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Paper:

Visual Cue in the Peripheral Vision Field for a Driving Support System

Hiroshi Takahashi

Faculty of Engineering, Shonan Institute of Technology
1-1-25 Tsujido-Nishikaigan, Fujisawa, Kanagawa 251-8511, Japan
E-mail: taka-hiro@sc.shonan-it.ac.jp

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This paper deals with the possibility of a new warning method for controlling drivers' sensitivity for recognizing hazardous factors in the driving environment. The method is based on a visual warning cue in the peripheral vision, which is outside of the central vision. In the human visual field, the central and peripheral vision fields have different processing mechanisms. In this study, the presentation of visual cues in the peripheral vision field is intended to provide a soft visual warning without intrusive interference to the task performed in the central vision. The results of many experiments performed with a 27-in. monitor display showed that a blinking visual cue at a view angle of around 26° from the center provided a good visual stimulus in the peripheral vision without being overlooked or being annoying to the subjects. The subjects tended to perceive the visual stimulus in the peripheral vision field beginning at 60°. A visual cue moving from the outer vision field to the center vision was perceived at around 60° regardless of its speed. A preliminary design guideline for installing visual warnings in the peripheral vision field is proposed.

Keywords: driver support systems, attention guide, warning, central/peripheral vision field

1. Introduction

Although automatic driving technology, in which the vehicle runs autonomously without the driver's operation, is attracting wide attention, research on man-machine systems in which the driver operates the vehicle is also important. During driving, one sometimes becomes unnerved by the sudden appearance of a pedestrian emerging from behind a parked car. One may also become unnerved when an unexpected event occurs, such as a pedestrian jumping out on the road or an approaching car from the side, which may greatly affect safe driving. Many professional drivers, whose occupation is to drive cars, learn from such unnerving experiences and are thought to have accumulated assumed scenes for predicting the situation so that they will not repeat such unnerving experiences. In this manner, they can raise their sensitivity to detect presumed dangerous events, which enables them to quickly notice the sudden appearance of a pedestrian and similar events and depress the brake pedal quickly to prevent or lessen accidents and damage. Meanwhile, drivers who have a limited amount of driving experience do not possess assumed scenarios regarding potentially dangerous events, have a low sensitivity to detect such dangerous events, and may lag in their response to the sudden appearance of a pedestrian.

In conventional driving assist devices designed for traffic safety, images of approaching vehicles at T intersections or fallen objects on the road are provided to each vehicle in real time by cameras set up along the road [1] or vehicle-mounted cameras or lasers are used to detect dangerous targets, and then the information is presented, a warning is issued, or driving is interrupted [2] to avert danger. However, there has been little discussion on driving assist methods for preventive-defensive driving to predict the occurrence of probabilistic danger events, such as the sudden appearance of a pedestrian, and to raise the driver's attention sensitivity.

Road signs such as "Accident-prone area ahead!" or "Watch carefully for the sudden appearance of pedestrians!" or messages on GPS navigation screen displays such as "Accident-prone curve! Drive carefully!" can be considered as information that can assist in preventive-defensive driving against hazards [3] that constitute potential danger factors in the driving environment. However, when many warning spots appear and the display is repeated, the driver may feel annoyed by the frequently occurring warnings and the alerts may lose their impact. Yet, since the locations where pedestrians frequently emerge onto the road are usually spatially limited, dangerous spots must be quickly notified to the driver as he or she drives. Thus, the driving assist information considered in this study consists of frequent warnings about potentially dangerous events and a quick notification to the driver about the presence of danger, if it exists. In this study, "annoyance" shall be defined as the "discomfort felt with the presentation of information while one is driving in cases when that information has no positive effect on one's driving and is repeated."

Information display in an automobile often comes in the form of visual information displayed on the navigation screen or within the instrument panel. In either case, the driver shifts his or her line of sight to the navigation screen, etc., when information is presented to confirm that information, which results in obstruction of the sensory perception of the driving-environment information on which the driver ought to concentrate to observe the driving conditions. Although it is set forth that shifting the line of sight to some object other than the driving scene for a period of about 2 s while driving generally does not impair the driving operations [4], it is preferable to minimize the duration of shifts of the line of sight besides that needed to grasp the driving conditions. Measures to minimize shifting of the line of sight during driving include placement of the navigation screen immediately below the instrument panel [5], moving the speedometer from near the steering wheel to the cabin center [6], and using a head-up display (HUD) [7]. They are implemented with the objective of reducing the driver's load in recognizing information related to the driving operation, thus preventing the diminishing of his or her attention resources used for the driving environment [8]. Yet, even with such measures for information display, the annoyance felt by the driver by the frequent presentation of information on the possibility of danger is a structural problem that cannot be avoided.

Focusing on an information presentation method that may act on the subconscious mind without explicitly registering in the conscious mind, the present author has been investigating the possibility of a method in which attention regarding dangerous situations is induced in the driver's subconscious mind [9, 10]. Although the author has found that there were cases in which attention was induced in the subconscious mind in several subjects, he is still investigating a method for inducing attention with certainty in all subjects. On the basis of this experience, the author focuses on the visual organ, which regularly processes a vast amount of information but selectively displays only the important information to the conscious mind, and investigates a method that satisfies the information presentation requirements stated above.

The rest of the paper is organized as follows. Section 2 reviews prior studies on peripheral vision. Section 3 describes the experiment on perceptual characteristics with static stimuli and discusses the results. Section 4 describes a basic experiment regarding the implementation of the presentation of visual stimuli in the peripheral vision and discusses the results. Finally, Section 5 gives the conclusions.

2. Difference in Characteristics Between the Central Vision and the Peripheral Vision

This section reviews the general perceptual characteristics of the human viewing field and discusses prior studies that focused on the viewing field characteristics from a physiological or an engineering standpoint. The author's previous study on peripheral vision is also discussed.

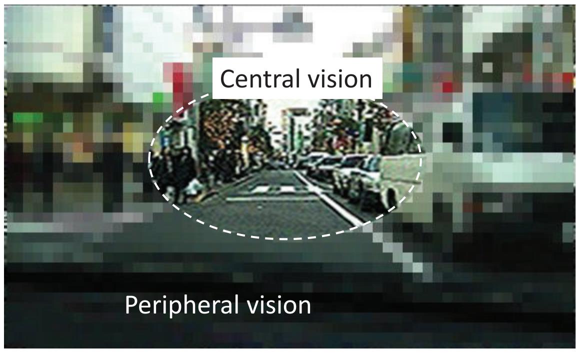

Fig. 1. Center/peripheral vision field.

2.1. Perceptual Characteristics of the Peripheral Vision

The human visual field is divided into the central vision and the peripheral vision. The area inside the broken-line ellipse in **Fig. 1** makes up the central vision, which extends to the left and right in the horizontal direction by 15° each and in the vertical direction above and below the central horizontal line by about 10° each [11]. The area outside the central vision is the peripheral vision. **Fig. 1** shows a model that exaggerates a visual image since, in reality, the central vision is not a left-right and up-down symmetric ellipse. There are also individual differences, wherein the center of the central vision is shifted somewhat lower in some people [12]. The range of the central vision becomes narrower depending on the visual attention or the mental concentration on the task at hand [13]. In this paper, the "view angle" refers to the angle formed by some point lying in front to the left or right, the center point between the eyes, and the center of the visual field when one is squarely facing the front. The "angle of view" generally refers to the apparent angle of the display on the monitor screen; here, however, "view angle" is used in the above sense. Since it is the angle from the center of the visual field when squarely facing the front, it is expressed, for example, as "the central view angle that extends 15° to the right and 15° to the left."

Sensory resolution and hue sensitivity are high in the central vision, in which an object is captured clearly. In the peripheral vision, which lies outside of the central vision, it has been pointed out that the presence of objects can be recognized, but the spatial resolution and hue perception are lower than those in the central vision [14]. It is said that the processing mechanism within the brain is different for visual stimuli presented in the central and the peripheral vision. Stimuli to part of the peripheral vision are processed at a section lying between the primary visual cortex and the hippocampus, and are transmitted via a shorter path compared to those presented to the central vision [15]. Because of this, stimuli in the peripheral vision may be perceived faster by humans than those in the central vision. It is also said that information processing in the peripheral vision is superior to that in the central vision in perceiving position changes and movement, and in identifying spatial coordinates.

In a study on information display to the peripheral vision, Shimura et al. investigated the use of peripheral vision in web searches on a tablet computer [16]. In a study on vehicle application [17], Funakawa et al. proposed a method of presenting visual information in the peripheral vision that does not interfere with the central vision. Wu et al. [18] studied the perceptual characteristics of moving objects in the peripheral vision among the elderly from the standpoint of traffic safety. In such prior studies, research was centered on analyzing the visual perceptual characteristics and did not examine the concrete methods for presenting attention display for driving assist devices or the annoyance felt by such presentation. When driving, drivers reflexively recognize a dangerous object in their peripheral vision, shift their line of sight to the object, and accurately capture it in their central vision. In this process, many objects perceived in the peripheral vision are not explicitly registered in the conscious mind, enabling one to respond quickly to particularly dangerous situations and to direct attention to them without being conscious of the frequent appearances of objects. The author believes that such a cognitive processing mechanism for environmental recognition can be applied toward preventing the "discomfort felt with the presentation of information while one is driving in cases when that information has no positive effect on one's driving and is repeated." Thus, the relationship between the presentation of visual stimulus in the peripheral vision and the annoyance felt from the above viewpoint was investigated in this study.

