Evaluation of interfaces presenting information to a person in terms of visual fields and the amount of information provided

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Abstract

Methods for presenting information by utilizing a visual field (such as driver peripheral vision) are attracting increased attention in association with an increase in the amount of information required for driver assistance. However, studies on interfaces utilizing such a visual field are currently insufficient. In addition, to avoid information overload, it is important to evaluate different interfaces in terms of the amount of information presented. The authors researched those interfaces from the viewpoint of ergonomics with the purpose that the result is possible to be applied to various researches mainly in the field of automobiles. Through an in-house experiment, participants viewed video clips presenting dot patterns within their peripheral vision or effective visual field (which is nearer to the gazing point than peripheral vision), and then answered questions regarding the positions and moving directions of the dots and the mental workload they experienced. The authors prepared two types of dotted patterns (fixed and moving) based on the perceptive characteristics of peripheral vision. The number of dots varied from one to six. The rate of misperception and participant mental workload were calculated. The results showed a tendency for the effect of the visual fields to depend on the type of dot pattern. It appears that the interface for peripheral vision may have resulted in a lower accuracy when fixed objects were presented, whereas fewer differences occurred when moving dots were shown. This implies that information with motion can be more suitable for interfaces utilizing peripheral vision. A larger amount of information and number of tasks resulted in lower accuracy and higher workload. Moreover, the relation between the number of dots and the rate of misperception (estimated based on percentage) suggests that the rate of misperception may increase significantly when either four or more fixed objects, or three or more moving objects, are presented.

Keywords: Human machine interface, Peripheral vision, Effective visual field, Amount of information, Automobile, Mental workload

1. Introduction

Researchers have recently shown an interest in utilizing the visual fields as a way of presenting information. First, because several researchers have proposed their own definitions, this paper defines three types of visual field: foveal vision, peripheral vision, and an effective visual field (as shown in Figure 1).

Foveal vision is defined as the visual field within 2° from the gazing point (Strasburger et al., 2011), with an accurate sight line.

Peripheral vision is the visual field outside the Foveal vision. Wertheim (1894) revealed that peripheral vision is significantly poor. By contrast, it is well known that peripheral vision has relatively better characteristics in perceiving a temporal stimulus. It was revealed that the visual field nearer the gazing point in peripheral vision surpasses the Foveal vision regarding the capability of processing temporal information such as flicker (Hartmann et al., 1979).
The effective visual field, sometimes called the useful field of view, is a visual field in which useful information can be gained in a brief glance without eye and head movements, and it is well known that its size varies depending on situations and individuals (Ball et al., 1988). Because it is difficult to measure the size of every participant at all times, this paper defines the size of the effective visual field as a constant. Referring to the definitions given in certain studies (Mochizuki and Suzuki, 2014; Tanishige et al., 2015), the size was defined as 30° wide and 20° high.

With regard to studies on peripheral vision in the field of automobiles, researchers have focused on such characteristics as the perception of temporal stimuli. As basic research into its application in automobiles, some researchers have investigated a suitable way to show a discriminable visual cue in the peripheral vision that is not annoying to drivers (Funakawa, 2009; Takaoka and Nakano, 2018; Takahashi, 2017). The approach of this paper is similar to these researches that are conducted from the viewpoint of ergonomics. In addition, as a more practical application to a driving support system, Mochizuki and Suzuki (2014) proposed a method to present two different types of information using both peripheral vision and the effective visual field in parallel at an intersection. Many of the proposed interfaces such as this research support driver's situational awareness by using LED or a display on the frame of the front window and so on. For example, a LED bar on the inside of the front door which indicates an approaching vehicle from the behind in lane change (Löcken et al, 2019), and a LED bar on the window frame which indicates danger and safety in front and side (Dziennus et al, 2016). This paper mainly assumes these researches as applications, although it is also applicable to other fields. The background of these related studies is an increase in the driver assistance information and information displays. Current automobiles may present drivers with large amounts of information from numerous sensors and data communication through the use of multiple digital displays. Therefore, a new method to present information is necessary. Although it is expected that large amounts of information will be presented through these visual fields in the future, there have been few reports comparing different interfaces utilizing peripheral vision and the effective visual field and how to utilize them. Some studies, such as that conducted by Mochizuki and Suzuki (2014), have compared these two visual fields, although the scenes and information presented were limited.

