis in this study, ‘Stop or go’, ‘Sudden brake’, ‘Turning left’, and ‘Cross-Traffic Collision’ showed higher degree centrality and betweenness centrality indicators than other driving situations. This means that ‘Stop or go’, ‘Sudden brake’, ‘Turning left’, and ‘Cross-Traffic Collision’ are the most used scenarios at controlled intersections and four-lane two-way road. And the text network analysis was carried out on the driving environments and scenarios per accident type, included in the driving stimulation contents originating from the selected papers, to exclude those that focused on the driving environments outside urban areas, or those that evaluated a certain cognitive domain, or the ability to control vehicle functions.

The visual stimuli presented in the current work were reclassified into static and dynamic ones, and another text network analysis was carried out based on visual behavior categorized as visual detection, visual perception, and visuomotor function to reclassify them. The static visual stimuli in the form of fixed objects in a driving environment included traffic light signals, stalled vehicles, and traffic signs, whereas the dynamic ones presented in the form of moving objects, such as moving vehicles and jaywalking pedestrians.

After merging similar scenarios to create driving environments that were more likely to take place with more visual stimuli, total 12 scenarios were chosen which are– ‘Stop or Go’, ‘Sudden Brake’ and ‘Jaywalk’ at a signal-controlled intersection; ‘Turning Left’ and ‘Turning Right’ at an intersection without signals; ‘Reversing Vehicle Collision’, ‘Speed Limit’ and ‘Stop or Go’ on a two-lane one-way road; and ‘Sudden Brake’, ‘Jaywalk’, ‘Avoiding Stalled Car’ and ‘Cut in Line’ on a four-lane two-way road.

Driving simulation contents were implemented to evaluate different aspects of visual behavior through measuring the number of gaze fixations and the time taken for saccade, and the behavior response time. The number of gaze fixations on the entire presented target stimuli made it possible to identify the level and distribution of the driver’s visual detection. The time taken by a driver to fix his gaze on a target stimulus and the time taken to subsequently maneuver the steering wheel or regulate the pedal were used to a assess quantitatively the driver’s perception and response.

The scenarios involving ‘Stop or Go’, ‘Turning Left’, ‘Turning Right’, and ‘Cut in Line’ were designed to evaluate the driver’s visual detection to gather information about his surroundings, while those reflecting ‘Speed Limit’ and ‘Avoid Stalled Car’ were aimed to estimate the driver’s visual perception of a static visual stimulus. In addition, the scenarios such as ‘Sudden Braking’, ‘Jaywalking’ and ‘Reversing Vehicle Collision’ were employed to check the visuomotor function against a dynamic visual stimulus when an unexpected situation was unfolded.

Various evaluation results have been quantitatively expressed by putting the above-mentioned measurement values in the equations indicated in Table 4. Since the driving simulation content proposed in this paper utilizes an HMD capable of collecting various gaze information, it can be said that it has the advantage of being able to easily measure and analyze the driver's visual behavior according to various stimulus factors occurring in driving situations.

5. Conclusions

This study intends to present the rationale for how to construct the driving environment and scenarios of VR driving simulation content to evaluate the visual behavior of elderly drivers according to static and dynamic visual stimuli by reviewing the literature that evaluated driving ability.

Literatures were searched through 5 academic databases, and 29 studies were selected out of 1,453 literatures collected. Based on the selected studies, factors of static and dynamic visual stimulus in driving situations were classified, and visual behavior was classified into visual detection, visual perception, and visuomotor functions, and then the text network was analyzed.