2.2. Experiment on Presenting Visual Stimuli in the Peripheral Vision

In a previous study, the present author conducted a preliminary investigation on the effect of visual stimuli presented in the peripheral vision and demonstrated its validity [19]. Specifically, a visual stimulus (white circle) was presented at an arbitrary position in the central vision when the subjects were carrying out the primary task of simple arithmetic addition displayed in the central vision. The time required for the subjects to detect this visual stimulus was measured. At this time, several seconds before the circle was displayed in the central vision, a separate mark was presented in the nearby peripheral vision. It was found that the detection time of the visual stimulus in the central vision was shortened by the presentation of the visual stimulus in the nearby peripheral vision. Thus, it was shown that a visual stimulus in the peripheral vision has the priming effect of quickening the detection of the visual stimulus in the central vision, even though the subjects might not be conscious of the former. On the basis of this finding, the author conducted a detailed investigation of a method for presenting a visual stimulus in the peripheral vision.

The driver's line of sight while driving is greatly affected by the oncoming scene. When the driver directs his or her attention to a specific object present in the oncoming scene, the center of the frontal scene will not always stay within the driver's peripheral vision as the line of sight shifts with the vehicle's movement. Therefore, in the author's previous study, only an arithmetic equation was displayed at a fixed position within the central vision to minimize the movement of the subjects' central and peripheral vision. Since the effect of the visual stimuli in the peripheral vision was clearly demonstrated in this setting, as a next stage in the current study, a task was set up, in experiment 1, that resembled actual driving conditions but in which the line of sight did not shift excessively, to avoid making the investigation of the perceptual characteristics of the peripheral and central vision overly complex. In actual driving, there are cases in which the driver's line of sight shifts considerably to the right or left as he or she turns his or her head, so that the central vision shifts drastically from the front of the windshield. In such an environment, the visual stimulus must be moved to present it in the driver's peripheral vision. In this case, it is necessary to determine the display range on the device used to present the visual stimuli in the peripheral vision. Experiment 2 was carried out to obtain the basic design guidelines for this. In this study, the various factors related to the driver's line of sight were considered and the perceptual characteristics of the peripheral vision were examined by setting up the experiment conditions in a way that they resembled actual driving situations in stages.

Experiment 1: Whereas a simple arithmetic addition in the central vision was employed as the primary task in the author's previous study [19], in this study, a primary task was set up that increased the workload in the central vision and that resembled actual driving operations. The perceptual characteristics of the visual stimuli presented in the peripheral vision were observed under this environment.

Experiment 2: There are many implementation issues in presenting visual stimuli in the driver's peripheral vision in an actual vehicle environment. Basic experiments were thus conducted to resolve these issues.

3. Static Perceptual Characteristics of Stimuli in the Peripheral Vision

For the task that increased the workload compared to that used in the author's previous study, which consisted of a simple addition task whose display was renewed every second, a driving game was set up as a task that was closer to actual driving operations. The task image consisted of a feedback system in which the driving scene changes in response to operations via the steering wheel, brake, etc., which requires a high concentration on the task. Although the attached game scenes included those for driving on public roads, there were scenes where the vehicle was following another vehicle ahead on a racing course, where attention was focused on the central vision, and where there were very few opportunities to drastically shift the driver's line of sight. Although verification must

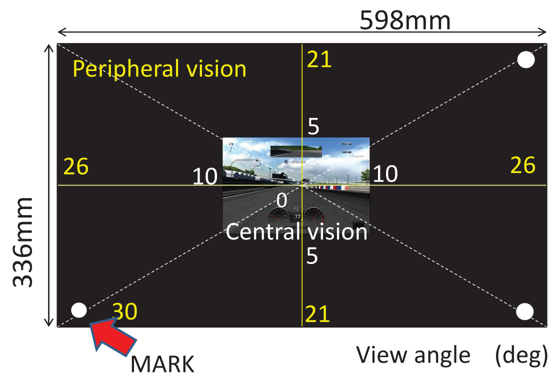

Fig. 2. Screen layout of experiments 1-1 to 1-6.

ultimately be done for driving scenes on public roads, a racing course scene was used as the task at this early stage since it was felt that it was desirable to employ an experiment task in which the scenery was not overly complicated and shifting of the line of sight was limited.

The driving game image was displayed within the peripheral vision of the subjects, who were squarely facing the monitor, and a visual stimulus consisting of a white circle was presented in their peripheral vision at a randomly chosen time. The time it took for the subjects to discover the white mark after it appeared was measured. In the author's previous study, the perceptual characteristics of the visual stimuli in the peripheral vision were measured, on the basis of the priming effect of the presence or absence of the visual stimuli displayed in advance in the peripheral vision, according to the time the subjects discovered the visual stimuli in their central vision. In this study, the application of presenting information in the peripheral vision in an actual vehicle was considered, the perceptual characteristics of the visual stimuli in the peripheral vision were directly measured, and the failure to detect the visual stimulus or the sensory evaluation of the annoyance felt by the subjects was observed.

3.1. Visual Stimuli in Experiment 1

Figure 2 shows the positions of the visual stimulus on the monitor presented to the subjects in experiment 1. The 27-in. LCD monitor (iiyama PROLite B2712HDS) has a maximum display range of 597.60 mm × 336.15 mm, contrast ratio of 1000:1, luminance of 400 cd/m^2 , and pixel pitch of 0.311 mm × 0.311 mm. The display monitor's view of angle extends 85° each to the left and right, and 80° above and below the central horizontal line. The face of a subject was fixed, where the center of the eyes (glabella) was at a distance of 600 mm in the normal direction from the intersection of the diagonals on the monitor. From that point, the subject's view of angle of the game screen extended 10° to the left and right, and 5° above and below the central horizontal line. The game used was Gran Turismo 5, which is a driving game played on PlayStation 3 in which the player drives on a circuit course.

The subject controlled the car's movement within the game screen using the steering wheel, accelerator pedal, and brake pedal. When the subject was playing the game, he concentrated on a range extending 5° to the left and right to observe the behavior of the car ahead. It is believed that, by concentrating on the game control, the subject experiences a narrowing of the range of his central vision [13]. The Logicool Driving Force GT was used as the input device, such as the steering wheel and brake and accelerator pedals. The game screen was displayed in the computer monitor as a "picture in a picture" using the video capture device PC-SDVD/U2G by Buffalo. The mark, which was the visual stimulus that the subjects were instructed to discover, was displayed in either the upper left, upper right, lower left, or lower right corner of the monitor screen, as shown in **Fig. 2**. The position of the mark lay at 26° to the left or right and 21° above or below the central horizontal line (view angle of 30°). The numerals that represented the view angle, the white lines for the x and y axes, and the monitor diagonals were not displayed on the monitor when the subjects were playing. The white circle was displayed at only one of the four corners at a time. The mark was displayed at the corners of the monitor since this created the widest view angle of 30° from the center of the monitor.

The possible design parameters of the mark were the display luminance, hue, display area (size), shape, blinking pattern, etc. In actual driving conditions, however, it is not easy to finely control the luminance of the visual stimulus under the varying lighting environments occurring while driving. Furthermore, spatial resolution and hue perception are lower [14] in the peripheral vision. For these reasons, a white circular visual stimulus was chosen for presentation. The use of the white color made it possible to present a visual stimulus with a wide dynamic range against the black background of the monitor. Moreover, the use of a circle allowed the directionality of the stimulus to be ignored. The display area (size) and blinking pattern of the visual stimulus were focused on as the initial experiment conditions.

The details of experiment 1 are described as follows. As presented in **Table 1**, six experiment conditions, from experiments 1-1 to 1-6, were set up for the visual stimulus presented in the peripheral vision.

In experiment 1-1, the game screen was not displayed and there were no game controls involved. A white circle with a diameter of 10 pixels was displayed at one of the four corners of the monitor at random, and the time that had elapsed until the subject discovered it was measured. The white mark continued to be displayed even when the subject was pressing the button in the center of the steering wheel, and it disappeared 5 s after the button had been pressed. The manner in which the mark disappeared was also the same as in the following experiments. In experiment 1-1, the entire monitor surface was black. The 10-pixel- diameter is equivalent to approximately 3 mm of diameter. This is the minimum detectable size for a subject who had his focus on the monitor center.

In experiment 1-2, the game screen was displayed in the central vision, as shown in **Fig. 2**, while a subject was

Table 1. Contents of experiments 1-1 to 1-6.