Moreover, it is important to consider the amount of information in evaluating the interfaces presenting information. Because there is a limitation in human cognitive capability, excessive information may become a risk. Ito et al. (2015) evaluated the amount of information for a motorcycle head-up display, and Uotsu et al. (1997) evaluated the amount of information for traffic signs. By contrast, there have been few studies on interfaces utilizing visual fields in terms of the amount of information provided. Therefore, such interfaces were investigated in this study in terms of the amount of information and the visual fields.

The purpose of this paper is to evaluate interfaces presenting information in terms of the visual fields and amount of information given from the viewpoint of ergonomics. This paper compares the interfaces for peripheral vision and the effective visual field when a more generalized and fluctuating amount of information is presented without limitation. In this study, the accuracy of the recognition is measured to evaluate the usability of each interface, because it is important for drivers to recognize the information clearly. In addition, the mental workload is measured in this study.

![Fig. 1 Definitions of the three visual fields](image-url)
study, because it has been suggested that an interface using peripheral vision tends to reduce the workload (Mochizuki and Suzuki, 2014). The authors discuss these interfaces in terms of their effect of the visual field and the amount of information given on the accuracy and workload.

2. Methods

Because the authors aimed that the result of the experiment can be applied to various conditions, they conducted an in-house experiment using a display monitor without a driving simulator to evaluate the interfaces without the influences of traffic conditions or driving operation. The authors prepared two types of video simulating interfaces. One interface presents information within the peripheral vision of the participants, and the other presents information within the effective visual field. Dot patterns were prepared as the information presented by these interfaces. After the participants viewed the dot patterns on the monitor, they answered questions about them. In addition, they responded to the mental workload they experienced. The authors calculated the rate of misperceptions from the answers and estimated the mental workload of the participants from a subjective evaluation.

2.1 Experiment setting

Figure 2 shows the experiment setting. Videos showing dot patterns were played on a 40-inch LCD monitor (JAPANNEXT JN-V400UHD). The eye position of participants was fixed using a chin fixing tool because many researches about peripheral vision in automobiles aimed to support for a driver to obtain information while the driver was gazing at foreground. Therefore, it is assumed driver's head and gazing direction are fixed at foreground. The distance from the eye position to the monitor was 40 cm. The size of dots and the angle from the eye point to the dots for peripheral vision were determined at first, and then the distance was adjusted to the maximum within the limitation of the monitor size. The authors didn't regard the distance as important as the size and angle of dots because visual cues for peripheral vision in many researches and this experiment were designed with the aim that a driver didn’t focus on them to get information. A laptop computer (Sony, VJS151C11N) and the iTunes (ver. 12.9.5.7) media player application were used to play the videos.

2.2 Dot patterns

The authors adopted simple dot patterns as the presented information, referring to a will-o'-the-wisp pattern (Funakawa, 2009), which is suitable to peripheral vision. Two types of dot pattern were applied. One consisted of fixed dots expressing information based on their position, and the other consisted of moving dots expressing information based on the position and moving direction of the dots. Corresponding to each type of dot pattern, the participants were imposed with two different tasks, namely, to answer questions about where dots in a fixed pattern were placed, and where dots in a moving pattern were located and their direction of movement.

In addition, to examine how the accuracy and mental workload changed based on the amount of information, the number of dots composing a dot pattern varied from one to six. The number of dots was determined based on an experiment about the peripheral vision (Takaoka and Nakano, 2018). Based on the experiment, the misperception rate for the fixed dots didn’t increased drastically between six and seven dots. On the other hand, the rate for moving dots increased abruptly from one to four and was expected to be almost 100% for six. Therefore, there seemed little gain from adding more conditions which displayed more than six dots.