The results showed that the static visual stimuli included stalled vehicles, traffic lights and signs, and dynamic visual stimuli were composed of vehicles in motion and pedestrians crossing the street. In this study, 12 scenarios with various visual stimulus factors and a higher frequency of occurrence were selected, and the results implemented as contents are as follows: 'Stop or go', 'Sudden brake', 'Jaywalk' at intersection with a traffic light; 'Turning left', 'Turning right' at intersection without a traffic light; 'Reversing vehicle collision', 'Speed limit', 'Stop or go', 'Sudden brake' on two-lane one-way road; 'Jaywalk', 'Avoiding stalled car', ' Cut in line' on four-lane two-way road;

As this study did not conduct any comparative experiments with respect to age group of the drivers, follow-up ones need additional testing process that can set the criteria and weight to be applied to a visual behavior evaluation. Specifically, it is deemed necessary to analyze the driving characteristics of elderly drivers against visual stimuli to come up with guidelines for quantitative assessment of their driving capabilities to determine whether they should return their driver’s license.

In case the results of this study serve as a fundamental basis to create evaluation items to encourage elderly drivers to voluntarily return their license, the objective assessment criteria and quantitative results offered by the study are expected to help them recognize the need to voluntarily hand back their license.

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References

Bernadette A. Fausto, Pedro F. Adorno Maldonaldo, Lesley A. Ross, Martin Lavallière, Jerri D. Edwards. (2021). A systematic review and meta-analysis of older driver interventions. *Accident Analysis & Prevention 149.e105852*, 1-20.

Anu Siren, Sonja Haustein. (2015). Driving licences and medical screening in old age: Review of literature and European licensing policies. *Journal of Transport & Health,* 2(1), 68-78.

Theodore J. Post, et al. (1981). A user’s guide to positive guidance (2nd Edition). *Federal Highway Administration: Office of Traffic Operations*.

Cynthia Owsley, Gerald McGwin Jr. (2010). Vision and driving. *Vision Research,* 50(23). 2348-2361.

Nicole A. Matas, Ted Nettelbeck, Nicholas R. Burns. (2014). Cognitive and visual predictors of UFOV performance in older adults. *Accident Analysis and Prevention*, 70, 74-83.

Qian Chayn Sun, Jianhong Cecilia Xia, Jibo He, Jonathan Foster, Torbjörn Falkmer, Hoe Lee. (2018). Towards unpacking older drivers' visual-motor coordination: A gaze-based integrated driving assessment. *Accident Analysis and Prevention*, 113, 85-96.

Shan Bao, Linda Ng Boyle. (2009). Age-related differences in visual scanning at median-divided highway intersections in rural areas. *Accident Analysis & Prevention*, 41(1), 146-152.

Marcin Piotr Biernacki, Rafal Lewkowicz. (2021). How do older drivers perceive visual information under increasing cognitive load? Significance of personality on-road safety. *Accdident Analysis & Prevention*, 157(106186), 1-12.

David B. Carr, Prateek Grover. (2020). The Role of Eye Tracking Technology in Assessing Older Driver Safety. *Geriatrics*, 5(2), 1-14.

Qian Chayn Sun, Jianhong Cecilia Xia, Yongfu Li, Jonathan Foster, Torbjörn Falkmer, Hoe Lee. (2018), Unpacking older drivers' maneuver at intersections: Their visual-motor coordination and underlying neuropsychological mechanisms. *Transportation Research Part F: Traffic Psychology and Behaviour*, 58, 11-18.

Youngji Kim, Soong-nang Jang. (2018). Mapping the knowledge structure of frailty in journal articles by text network analysis. *PloS one*, 13(4), 1-12.

Philipp Drieger. (2013). Semantic network analysis as a method for visual text analytics. *Procedia-social and behavioral sciences*, 79(6), 4-17.

Eileen Kowler. (2011). Eye movements: The past 25 years. *Vision Research*, 51(13), 1457-1483.

Tania Dukic, Thomas Broberg. (2012). Older drivers' visual search behaviour at intersections. *Transportation Research Part F: Traffic Psychology and Behaviour*, 15(4), 462-470.

Aurenice Cruz Figueira, Ana Paula C. Larocca. (2020). Analysis of the factors influencing overtaking in two-lane highways: A driving simulator study. *Transportation Research Part F: Traffic Psychology and Behaviour*, 69, 38-48.