Experiment	Displayed mark/Position to be appeared
1-1	10-pixel white mark/somewhere in the four corners of the black screen
1-2	10-pixel white mark/somewhere in the four corners outside of the game display
1-3	10 ～30 changing pixels white mark/ somewhere in the four corners outside of the game display
1-4	30-pixel white mark/somewhere in the four corners outside of the game display
1-5	10-pixel white–black blinking mark/ somewhere in the four corners outside of the game display
1-6	30-pixel white–black blinking mark/ somewhere in the four corners outside of the game display

Table 2. Attribute of the subjects.

	Gender	Age	Left eyesight	Right eyesight	Glasses
Subject A	Male	22	0.7	0.7	Glasses
Subject B	Male	22	1.0	1.0	Glasses
Subject C	Male	22	1.0	1.0	Glasses
Subject D	Male	21	1.5	0.7	Glasses
Subject E	Male	21	1.5	1.5	
Subject F	Male	22	1.2	1.2	
Subject G	Male	24	1.0	1.0	Glasses
Subject H	Male	22	1.5	1.5	
Subject J	Male	22	1.0	1.2	Glasses

playing the driving game. While a subject was playing the game, a white circle with a 10-pixel- diameter was displayed at random at one of the four corners, within the peripheral vision shown in **Fig. 2**. The time it took until a subject detected the mark and pressed a button was measured.

In experiment 1-3, the arrangement of the stimulus was similar to that in experiment 1-2, but the size of the white mark was varied over time. Specifically, the mark was displayed with a diameter of 10 pixels, which increased to 30 pixels (approximately 9 mm in diameter) in 0.5 s, without any change in the position of the mark's center, and then decreased back to 10 pixels in 0.5 s. This was repeated, and the size change was stopped when the button was pressed. Since spatial resolution is low in the peripheral vision, it was thought that a considerable change in the shape was necessary. To vary the stimulus, one can use a blinking pattern, in which the mark is displayed on and off alternately, or vary the size of the mark. While it is also possible to display 30 pixels and 10 pixels alternately, a suddenly changing stimulus is similar to a blinking stimulus. Thus, experiment 1-3 was set up so that the diameter gradually changed over time. The maximum size was set to 30 pixels, which is about 9 mm on the monitor, because any size exceeding this was thought to interfere with the view when driving.

Experiment 1-4 was similar to experiment 1-2, but the white mark had a diameter of 30 pixels.

In experiment 1-5, the display pattern was the same as in experiment 1-2, but the 10-pixel-diameter white mark blinked at a frequency of 3 Hz. The reason for using 3 Hz is explained as follows. In a preliminary experiment with nine subjects, a set of consecutive experiments was carried out in which the blinking frequency of the mark was varied in 1-Hz steps between 1 and 30 Hz, with each frequency being held for 5 s. The result obtained from a sensory evaluation showed that 3 Hz (average 3.1 Hz, standard deviation 0.73 Hz) was a "blinking frequency that was neither too fast nor too slow, and was easy to view." In addition, since this blinking frequency was sufficiently lower than the flicker frequency [20], it was believed that the blinking would not cause eye fatigue among the subjects.

In experiment 1-6, the diameter of the white mark in experiment 1-5 was increased to 30 pixels, and the display and non-display of the stimulus were alternated at 3 Hz. The display patterns employed in experiments 1-1 to 1-6 were created using Adobe Flash [21]. In all the experiments, the subjects were instructed to press the button in the center of the steering wheel whenever they detected the display of the white circle. Since the steering wheel was relatively small, with a diameter of 270 mm, a subject could press the center button without difficulty, regardless of the position of the steering wheel, when he discovered the white mark even when he was moving the steering wheel. When the computer transmitted the signal to display the mark, it simultaneously transmitted a signal from the output port to start a stopwatch, which began measuring the time at a resolution of 1/100 s . The stopwatch stopped when a subject pressed the button in the center of the steering wheel. The experiments were conducted in a dark room.

The subjects taking part in the experiment are described as follows. As shown in **Table 2**, all the subjects were male in their early 20 s. The subjects' left and right eyesight are also presented. The eyesight of those wearing glasses was the corrected one with glasses. The subjects initially individually experienced the tasks of experiments 1-1 through 1-6 in sequence, then partook in experiments 1-1 and 1-2 in order. The remaining experiments, from 1-3 to 1-6, were carried out in random order for each subject. The subjects undertook 20 consecutive trials for each experiment. Each trial took 30–80 s, and a 10-min break was taken after the 20 trials. The subjects were not allowed to see one another during the break. After each experiment, the subjects were interviewed about their impressions of the display and the respective experiment conditions. Before the experiment, the subjects were given a detailed explanation of the experiment and told that they could terminate the experiment whenever they

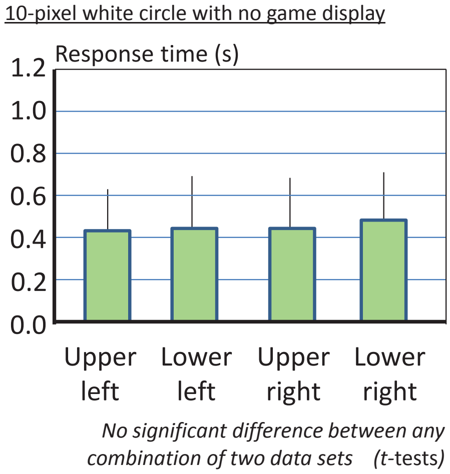

Fig. 3. Results of experiment 1-1.

Table 3. Number of oversight in experiment 1-1.

Subject	Upper left	Lower left	Upper right	Lower right
Subject A	0/5	0/5	0/5	***1/5***
Subject B	0/5	0/5	0/5	0/5
Subject C	0/5	0/5	0/5	0/5
Subject D	0/5	0/5	0/5	0/5
Subject E	0/5	0/5	0/5	0/5
Subject F	0/5	0/5	0/5	0/5
Subject G	0/5	0/5	0/5	0/5
Subject H	0/5	0/5	0/5	0/5
Subject I	0/5	0/5	0/5	0/5

Number of oversight/Number of displayed marks

felt eye fatigue or some physical problem. The entire experiment set took about 3 h. The experiment was conducted in 1 day, and in no case did the same subject partake in an experiment for over two consecutive days. In a single experiment, the white circle was displayed randomly in one of the four corners of the monitor in the 20 consecutive trials. However, the mark was displayed in each corner five times. The subjects were not informed that the mark would be displayed in each corner for five times.

3.2. Experiment Results and Discussion

The measurement results of experiments 1-1 to 1-6 and discussions are presented below.

3.2.1. Results of Experiment 1-1

Figure 3 shows the average response times of the nine subjects and the standard deviations. When *t*-tests were carried out on pairs of data for the appearance of the white circle in the upper left, upper right, lower left, and lower right corners, no significant difference in the detection time was found in all combinations. Similarly, no significant difference in the detection time was found in all combinations of the appearance location in individual measurements for each subject. Although it was hypothesized that the response speed would be quicker in descending order of upper left, upper right, lower left, and lower right, on the basis of the general characteristics of the shift of the line of sight known in speed-reading, in none of the subjects' results was the average response time for the upper left corner the fastest.

Table 3 shows the number of times the subjects failed to detect the white mark. A failure to detect the mark was judged to have occurred whenever the subject did not press the button for 2 s after the white mark was displayed. The results showed that subject A failed to detect the mark within 2 s once out of the five times it was displayed in the lower right corner. The other subjects all detected the white mark without fail.

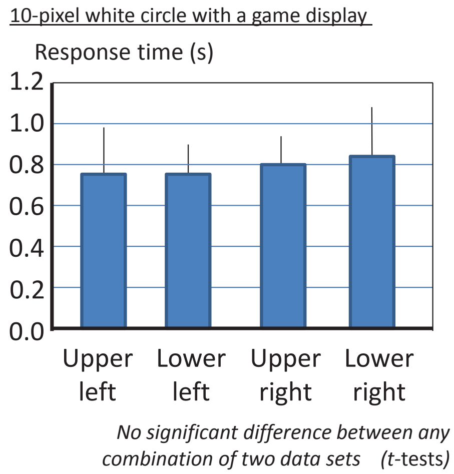

Fig. 4. Results of experiment 1-2.

Table 4. Number of oversight in experiment 1-2.

Subject	Upper left	Lower left	Upper right	Lower right
Subject A	0/5	0/5	***1/5***	0/5
Subject B	0/5	0/5	0/5	0/5
Subject C	***1/5***	0/5	0/5	***1/5***
Subject D	0/5	0/5	0/5	***1/5***
Subject E	0/5	0/5	0/5	***1/5***
Subject F	0/5	0/5	***1/5***	0/5
Subject G	0/5	***1/5***	0/5	0/5
Subject H	0/5	***1/5***	0/5	***1/5***
Subject I	0/5	0/5	0/5	0/5

Number of oversight/Number of displayed marks

3.2.2. Results of Experiment 1-2

Figure 4 shows the results of experiment 1-2. When *t*-tests were carried out on pairs of data for the appearance of the white circle in the upper left, upper right, lower left, and lower right corners, no significant difference in the detection time was found in all combinations.