A total of 60 different patterns of fixed dots were prepared. The 16 positions where a dot could be placed are shown in Fig. 3, and 10 patterns were made for each number of dots. The positions were determined randomly. The patterns in which the dots were at adjacent places were removed to decrease the variation in difficulty among the patterns for the same number of dots because such dots can be memorized as a single set. In addition, Baddeley (1992) reported that the human short-term memory system has two subsystems, a visuospatial sketch pad that stores visual images and a phonological loop that stores speech-based information. In this experiment, several patterns in which dots formed a well-ordered polygon or character were much easier to be memorized because they can be memorized as a name of the polygon or character with a phonological loop. Therefore, such patterns were also removed to focus on the visual memory and to average the degree of difficulty.
Sixty different patterns of moving dots were prepared in the same way. The positions were determined randomly for the 16 positions. For the patterns of moving dots, each dot moved over the position in one of four directions, up, down, left, or right. The moving dots started from the positions shifted from the positions of the fixed dots, and the middle point of the movement corresponded to the positions of the fixed dots. The moving directions were determined randomly. The moving areas of each position did not overlap each other. Easy patterns were removed in the same way as the fixed dot patterns. In addition, patterns in which more than half of the dots moved in the same direction and patterns that were considered to have a well-ordered motion such as a vortex were removed for the same reason.

The participants were informed of the 16 positions and the 4 moving directions in the explanation regarding the experiment, but were not informed of the rules used to remove the specific dot patterns.

2.3 Videos

Two types of video clips were prepared for each dot pattern to simulate two interfaces, namely, an information display for peripheral vision, and an information display for the effective visual field. The size, the angle from the eye position and the color of dots for the peripheral vision were determined by reference to the previous researches about peripheral vision (Funakawa, 2009; Mochizuki and Suzuki, 2014; Tanishige et al., 2015). Because there are few references about other factors such as the size of dots for the effective visual field, brightness and speed, they were adjusted to satisfy the limits of the experiment setting such as the monitor. In addition, it was considered that participants can distinguish the position and the moving direction of a dot in the single dot condition because an interface that a driver cannot see precisely even in the easiest condition was regarded useless. The process applied to show a dot pattern in one video clip is shown in Fig. 4. The presentation time of the pattern was 2 s and the participants needed to wait for 1 s until the answer time. The presentation time was determined by referring to guidelines concerning the provisioning of traffic information (National Public Safety Commission, 2002). The frame rate was 30 fps. These videos clips were made using the Aviutl (ver. 1.00) video editing application.

The layout of the video clips for peripheral vision is shown in Fig. 5(a). In the video clips used for peripheral vision, dots were presented on a monitor 49.8 cm high and 88.4 cm wide. The background was black, and the dots were orange in color. The dots were placed at an angle of 27.4° vertically and at an angle of 38.9° horizontally from the eye position. The vertical distance between dots in the side lines was 10.4 cm (center to center), and the horizontal distance between dots in the upper and lower rows was 16.1 cm (center to center). In addition, the diameter of the dots was 3.1 cm. The movement distance of the moving dots was 4.6 cm, and thus the speed was 2.3 cm/s. The edge of the dots was blurred by a filter of the application to avoid the gaze of the participant. Moreover, a white star (0.7 cm by 0.7 cm) was placed at the center as a gazing point to deter the participants from gazing at each dot directly with their effective visual field.

The layout of the video clips for the effective visual field is shown in Fig. 5(b). In the video clips used for the effective visual field, dots were shown in a black frame 7.2 cm high and 12.6 cm wide. The colors of the background
and dots were the same as in the video clips for the peripheral vision, and the color outside of the frame was gray. The
dots were placed at an angle of 4.2° vertically and at an angle of 6.6° horizontally from the eye position. The vertical
distance between dots in the side lines was 1.5 cm (center to center), and the horizontal distance between dots in the
upper and lower rows was 2.3 cm (center to center). The diameter of the dots was 0.4 cm. The movement distance of
the moving dots was 0.6 cm, and thus the speed was 0.3 cm/s. Although it is not necessary to set a gazing point under
the condition of an effective visual field, the same white star was set to make the conditions equal to those of the videos
used for peripheral vision.

2.4 Answer Method

The participants answered regarding the positions and directions of the dots on a marked sheet upon which the
circles corresponding to the 16 positions and the central star were printed. They marked the circles where they had
perceived the dots. When a moving dot pattern was presented, they drew arrows over the circles corresponding to the
middle point of the movement. A strict criterion requiring perfect answers by the participants was adopted because only
one misperception may lead to a traffic accident when driving. An answer was regarded as correct when all answers
were correct. One condition consisted of ten trials, and the rate of misperception of one condition of one participant
was calculated by dividing the number of incorrect answers by 10. In addition, the participants evaluated their mental
workload using Raw TLX, a simple NASA-TLX method (Miyake and Kumashiro, 1993), for each condition. The range
of value of Raw TLX is zero to 100, and a higher value indicates a higher mental workload. A Python application
running on a laptop PC (Dell, INSPIRON N5110) was used to apply the Raw TLX.

2.5 Participants

A total of 30 people participated in the experiment, but the data of 6 were not used owing to an error in the
experimental instruction or the video clip. Accordingly, data from 17 men and 7 women (18–29 years in age, mean of
21.7, SD of 2.3) who self-reported as healthy were used. All participants completed an informed consent form. Ethical approval for the experiment was obtained from the Ethics Committee Regarding Experiments and Surveys on Human Subjects of Interfaculty Initiative in Information Studies, Graduate School of Interdisciplinary Information Studies, the University of Tokyo.

### 2.6 Experiment procedure

The procedure used for this experiment was as follows.

- The participants received a description about the dot patterns and the tasks required. At this time, they were instructed to not memorize the multiple dots clustered together and to not name the positions of the dots similar to an address. They were also instructed to not gaze at each dot in the video clips used for the peripheral vision, and a star was placed at the center to act as a gazing point.

- The participants practiced answering on a marking sheet using 12 video clips. The video clips consisted of fixed dots for the effective visual field, fixed dots for the peripheral vision, moving dots for the effective visual field, and moving dots for the peripheral vision. The number of fixed and moving dots were four and three respectively. Three video clips of each type were used. The participants were also instructed how to answer the mental workload on the Python application.

- The participants answered regarding all 24 conditions shown in Table 1. The order of these 24 conditions was counterbalanced between the participants using a Latin square.

- Every condition consisted of 11 trials: 1 for practice and 10 for analysis. Because the dot patterns of the video clips were displayed in small thumbnails on the video player for a short time before starting the 11 consecutive clips, the first video acted as a cushion to leave time before the 10 trials for analysis. In addition, to deter the participants from memorizing the patterns by seeing the thumbnails beforehand, at the beginning of the experiment they were instructed to answer based on what they saw during each trial.

At the beginning of one condition, the participants received a description regarding the type of interface, the type of task, and the number of dots. The 11 video clips were shown in the same order for all participants. When a trial was skipped because the video continued to play while a participant answered regarding the previous clip, the skipped trial was reapplied at the end of the current condition. After all trials under one condition were conducted, the mental workload felt by the participant under that condition was evaluated.

| Table 1 24 conditions applied for the participants. Each condition included 10 trials. | Number of dots | Total |
|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| peripheral vision | fixed dot | 10 | 10 | 10 | 10 | 10 | 10 | 60 |
| | moving dot | 10 | 10 | 10 | 10 | 10 | 10 | 60 |
| effective visual field | fixed dot | 10 | 10 | 10 | 10 | 10 | 10 | 60 |
| | moving dot | 10 | 10 | 10 | 10 | 10 | 10 | 60 |
| Total | 40 | 40 | 40 | 40 | 40 | 40 | 240 |