As **Table 4** shows, there were many cases in which the subjects failed to detect the 10-pixel white mark within 2 s. Subjects C and H both had instances of failing to detect the white mark when it appeared in two locations.

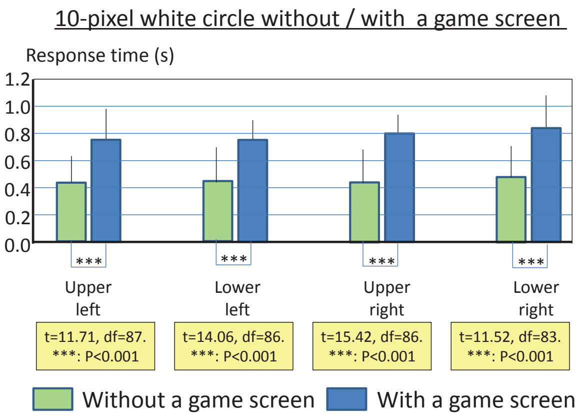

Fig. 5. Comparison between experiment 1-1 and experiment 1-2.

Table 5. Number of oversight in experiment 1-3.

Subject	Upper left	Lower left	Upper right	Lower right
Subject A	0/5	0/5	0/5	0/5
Subject B	0/5	0/5	0/5	0/5
Subject C	0/5	0/5	0/5	0/5
Subject D	0/5	0/5	0/5	0/5
Subject E	0/5	0/5	**1/5**	0/5
Subject F	0/5	0/5	0/5	0/5
Subject G	0/5	0/5	0/5	0/5
Subject H	0/5	0/5	0/5	0/5
Subject I	0/5	0/5	0/5	0/5

Number of oversight/Number of displayed marks

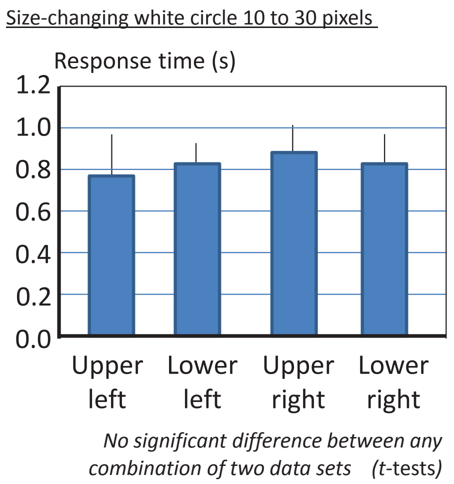

Fig. 6. Results of experiment 1-3.

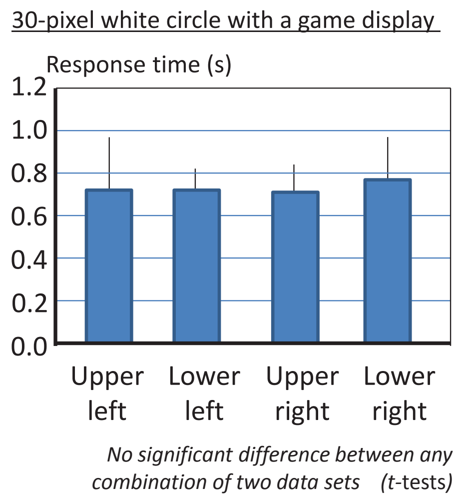

Fig. 7. Results of experiment 1-4.

The detection times in experiments 1-1 and 1-2 are shown again in **Fig. 5** for comparison. Overall, there was a significant difference in response time between when a subject was not playing the game and when he was playing the game within his central vision; detection was delayed by 0.2–0.4 s when he was playing the game. This is thought to be the result of channeling his attention resources into playing the game [8]. As noted above, however, there was little difference between the displayed locations.

3.2.3. Results of Experiment 1-3

Figure 6 shows the results when the white mark was displayed in the peripheral vision while its diameter was alternately being enlarged and shrunk to between 10 and 30 pixels. When t-tests were carried out on pairs of data for the appearance of the white circle in the upper left, upper right, lower left, and lower right corners, no significant difference in the detection time was found in all combinations. As shown in **Table 5**, almost none of the subjects failed to detect the white mark. Thus, it can be concluded that the area change of the white mark was effective in making a subject notice the mark displayed in his peripheral vision when he was engaged in a primary task in his central vision.

3.2.4. Results of Experiment 1-4

As indicated in **Fig. 7**, a white mark with a diameter of 30 pixels was displayed. When t-tests were carried out on pairs of data for the appearance of the white circle in the upper left, upper right, lower left, and lower right corners, no significant difference in the detection time was found in all combinations. Furthermore, there was no significant difference in the detection time between the 10- and the 30-pixel-diameter white mark appearing in the same location. However, there were fewer cases of failing to detect the 30-pixel mark as compared to the 10-pixel mark, as shown in **Table 6**. Yet, the improvement was not as great as in experiment 1-3, when the mark's size was varied. However, the subjects remarked, "the display of the mark in the peripheral vision did not feel bothersome or annoying."

3.2.5. Results of Experiment 1-5

The experiment results are shown in **Fig. 8**. The white mark with a 10-pixel-diameter was displayed in one of the four corners in the peripheral vision while it was blinking

Table 6. Number of oversight in experiment 1-4.

Subject	Upper left	Lower left	Upper right	Lower right
Subject A	0/5	0/5	0/5	0/5
Subject B	0/5	0/5	0/5	***1/5***
Subject C	0/5	0/5	0/5	0/5
Subject D	0/5	0/5	***1/5***	0/5
Subject E	0/5	0/5	0/5	***1/5***
Subject F	0/5	0/5	0/5	0/5
Subject G	0/5	***1/5***	***1/5***	0/5
Subject H	0/5	0/5	0/5	0/5
Subject I	0/5	0/5	0/5	***1/5***

Number of oversight/Number of displayed marks

Table 7. Number of oversight in experiment 1-5.

Subject	Upper left	Lower left	Upper right	Lower right
Subject A	0/5	0/5	0/5	0/5
Subject B	0/5	0/5	0/5	0/5
Subject C	0/5	0/5	0/5	0/5
Subject D	0/5	0/5	0/5	***1/5***
Subject E	0/5	0/5	0/5	0/5
Subject F	0/5	0/5	0/5	0/5
Subject G	0/5	0/5	0/5	0/5
Subject H	0/5	0/5	0/5	0/5
Subject I	0/5	0/5	0/5	0/5

Number of oversight/Number of displayed marks

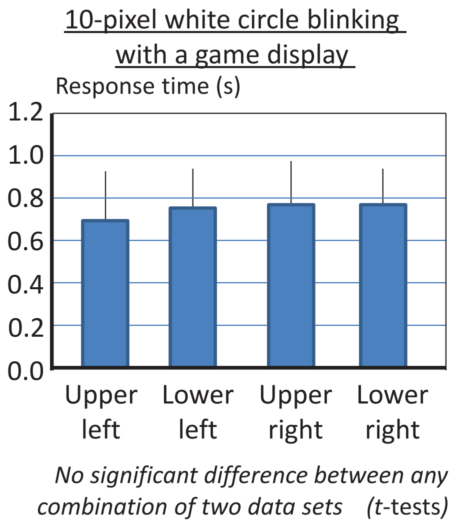

Fig. 8. Results of experiment 1-5.

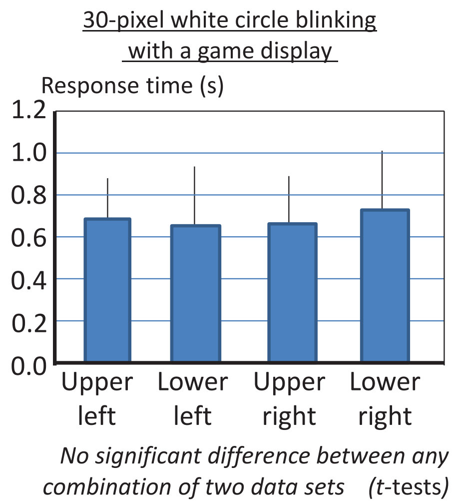

Fig. 9. Results of experiment 1-6.

at 3 Hz. When t-tests were carried out on pairs of data for the appearance of the white circle in the upper left, upper right, lower left, and lower right corners, no significant difference in the detection time was found in all combinations. Although there was no major change in response time, cases of failing to detect the mark were drastically reduced, as shown in **Table 7**. Although there were nine cases of failure to detect the mark among the 180 trials for all subjects when the 10-pixel mark was displayed, this was reduced to once when the mark blinked. This indicates that the rate of perception and recognition could be improved by varying the size or brightness of the mark displayed in the peripheral vision.