### 2.7 Logistic Regression

Logistic regression is an analysis used when the dependent variable is binary. It is able to estimate the ratio of one category against all categories from the value of independent variables. Logistic regression presumes the relation shown in Eq. (1), and regresses the ratio \( y \) from the independent variables \( x_i \). The strength of the effect of \( x_i \) can be evaluated from \( b_i \) and its \( p \)-value.

\[
y = \frac{1}{1 + \exp(-(b_0 + \sum b_i x_i))}
\]  

(1)

In this paper, because the answers were separated into two categories, correct or incorrect, the authors adopted a logistic regression. The ratio \( y \) is the rate of misperception and \( x_i \) is the type of interface (peripheral vision or effective
visual field), the type of task (fixed or moving dot), the number of dots (one to six), and their interactions. The authors used the forced entry method. Before applying a logistic regression, the number of dots was centralized by subtracting its average to avoid a multicollinearity. With regard to the coding of categorical variables, the authors encoded “peripheral vision” as -1, “effective visual field” as 1, “fixed dot” as -1, and “moving dot” as 1. It was confirmed that the variance inflation factor (VIF) used for checking the multicollinearity was below the threshold of 10.

By contrast, logistic regression is applicable only to between-subject factors. Therefore, it is inadequate to apply such regression to this experiment in which every factor is a within-subject factor. To solve this problem, the authors used logistic regression with generalized estimating equations (GEEs). A GEE is a statistical method used to conduct an analysis of the longitudinal data (Liang and Zeger, 1986), and is widely used to apply logistic regression to the analysis of the within-subject factors. The authors applied a GEE to conduct a logistic regression using SPSS (ver. 23, including Advanced Statistics Package), which is a statistical analysis software developed by IBM (IBM Knowledge Center, n.d.).

GEE applies an analysis using a working correlation matrix, which presumes the correlation between repeated measurements of the data. If the presumed correlation is similar to the actual correlation of the data, the result of the GEE is more reliable. Thus, it is important to choose the proper matrix. Some working correlation matrices have been developed. For example, if the values of the repeated measurements fluctuate over time, the first-order autoregressive working correlation structure “(AR(1)),” which assumes that repeated measurements have a first-order autoregressive relationship, is suitable. If the repeated measurements are from one person or cluster, the “exchangeable” working correlation structure, which assumes homogenous correlations between the repeated measurements, performs well. Although the correlation of the measurements is occasionally unclear, it is possible to determine which matrix is superior based on the goodness of the regression model by using a statistical criterion—the QIC (Pan, W., 2001). The authors arranged certain types of matrices and compared them using the QIC. The arranged matrices were “AR(1),” “exchangeable,” and “independent,” which assumes no correlation between repeated measurements. A GEE with these matrices was conducted during each test and sub test, and the most suitable working correlation matrix was selected based on the QIC. The results of the statistical tests shown in the results were calculated from the selected working correlation matrices.

3. Results

3.1 Rate of misperception

The rate of misperception under each condition is shown in Fig. 6(a). The interaction between the type of interface and the type of task is marginally significant \( p < 0.10 \). For each type of task, the simple main effect of the interface was tested. For a “fixed dot,” the rate of misperception for the peripheral vision tended to be higher than that of the effective visual field with marginal significance \( p < 0.10 \). For a “moving dot,” no significant difference \( p > 0.10 \) was shown. The boxplots of these comparisons are shown in Figs. 6(b) and 6(c). For each type of interface, the simple main effect of the task was tested. The rate of misperception of a moving dot is significantly higher than that of a fixed dot on each interface \( p < 0.01 \).