3.2.6. Results of Experiment 1-6

The experiment results are shown in **Fig. 9**. A 30-pixel-diameter white mark blinking at 3 Hz was displayed in the peripheral vision. When t-tests were carried out on pairs of data for the appearance of the white circle in the upper left, upper right, lower left, and lower right corners, no significant difference in the detection time was found in all combinations. When compared to experiment 1-5, there was no significant difference in the detection time between marks that were displayed in the same location.

Table 8. Number of oversight in experiment 1-6.

Subject	Upper left	Lower left	Upper right	Lower right
Subject A	0/5	0/5	0/5	0/5
Subject B	0/5	0/5	0/5	0/5
Subject C	0/5	0/5	0/5	0/5
Subject D	0/5	0/5	0/5	0/5
Subject E	0/5	0/5	0/5	0/5
Subject F	0/5	0/5	0/5	0/5
Subject G	0/5	0/5	0/5	0/5
Subject H	0/5	0/5	0/5	***1/5***
Subject I	0/5	0/5	0/5	0/5

Number of oversight / Number of displayed marks

Table 8 shows the incidences of failure to detect the mark. As in the case of the blinking 10-pixel mark, there was one case of failing to detect the 30-pixel mark.

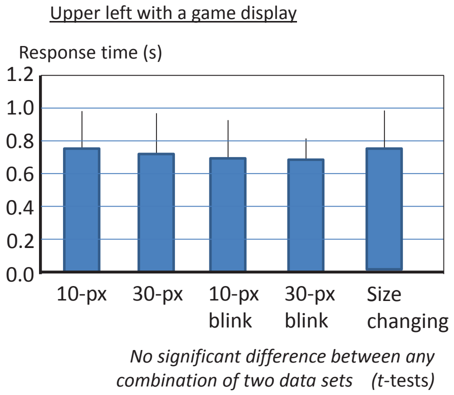

Fig. 10. Response time to the marks.

Table 9. Subjective evaluation of the marks.

Subject	10-pixel mark	30-pixel mark	Size-changing	10-pixel blinking	30-pixel blinking
Subject A	2	3	5	3	4
Subject B	2	2	4	3	4
Subject C	2	3	4	3	3
Subject D	2	3	3	2	3
Subject E	2	3	4	3	4
Subject F	2	2	3	3	3
Subject G	2	3	3	2	3
Subject H	2	3	4	3	3
Subject I	2	2	3	2	3
Average	**2**	**2.7**	**3.6**	**2.9**	**3.3**

Subjective evaluation
1 : Not annoying; >2>3>4>5 : very annoying

3.3. On the Mark Displayed in the Peripheral Vision

The difference in detection time due to the method used for displaying the mark in the peripheral vision was examined. **Fig. 10** shows again the average detection times of all subjects when the mark was displayed in the upper left corner of the monitor.

When a t-test was carried out between the blinking 30-pixel mark and the mark that alternated its size between 10 and 30 pixels, no significant difference was found, with $P > 0.1$, a t-value of 1.65 and degrees of freedom (df) of 88. Similarly, no significant difference was found between any pairs of the five display modes. Neither were there any significant differences, with a significance level of 1%, in the results of the t-tests for the different display locations or for individual subjects. With regard to the failure to detect the mark, perception and recognition improved when the mark's shape changed by varying its size or making it blink as compared to the simple display, as shown in **Tables 4** to **8**. The subjects' views of the white mark displayed in the peripheral vision recorded after each experiment are presented in **Table 9**. The subjects were asked to rate their impressions or views about the mark displayed in the peripheral vision according to five ranks immediately after they had completed the 20 trials for each experiment. A ranking of "1 (one)" indicated that

Table 10. Validation summary of experiments 1-2 to 1-6.

Mark in Peripheral vision		Response: Average Time (s)		Oversight: Amount of oversight		Annoying: Subjective score	
Exp. 1-2	10-Pixel mark	0.79	No significant difference	9		2.0	○
Exp. 1-3	Size changing mark	0.81		1	○	3.6	
Exp. 1-4	30-Pixel mark	0.75		6		2.7	△
Exp. 1-5	10-Pixel blinking	0.76		1	○	2.9	△
Exp. 1-6	30-Pixel blinking	0.71		1	○	3.3	
Reference		Figs. 4,6,7,8,9,10		Tables 3,4,5,6,7,8		Table 9	

○ : good △ : fair

the subject "did not mind at all the white mark presented in the peripheral vision," whereas a ranking of "5 (five)" indicated that the display "was very bothersome and annoying." Since it is difficult to measure an absolute sensory evaluation of annoyance, the continuous display of the 10-pixel mark was given a ranking of "2 (two)" to provide a reference for the annoyance of the visual stimuli, and the other display modes were evaluated on the basis of this relative scale. Note that the subjects' sensory evaluations were obtained after they had experienced all trials and become proficient. The subjects were briefed about the purpose and contents of the experiment, but were not told that the mark displayed in the peripheral vision "may not be annoying."

There was a tendency for the subjects to be annoyed or bothered by the mark when its size varied as compared to when it remained constant. This is true for marks in the peripheral vision that were less overlooked, but it is interesting to note that, within changing marks, the mark with varying sizes received fewer positive (favorable) evaluations. Furthermore, the annoyance level appeared to increase with larger-sized marks compared to those with small display areas, whether they were continuously displayed or blinking. Based on these considerations, the conclusion is that it is more effective to vary the brightness instead of the size of the mark to prevent the failure of detecting it and to lessen the annoyance level. As shown in **Table 9**, however, individual differences existed between the subjects' sensory evaluations regarding annoyance; subject I, for instance, felt the same level of annoyance whether the 10-pixel mark was continuously displayed or was blinking. Thus, an important issue was how to take the individual differences into account in the system. For reference, it was noted that all subjects gave a ranking of 5 when a 10-pixel white mark was displayed at random within the central-vision region in the game display screen.

3.4. Summary of Experiment 1

The results of experiment 1 are summarized in **Table 10**. The display mode of the visual stimuli in the peripheral vision was evaluated. The evaluation functions consisted of the detection time, the number of detection failures, and the annoyance level felt. The table presents a summary of the average values of the experiment results and the display modes of the visual stimuli for evaluation. There was no significant difference in the detection time when the area of the mark displayed in the peripheral vision was changed from 10 to 30 pixels. Furthermore, it was preferable to vary the brightness (blink) or to periodically vary the mark's area to reduce the detection failure of the white circles displayed in the peripheral vision. Since there was a tendency for the subjects to feel annoyed when the mark size was varied, however, it was preferable to have the mark blink in the peripheral vision. Furthermore, although blinking a larger mark would intuitively seem to be more noticeable, it was preferable to employ a blinking mark of about 10 pixels from the standpoint of annoyance. Although it was possible that an optimal value other than the parameters tested in the experiment existed, the author felt that the basic design guidelines had been obtained. The results of this study are not in conflict with physiological findings [22] regarding the static peripheral-vision response time at a 20° view angle.

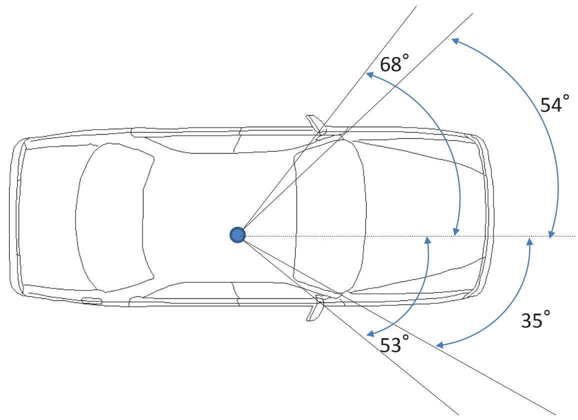

Fig. 11. View angle of a driver in a vehicle.

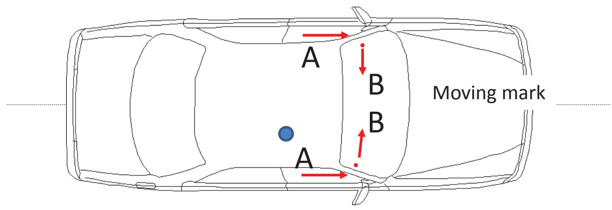

Fig. 12. Method to generate a peripheral warning.

4. Issues Regarding Vehicle Implementation

In experiment 1, the static perceptual characteristics of visual stimuli in the peripheral vision were investigated. The view angle in which the visual stimulus was presented in experiment 1 extended by about 26° to the right and left in the horizontal direction when a subject fixed his view at the center of the monitor.

Although this view angle is considered sufficiently wide to cover the peripheral vision for a range of individual differences, it is necessary to examine the right and left range of vision that the driver can secure when driving. Although it was assumed that the driver was facing the front in experiment 1, there were cases when the driver's peripheral vision shifted drastically from the wind shield to the right or left side, depending on the angle of head-turning of the driver. It is thus necessary to display the visual stimulus in the driver's peripheral vision in such cases as well. Therefore, the manner in which the visual stimulus should be displayed in the peripheral vision was examined by considering the system layout for practical vehicle implementation.

4.1. Method of Displaying a Visual Stimulus in the Peripheral Vision

When the layout of the driver's seat in a car was considered, the driver's view angle extended roughly 35° to the front right pillar of the windshield in a right-hand drive vehicle and to the front left pillar in a left-hand drive vehicle, as shown in **Fig. 11**. In the other direction, it extended by about 50° to the front left pillar in a right-hand drive vehicle and to the front right pillar in a left-hand drive vehicle. Thus, it is possible to secure a sufficient peripheral vision angle in the direction opposite of the steering wheel position. However, when designing a display device that displays visual stimuli in the driver's peripheral vision at an angle of 20°, it is not easy to identify the position of 20° in the peripheral vision angle, depending on the driver's seated posture and the direction he faces. Even if the display is located at 20° to the right in the driver's peripheral vision when he is facing front, he will see it in his central vision if he turns his head to the right.

It is necessary to employ a method that can structurally display visual stimuli within the driver's peripheral vision and that is not greatly affected by the direction of his or her face, when applying the system to an actual automobile. Thus, a method that is simple in principle was considered, where the mark travels horizontally from the outer fringe (beyond the peripheral vision) of the driver's view toward the vehicle's front when displaying the mark to his peripheral vision, as shown in **Fig. 12**. In the figure, the mark travels from A to B. In many cases, this arrangement will allow the mark to travel from the driver's peripheral vision to his central vision when he faces the front, thus allowing him to perceive the mark in his peripheral vision. Using a traveling mark will also make it possible to respond to individual differences in the range of peripheral vision. Even with this method, there will be cases when the mark will travel to within the driver's central vision, depending on the direction he faces. Limiting the position of the travel of the mark on the basis of the statistical data obtained by analyzing the drivers' behavior will make it possible to display the visual stimuli in the peripheral vision in many cases. Thus, the perceptual characteristics when the visual stimulus was moved

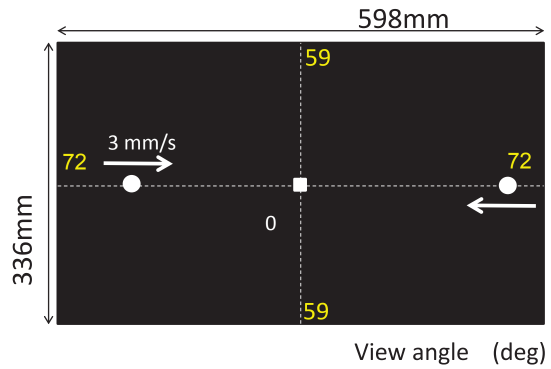

Fig. 13. Displayed pattern of experiment 2.

horizontally from the peripheral vision toward the central vision were investigated.

4.2. Mode of Displaying a Visual Stimulus in Experiment 2

In experiment 2, the location at which the visual stimulus was perceived when it traveled horizontally from the outside of the view field toward the central vision was measured. Specifically, the view angle at which the stimulus was consciously registered in the peripheral vision was determined. The travel speed of the visual stimulus was varied within that range and the detected position was measured.

As shown in **Fig. 13**, the same 27-in. LCD monitor used in experiment 1 was used. A white square mark with 2-mm sides was placed at the intersection of the monitor's diagonals. A video was displayed in which a white circle was traveling from the right or left edge of the screen toward the center white square at a constant speed. To use a larger view angle than that used in experiment 1, a subject had to sit so that his face was at a perpendicular distance of 100 mm from the monitor screen and so that the center point of the eyes was at the same height as the white square mark and gazing upon the white square mark. In this condition, a white circle was displayed traveling from either of the outer edges toward the white square mark. When a subject detected this traveling mark, he pressed the button in the steering wheel used in experiment 1, which stopped the video, after which the distance between the square and the circle was measured and then converted to the view angle. The diameter of the moving white circle was set so that it appeared to have the same size as the 10-pixel white circle used in experiment 1; as shown in **Table 10**, this size was found to result in few detection failures and was considered to be less annoying. Since the distance between the screen and the subject's eyes was narrower in experiment 2 to increase the view angle, the diameter of the displayed mark must be corrected, however, to produce the same apparent size. The distance between the center of the circle and the center of the eyes was 692 mm in experiment 1. The distance between the edge of the monitor, from which the mark initiated its movement, and the center of the eyes

Table 11. Contents of experiments 2-1 to 2-3.

Experiment	Displayed mark/Position to appear
2-1	4-pixel white mark moving to the center of the screen from the left or right edge at 3 mm/s
2-2	4-pixel white mark moving speed at 50 mm/s
2-3	4-pixel white mark moving speed at 100 mm/s

was 315 mm in experiment 2. Since the distance was reduced by 315/692 (= 0.455), the diameter of the mark was also reduced by 315/692. In experiment 2, the mark appeared at the edge of the monitor and traveled toward the center of the monitor, and, therefore, the apparent size increased as it approached the center. Therefore, the diameter of the mark immediately after it appeared was set to 4 pixels. The diameter did not change as the mark was traveling. In experiment 2, the subjects were instructed to focus their gaze only on the white square mark displayed in the center of the monitor and they did not play a driving game, unlike in experiment 1. The video was produced with Adobe Flash.

In experiment 2, the three experiments presented in **Table 11** were carried out. The detected position of the marker was measured when the direction from which it appeared and its traveling speed were varied. The numbers representing the view angles, the broken lines of the x and y axes, and the arrows by the white circles, shown in **Fig. 13**, were not shown to the subjects during the experiment. The displayed mark appeared from one side only and did not blink.

4.2.1. Details of Experiment 2-1

The white circle traveled at a constant speed of 3 mm/s in experiment 2-1. The view angle velocities were approximately 0.5°/s in the vicinity of a view angle of 60° and were approximately 1.5°/s in the vicinity of a view angle of 20°. The mark traveled slowly, requiring about 99 s for it to travel from the monitor edge to the center. After the circle started from either the left or the right edge, the position where it was detected was measured. Ten trials were carried out from each side (20 trials total) to make a single set, and two sets were carried out. The side from which the mark appeared was chosen at random and was not disclosed to the subjects. Measurement was commenced after the subjects had become sufficiently used to the trial and stated that they had grasped the "knack" for detecting the mark. A single measurement took about 60 s. A break of approximately 10 min was inserted between sets to prevent eye fatigue resulting from repeated measurements. The subjects consisted of six persons, namely, subjects A to F in **Table 2**. They were not allowed to exchange information about the experiment with each other. The experiment was conducted in a dark room.

4.2.2. Details of Experiment 2-2

Experiment 2-2 was basically similar to experiment 2-1, but the travel speed of the 4-pixel white circle, which traveled from the right or left edge to the center of the monitor, was changed. Specifically, the mark traveled at a faster speed than that in experiment 2-1, traveling at a constant speed of 50 mm/s. The position where a subject detected the white mark was measured. The mark did not blink. Ten trials were carried out from each side (20 trials total) to make a single set, and two consecutive sets were carried out. The side from which the mark appeared was chosen at random and was not disclosed to the subjects. Measurement was commenced after the subjects had become sufficiently used to the trial and stated that they had grasped the knack for detecting the mark. A single measurement took place within a minute. A break of approximately 10 min was inserted between sets to prevent eye fatigue resulting from repeated measurements. Although a constant-speed movement on the monitor did not result in a constant view angle speed, since the angle of the view changed, it was assumed that the two were roughly proportional and the travelling speed on the monitor was used as the index. The subjects consisted of three persons, namely, subjects A, B, and C in **Table 2**. The experiment was conducted in a dark room.

4.2.3. Details of Experiment 2-3

In experiment 2-3, the same mark used in experiment 2-2 traveled at a constant speed of 100 mm/s from either the left or the right edge to the monitor center. The other conditions were the same as those in experiment 2-2, and the subjects consisted of three persons, namely, subjects A, B, and C in **Table 2**. Experiments 2-1 to 2-3 were conducted consecutively on the same day. They were conducted about a week after experiment 1. As in experiment 1, the subjects were informed that they could terminate the experiment immediately whenever they felt unwell during the measurements. For each experiment, a subject practiced about 10 trials each from the left and right, and measurement commenced after he stated that he had grasped the knack for detecting the mark. It has been pointed out that, in an experiment in which a white circle was traveling horizontally on the monitor, the luminance of the visual stimulus affected the perception [23]. Although numerical correction should ideally be carried out to achieve a uniform luminance over the entire monitor, if the author considered the varying characteristics among the different monitors or the non-uniform luminance in the monitor's center and periphery, he would not be able to make any corrections in this experiment.

4.3. Experiment Results and Discussion

The measurement results of experiments 2-1 to 2-3 are discussed below.