The type of task, the number of dots, and their interaction were significant \( p < 0.01 \). The main effect of the number of dots on each task was tested. The effect was significant for each task \( p < 0.01 \). A multiple comparison between the numbers of adjacent dots, such as two and three, was conducted for each task. The significance level was revised based on a Bonferroni correction. The larger number of dots increased the rate of the misperception when the number of dots was one to five for each task with significance \( p < 0.05 \) between two and three fixed dots, and \( p < 0.01 \) for every other difference. By contrast, between five and six fixed dots there was no significant difference \( p > 0.10 \), whereas a marginally significant difference \( p < 0.10 \) was shown for moving dots. The main effect of the type of task on each number of dots was tested. The rate of the misperception of moving dots was higher than that for fixed dots \( p < 0.05 \) when the number of dots was one, and \( p < 0.01 \) when the number of dots was two to six.)
3.2 Mental Workload

The results of Raw TLX are shown in Fig. 7. A three-way ANOVA showed that the type of task, the number of dots, and their interaction were significant ($p < 0.01$). After the data were paired based on the participants, a test of the main effect and multiple comparisons were conducted. The main effect of the number of dots was tested through a Friedman test, and was shown to be significant for each task ($p < 0.01$). A multiple comparison between the adjacent numbers of dots on each task was conducted using a Wilcoxon signed-rank test. The significance level was revised based on a Bonferroni correction. The larger number of dots increased the value of Raw TLX ($p < 0.05$ between four and five fixed dots, and between five and six fixed dots, and $p < 0.01$ for all other differences). The main effect of the type of task on each number of dots was tested using a Wilcoxon signed-rank test. The value of Raw TLX for moving dots was higher than for fixed dots for all numbers of dots ($p < 0.01$).
3.3 Cumulative percentage

To examine the relation between the number of dots and the rate of misperception precisely, the cumulative percentage was calculated. The plots of the cumulative percentage based on the number of dots for each interface and task are shown in Figs. 8(a)–8(d). These plots show within what percentile the participant was when conducting a task with a particular rate of misperception. For example, in Fig. 8(a), when the condition was five dots, a participant who answered with a 10% misperception rate was within the top 20th percentile. In other words, only the participants in the top 20th percentile were able to answer with a misperception rate of no more than 10%. For another condition (four dots), the participants in the top 40th percentile were able to answer with a misperception rate of no more than 10%. In this way, the difficulty for each condition could be estimated.

With reference to the 50th percentile for fixed dots (Figs. 8(a) and 8(c)), for peripheral vision, at least 50% of the participants were able to answer with a misperception rate of no more than 0% for one and two dots, 10% for three dots, 30% for four dots, and 40% for five and six dots. For the effective visual field, the misperception rate was 0% for one, two, and three dots, 20% for four dots, and 40% for five and six dots. The gaps between three, four, and five dots were relatively large. With reference to the 50th percentile for the moving dots (Figs. 8(b) and 8(d)), for peripheral vision, at least 50% of the participants were able to answer with a misperception rate of no more than 0% for one dot, 10% for two dots, 40% for three dots, 70% for four dots, and 100% for five and six dots. For the effective visual field, the misperception rate was 0% for one dot, 10% for two dots, 40% for three dots, 70% for four dots, and 100% for five and six dots. The gaps between two, three, four, and five dots were relatively large.

Fig. 7 The boxplots show the value of Raw TLX under each condition. The type of task, the number of dots, and their interaction were shown to be significant ($p < 0.01$). The bottom, middle, and top lines of the boxes indicate the 25th percentile, the 50th percentile, and the 75th percentile, respectively. The whiskers were 1.5-times the height of the box or are the minimum or maximum values if there is no case within that range. The points are outliers, and the asterisks represent cases whose values are more than 3-times the height of the boxes.
4. Discussion