4.3.1. Results of Experiment 2-1

A 4-pixel white circle traveled at 3 mm/s from the left or right edge to the monitor center. The angles from the monitor center of the position of the mark when it was detected by the subjects are shown in **Fig. 14**. The averages represent the average right and left view angles for the six subjects. The detected view angles of each subject for the mark traveling from left and right are also shown. The bars in the graph represent the standard deviations of the measurements.

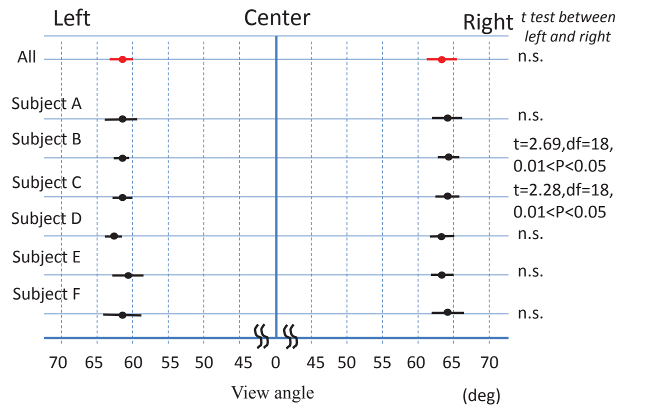

Fig. 14. Results of experiments 2-1 (n.s.: not significant).

Although the view angle of the detected white mark traveling toward the center from the right edge appeared slightly greater than that from the left edge, there was no significant difference between the right and the left except for subjects B and C. The effect of different left and right eyesight was considered, but there were no significant differences for the majority of subjects for a 4-pixel mark observed from a distance of 100 mm. The experiment results showed that the mark was detected in the vicinity of 60–65°.

4.3.2. Results of Experiments 2-2 and 2-3

Figures 15(a)–(c) show the results of the detection view angle for different traveling speeds for each subject. When the white circle traveled from the left and right edges to the center, the view angle of the detected mark traveling at 100 mm/s was narrower than that traveling at 50 mm/s.

It appears that the view angle of detection became narrower as the speed of the traveling visual stimulus was increasing. However, when the visual stimulus was traveling toward the center at a relatively high speed, the apparent view angle could be observed as being smaller than the true angle, considering the distance traveled by the mark during the time delay, owing to the time it took for a subject to press the button after detecting the visual stimulus. In other words, if the process taking place from the time a subject detected the visual stimulus and the time he pressed the button was considered, the "position of mark detection" represented the sum of "the mark's actual position when it was detected" and "the distance traveled by the mark after it was detected until the time the button was pressed." For a traveling mark, the "position of mark detection" was the sum of "the mark's actual position when it was detected" and the "(time until the but-

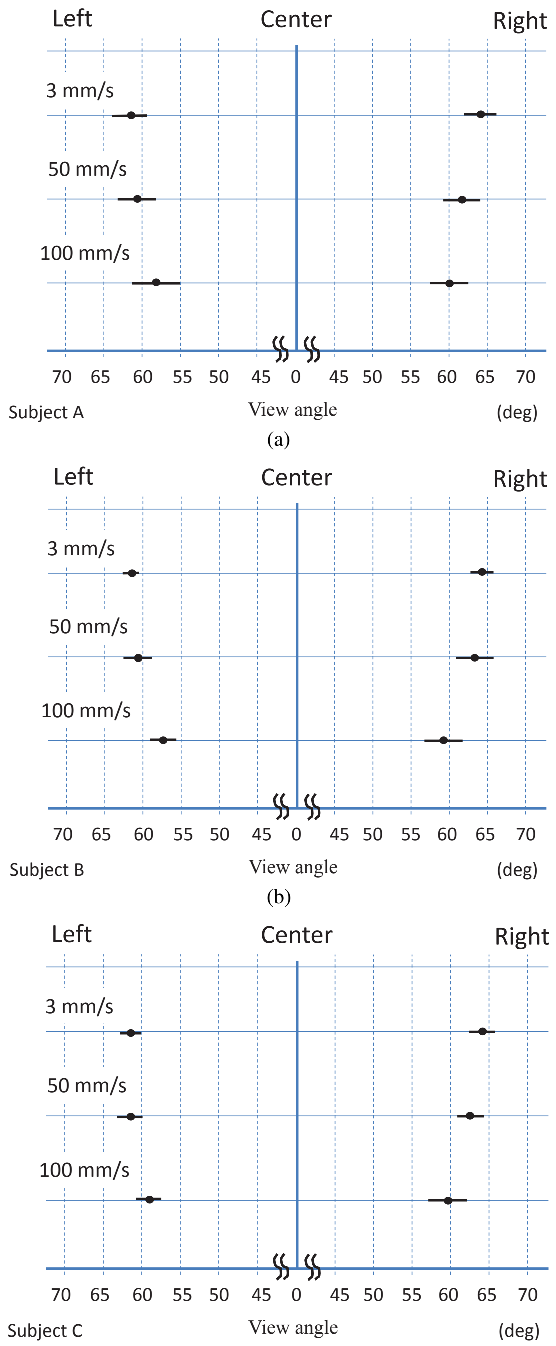

Fig. 15. (a) Results of subject A, (b) results of subject B, (c) results of subject C.

ton was pressed) × (the mark's traveling speed)." Therefore, corrections had to be made for the mark's movement between its detection and the time when the button was pressed.

To this end, the subjects were instructed to focus their gaze on the white square mark displayed at the center of the monitor as in experiment 2. Then, the white (4-pixel) circle was displayed at a view angle of 60° to the right or left at random time intervals. Subjects A, B, and C were instructed to press the button when they detected this circle. The time that had elapsed after the white circle was

Table 12. Response time of the mark at 60°.

	Subject A		Subject B		Subject C	
	Left	Right	Left	Right	Left	Right
Average (s)	0.42	0.44	0.39	0.34	0.41	0.39
Standard Deviation (s)	0.03	0.04	0.04	0.08	0.07	0.04

displayed on the monitor until the subject pressed the button was measured. In this experiment, the subjects were informed in advance that the white circle would be displayed at a view angle of 60° either to the right or to the left. Twenty trials were carried out, and the response time was measured. The mark was displayed to the left and right 10 times each in random order. The results are presented in **Table 12**.

It has been pointed out that the response times for stationary and traveling visual stimuli depended on the view angle. According to a study by Oyama and Ishigaki [22], the response time in the peripheral vision for a moving object is approximately 500 ms in the vicinity of a view angle of 5°, which is the most sensitive angle for motion cognition in the parafovea and central fovea; this response time is approximately 1.3 times slower than that for a stationary visual stimulus. Meanwhile, it has been reported that the response times for stationary and moving visual stimuli are 435 ms and 455 ms, respectively, at a view angle of 20°, which has the highest retinal cell density and greatest photosensitivity, indicating that there is no major difference between stationary and moving objects. It was thus assumed that the response times for stationary and moving visual stimuli at a view angle of 60° did not differ greatly. On the assumption that the response time against a moving visual stimulus at a view angle of 60° in the peripheral vision was approximately equal to that for a stationary stimulus and that the white circle was traveling during this response time, a correction had to be made to determine the position where the mark was actually detected. The results are shown in **Figs. 16(a)–(c)**. The 3 mm/s mark was sufficiently slow so that no correction was necessary. Meanwhile, the marks that traveled at 50 mm/s and 100 mm/s were considered to have traveled toward the center during the response time and were corrected, which are indicated by the red triangles in **Fig. 16**. The corrected positions represented the view angles in the range 60–65°. Although a series of stricter physiological tests should have been carried out, as a basic design guideline for the system, it can be said that a visual stimulus, whether stationary or moving, was detected at a view angle of 60–65° in both the right and the left side, when a mark was moving from the peripheral toward the central vision. As stated in Section 4.1, when the driver's peripheral vision could not be clearly localized, an approach in which the stimulus traveled from the vehicle's sides toward the center of central vision when the driver was facing the front, as shown in **Fig. 12**, was thought to