4.1 Effect of the type of interface

The effect of the visual field tends to differ depending on the type of task. The misperception rate of the interface for peripheral vision tends to be higher for fixed dot, whereas such a difference did not appear for moving dots. A possible reason for this tendency is the properties of the peripheral vision. It was reported that the peripheral vision has superior properties, such as the perception of a stimulus with high-speed motion (Fukuda, 1979). Fukuda also suggested that the background of these properties is an ecological necessity such as security. The author proposed an information gathering process in which a human being reacts acutely to temporal changes in a broader area through peripheral vision and then checks the change precisely through the effective visual field. Based on these characteristics, it is reasonable for the interface used for peripheral vision to have a better performance when information with motion is presented. In other words, the result implies that motion can be a more suitable method for presenting information within the peripheral vision.
In addition, there seemed larger difference between two visual fields when the number of fixed dots was small based on the cumulative percentage when the rate of misperception was around 0% in Figs. 8(a) (c). However, it was difficult to find the difference based on the result of GEE and the 50th percentile in Section 3.3. Because the experiment was designed to cover many conditions, it was possible that such partial difference was difficult to be observed. One potential future work is more detailed research focusing on the difference of the two visual fields when the amount of information is small.

4.2 Effect of the type of task and the number of dots

A tendency for the misperception rate to be higher against a larger number of dots was shown when one to five dots were shown. It is understandable for a larger number of dots, which indicates a larger amount of work, to result in a higher rate of misperception. In addition, the moving dots increased this rate, the reason for which seems to be the amount of work per dot required by the participants. For moving dots, the participants answered both the position and direction, whereas for fixed dots, the participants answered only the position. This can also explain why the boxplot in Fig. 6(a) shows a larger difference as the number of dots increased. The difference in the amount of work between the two tasks is relatively small when the number of dots is small, but increases when many dots are shown. In addition to these factors, the type of task, the number of dots, and their interaction also have an effect on the value of Raw TLX. The Raw TLX results indicate that the participants may have felt the amount of work required.

The difference in the rate of misperception between five and six dots was less apparent during the experiment. For the moving dots, the reason for this seems to be the extreme difficulty of the conditions when five and six dots are shown. Because the rate for these conditions was almost 100%, the difference was difficult to show. However, for fixed dots, a different reason is shown. A possible reason for this is the limitation of the experiment design. It is likely that the participants who are able to memorize fewer than six dots can answer the positions of the six dots easily. Figure 9(a) shows an example of this. If the participants can memorize dots A, B, C, D, and E, they must choose one of the remaining 11 positions. However, if they notice consciously or unconsciously the rule in which the dots must not be placed adjacently, they can guess the position of dot F easily from positions 1 and 2. In the easiest case, if the participants memorize the positions of dots B, C, D, E, and F and notice the rule, they can answer the position of dot A with certainty. This assumption, based on noticing the rule and its elimination, could have helped the participants. When a smaller number of dots is shown, such a presumption can also be used. However, the gain is smaller because the elimination method is not as helpful as when six dots are shown. For example, the easiest case of five dots is shown in Fig. 9(b). Even if the participants remember the positions of dots A, B, C, and D and notice the rule, they must choose one of four positions, 1, 2, 3, or 4. Therefore, it is still difficult to obtain a correct answer. This corresponds to the result in which the rate of misperception increases with the number of dots when the number of dots is one to five. By contrast, it should be noted that the rate of misperception tends to be underestimated in this experiment owing to the effect of the presumption.
4.3 Effect of the amount of information