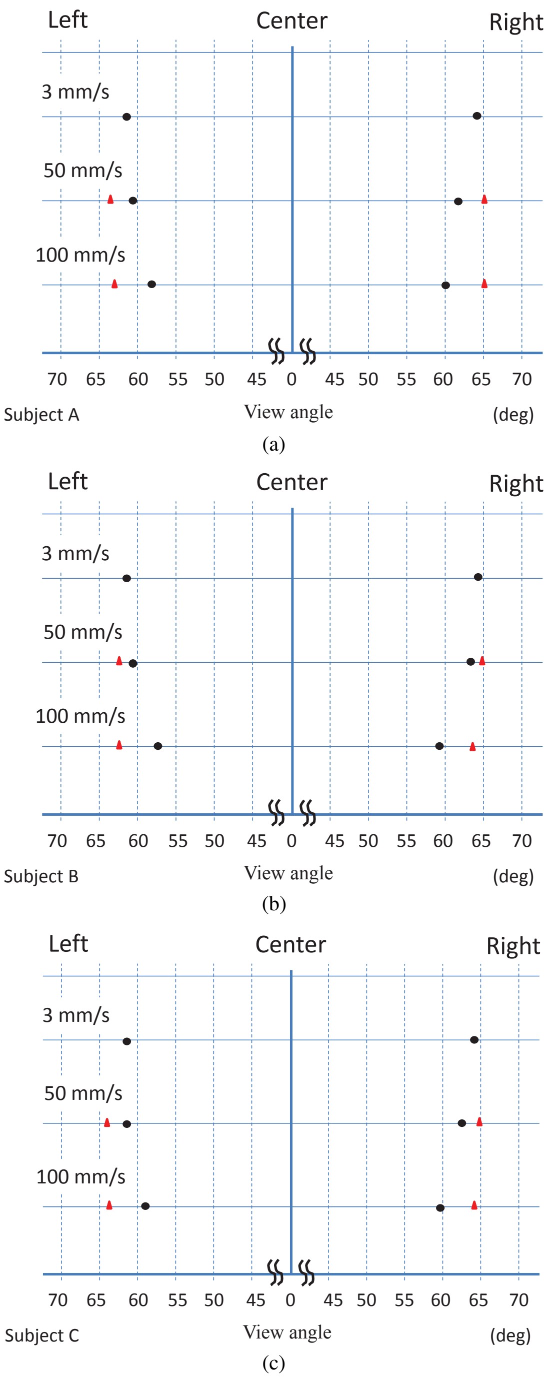

Fig. 16. (a) Compensation of the moving mark of subject A, (b) Compensation of the moving mark of subject B, (c) Compensation of the moving mark of subject C.

be valid.

After the three subjects completed the experiments with the traveling stimuli, they were individually interviewed about their impressions of the moving stimuli. All three stated that they recognized the "difference in speed" of the moving visual stimulus, and they did not have significantly different subjective impressions about the display mode of the stimulus.

4.4. Summary of the Results of Experiments 1 and 2

The following results were obtained from experiments 1 and 2.

1. When a visual stimulus was displayed in the peripheral-vision region of the screen as a subject was playing a game displayed on the game control screen in his central vision, it was found, for example, that the display of a white circle of about 10 pixels blinking at 3 Hz at a horizontal position of 26° and a vertical view angle of 21° resulted in fewer detection failures and was not so annoying.
2. For the subjects in the present study, there was no significant difference in detection time between the four corners of the monitor when the visual stimulus was displayed at a view angle of about 26° in the peripheral vision.
3. In item 1 above, there existed a tradeoff between the frequency of failure to detect the visual stimuli and the subjective evaluation regarding the annoyance level. Visual stimuli that tended to annoy the subject were less overlooked, whereas those that tended not to annoy were likely to be overlooked.
4. When considering the vehicular application of a visual stimulus in the peripheral vision (warning display), it was not easy to accurately determine the driver's peripheral vision because of his change in posture during driving. Thus, a mode of displaying a visual stimulus in which it was traveling horizontally from the outer perimeters of the peripheral vision toward the center of the central vision was investigated. The results showed that a visual stimulus traveling slowly at 3 mm/s on the monitor screen from the outside of the peripheral vision to the center was detected in the vicinity of a view angle of 60°. In many of the subjects, there were no clearly significant differences between the right and the left direction.
5. In item 4 above, there was no major difference in the detected view angle in cases when the white mark traveled on the monitor screen at 50 mm/s and 100 mm/s. Note, however, that it was assumed that the response times against the stationary and moving stimuli were the same as in the vicinity of a view angle of 60°.
6. From experiment 2, it was found that the driver recognized an object at the view angle range of 60–65° to the right and left in the peripheral vision. Design parameters such as the illumination range of the visual-stimulus display device and the traveling speed should be determined on the basis of this view angle.

Important design parameters related to design guidelines for a system that displays visual stimuli to the peripheral vision can be obtained from the above experiment results. For the configurations for actually displaying a visual stimulus to the driver's peripheral vision, we can consider a method in which an optical illumination device, whose illumination direction can be controlled, can be mounted close to the center of the overhead console to project the stimulus to the inside of the windshield or a method that can project an image using LEDs from the upper surface of the dashboard to the inside of the windshield, such as the HUD mentioned earlier. Alternatively, one can mount a device such as an LED tape, in which a string of LEDs are positioned beginning at the driver's door side, pass over the upper part of the front dashboard, extend to the assistant driver's seat door side, and are illuminated in sequence. Although the display of a visual stimulus is limited to a low position, this is a low-cost and practical mounting method.

The present study is an elementary investigation of the effect of presenting a visual stimulus within the peripheral vision. An experiment in which a white mark is displayed on a black monitor screen, which involves a visual stimulus with a high contrast, can be considered to employ an ideal stimulus as compared to realistic usage conditions. Since the objective of this experiment was to examine the effect of a visual stimulus presented in the peripheral vision on humans, at the initial stage, it was evaluated under ideal conditions to assess the method's potentiality. Although actual applications must take place under conditions different from an ideal one, the author believes that this study has been able to propose design guidelines that can be used to determine the optimal specifications of the system, by quantitatively examining the sensitivity of the contrast in terms of the effect of the visual stimulus. Similarly, it is necessary to increase the experiment parameters and the variety of subject attributes, such as including the elderly. Furthermore, although the present experiment was conducted from the standpoint of transmitting information by consciously recognizing visual stimuli in the peripheral vision, it is also necessary to investigate the subliminal effect of presenting a stimulus in the peripheral vision lying beyond 65° that is not explicitly registered in the conscious mind.

5. Conclusions

This study examined a method for frequently inducing the driver's attention in locations where dangerous events may occur from a statistical standpoint, such as alleys where pedestrians may emerge or accident-prone locations, when the driver is operating the vehicle on his or her own instead of with autonomous driving. This study proposed design guidelines for vehicular application from the standpoint of issuing warnings by presenting a visual stimulus in the peripheral vision.

Since it is unknown whether a dangerous event will always occur when attention is induced on the basis of the probability of the occurrence of a dangerous event determined from statistical data, the user's trust of the system's warning will be lowered when his or her attention is frequently induced, making it highly probable that he or she will be annoyed by this display. However, this study found that the sensory evaluation level on the sense of annoyance may be low when visual stimuli are presented in the peripheral vision. It also found that there was a tradeoff between the sensory evaluation of annoyance and the frequency of overlooking the mark displayed in the peripheral vision and that this tradeoff was found to be related to the size (displayed area) and to the presence or absence of a blinking mark. Furthermore, in view of actual vehicle applications, the study investigated the display of a visual stimulus that traveled from outside the peripheral vision toward the central vision and found that it was detected in the view angle range of 60–65°. It was considered that, in the vicinity of a view angle of 60°, the view angle of detecting a moving visual stimulus was not so different from that of a stationary one.

Since the number of subjects was low, the author is planning to extend the experiment by employing subjects over a wider age range. In particular, since the visual characteristics of the elderly are different, it is necessary to carry out similar experiments with elderly subjects. In addition, the author plans to investigate in detail concrete measures aimed at actual vehicular applications.

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Name:
Hiroshi Takahashi

Affiliation:
Professor, Shonan Institute of Technology

Address:
1-1-25 Tsujido-Nishikaigan, Fujisawa, Kanagawa 251-8511, Japan

Brief Biographical History:

1981 Graduated from Yokohama National University with a BS Degree in information engineering
1983 Completed the Master's Degree program in electronic systems in the Interdisciplinary Graduate School of Science and Engineering at the Tokyo Institute of Technology
1983-1986 Worked for Toshiba Corporation
1986-2007 Joined Nissan Motor Co., Ltd. and was engaged in research at the Nissan Research Center
1999-2002 Served as a Visiting Professor at the Tsukuba Advanced Research Alliance, University of Tsukuba Graduate School
2003-2007 Visiting Professor in the Interdisciplinary Graduate School of Science and Engineering at the Tokyo Institute of Technology
2007- Professor in the Faculty of Engineering at the Shonan Institute of Technology

Main Works:

- "A Preliminary Study on the Handling of a Robotic Arm Based only on Temporarily Provided Auditory Information as a Substitute for Visual Information < The Case Study that Assumed the Resilient System Architecture >," H. Takahashi, J. Robot. Mechatron. (JRM), Vol.29, No.2, pp. 406-418, 2017.
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- "Key Technology Analysis for Driver Support Systems in Japan," H. Takahashi, J. of Computer Technology and Application (CTA) David Publishing, Vol.4, No.4, pp. 212-222, 2013.

Membership in Academic Societies:

- The Institute of Electrical and Electronics Engineers (IEEE)
- The Institute of Electrical Engineers of Japan
- The Japan Society of Mechanical Engineers
- Japan Society for Fuzzy Theory and Intelligent Informatics (SOFT)
- The Society of Instrument and Control Engineers