Based on the logistic regression and the cumulative percentage shown in Fig. 8, there is an apparent difference between two tasks, and the plots can be divided into two groups based on the type of task. With reference to the plots for fixed dots (Figs. 8(a) and 8(c)) and their 50th percentile, the difference in the rate of misperception was much larger between three and four dots than that between one and two, or two and three dots. With reference to the plots of the moving dots (Figs. 8(b) and 8(d)) and their 50th percentile, the difference between two and three dots was much larger than that between one and two dots. Based on these increasing tendencies, the appropriate amount of information in these interfaces seems to be limited to three fixed objects and two moving objects. Psychological experiments showed that the limit to the visual short-term memory is approximately four items at most (Luck and Vogel, 1997), and the results of the neuropsychological experiments were consistent with this (Vogel and Machizawa, 2004; Xu and Chun, 2006). The results of this experiment do not conflict with these studies. By contrast, it must be pointed out that a simple comparison is difficult because these results can be affected by the experiment procedure, such as the presentation time of the information and the answer method. In addition, it is well known that the cognitive capability of the drivers varies depending on the individuals and situations (Ishimatsu and Miura, 2008; Miura, 1998; Vogel and Machizawa, 2004). Based on these previous studies, further research regarding the limitation of information from several points of view is needed, although the results of this study are considered as one criterion for designing these interfaces utilizing visual fields. In addition, the limitation is considered only from the viewpoint of human cognitive characteristics without the relationship to risks in driving. Because assumed risk and the allowable misperception rate depend on each driving condition and the purpose of an interface, designers may reconsider the limitation based on their purpose.

4.4 Application to real driving conditions

The authors evaluated the interfaces without other loads and tasks. Therefore, the limitation of the amount of information and workload estimated in this study can be regarded as the lowest. In the real driving condition, the values can be worse. To apply the result to real driving conditions, each researcher should arrange the limitation probably becomes stricter, depending on the assumed driving condition or the purpose of the interface.

As a method to apply our result to real driving conditions, the authors expect an approach to estimate driver's cognitive resources and workload as the sum of those of subtasks. In this approach, a researcher first estimates resources and workload required in each subtask such as seeing an information display as we tested, seeing other information display, turning the steering wheel and so on, and then evaluates total resources and workload in one driving condition. For example, VACP used in the field of airplane is a method to evaluate the workload in this way (McCracken and Aldrich, 1984). VACP defines cognitive resources of each subtask as a value between one to seven. For example, the value of "Visually Register / Detect" is 1.0 and "Visually track / follow" is 5.4 (Bierbaum et al, 1989). Total cognitive resource is estimated as the sum of these values. In the field of automobile, the workload of information display was estimated by VACP (Aoyagi et al, 2018). They hypothesized the value of VACP of each content of information display and adjusted it to balance with values of other subtasks through a simulator experiment. In this way, they evaluated the workload caused by the information display in the same criterion with other subtasks in driving conditions. In this hypothesizing process, researchers can hypothesize the value of cognitive resource more precisely based on our result that indicates the influence of the content of information such as the amount of the information, the kind of information and the visual field on the rate of misperception and workload.

5. Conclusion

The authors researched interfaces utilizing the peripheral vision and the effective visual field from the viewpoint of ergonomics mainly assuming application to automobiles. They evaluated different interfaces for presenting information in terms of the visual fields and the amount of information provided. They examined the effect of the visual fields, the type of information, and the amount of information in terms of the accuracy and mental workload. An in-house experiment using video clips was conducted. Fixed and moving dot patterns consisting of one to six dots were prepared. The video clips showed the dot patterns within the peripheral vision or effective visual field. The rate of misperception and the mental workload were calculated from the participants’ answers. The results show that the tendency regarding...
the effect of the visual fields depends on the type of dot patterns. It appears that the interface for the peripheral vision may have led to a lower accuracy when fixed objects were presented, whereas little difference appeared when moving dots were shown. Information with motion seems to be more suitable to interfaces utilizing peripheral vision based on these tendencies. Moreover, the larger amount of work led to a lower accuracy and a higher workload. Based on the cumulative percentage of the rate of misperception, the limit to the number of objects in the interfaces presenting information seemed to be three fixed objects or two moving objects. The possibility of a misperception increased significantly when the amount of information surpassed this limit. This implies that these limitations can be a criterion for an information display, but further studies are needed to develop a method to present an appropriate amount of information to drivers. Researchers can hypothesize the cognitive resources needed and workload caused by their interfaces based on the result and apply it to the real driving condition through an adjustment to each interface and driving condition.

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