# Investigating the effectiveness of peripheral vision in reading digital speed limit information displayed in AR-HUD technology

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doi.org/10.21606/iasdr.2023.117

This study aimed to evaluate the effectiveness of peripheral vision in reading digital speed limit information displayed in Augmented Reality Head-Up Display (AR-HUD) technology. In particular, the experiment investigated whether the larger display area and expanded access provided by AR technology in the HUD could improve the efficiency of peripheral vision in reading FHWA Series F font used in U.S. highway signs. Thirty participants aged 19 to 39 were recruited for a simulated driving video experiment. Stimulus numbers were set at the speed limit for urban roads and viewing angles of 20° left, 10° left, 10° right, 20° right, and 5° (above the fovea). The results indicate that peripheral vision can conditionally perceive and read digital speed limit information. However, this ability depends on the angular size and eccentricity of the stimulus height. Our study findings suggest that adjusting the information size, font spacing, and peripheral vision angle can improve the peripheral vision reading of digital speed limit information displayed by AR-HUD.

***Keywords: eccentricity; peripheral vision; digital speed limit information; ar-heads up display (AR-HUD)***

## 1 Introduction

Most traffic accidents and driving incidents are often attributed to drivers taking their eyes off the road. Thus, head-up displays (HUDs) have been proposed to improve driving attention. Previous studies have shown that HUDs effectively reduce a driver's attentional load, have no adverse effects on attention, and preserve the ability to respond to environmental information outside the focus of attention. Compared to HDDs, HUDs reduce the driver's Eyes of Off-Road Time (EoRT) and shorten the time to regain forward field of view (FFOV) attention to the road(Gish & Staplin, 1995; Palinko et al., 2013; Steinfeld, 1995; Weinberg et al., 2011). The HUD's projection penetration feature allows the driver to spend more time scanning the traffic environment and responding intuitively to external conditions and obstacles, thus reducing the driver's mental load and lowering the detection error rate compared to conventional HDD dashboards (Liu & Wen, 2004; Ward et al., 1995). Most drivers feel safer when driving with an HUD due to its improved understanding of the surrounding space, especially in low-visibility conditions(Park et al., 2013; Pauzie, 2015; Tonnis et al., 2007), which enhances driving safety and comfort. In particular, using AR-HUD technology in automobiles provides a broader, more stereoscopic view of the driving environment. This means that drivers using AR-HUD can also see virtual information, such as navigation routes and obstacle warnings, directly in the real environment through the windshield.

However, the information provided by HUDs has been found to be an extension of other traffic hazards. In particular, Eyraud et al. (2015) suggested that HUD information may be a contributing factor to driver distraction crashes. Although HUDs keep the driver focused on the road, they can also monopolize the driver's attention with too many warnings or displays that are poorly designed, leading to visual confusion, reversal of primary and secondary tasks, or overreliance on the information provided by the electronic system and loss of awareness of the environment, resulting in driving hazards. Interface design can lead to additional problems such as confusing and disorienting visual information, unresponsiveness, and cognitive dissonance (Charissis & Papanastasiou, 2010; Gish & Staplin, 1995; Pauzie, 2015). The system design of various HUD-enabled technologies that have been developed cannot display unlimited information. In addition, the cognitive load on the driver due to in-vehicle messages may be more detrimental to driving safety.

Several studies have investigated the potential use of visual and auditory feedback to improve the effectiveness of warning messages and reduce visual overload in automotive HUD interfaces. For instance, studies have examined the impact of color, flashing frequency, and display angles on the effectiveness of message delivery (Horrey & Wickens, 2004; Huang et al., 2013; Moon & Park, 1998). Other studies have focused on the layout (Park et al., 2012) and the location of the display (Chao et al., 2009; Tangmanee & Teeravarunyou, 2012; Tretten et al., 2011). While some studies have suggested the use of auditory or tactile feedback to complement visual feedback, these have been found to have limitations in terms of the immediacy of message delivery and driver attention(Dingus et al., 1998; Park, 2013).

To improve road safety, researchers have explored the potential of peripheral vision to design safer message display methods (Costa et al., 2018; Crundall et al., 2002; Lewandowska et al., 2022; Maglio & Campbell, 2000; Martens & Van Winsum, 2000; Skrypchuk et al., 2019; Strasburger et al., 2011; Svärd et al., 2021). Research suggests that projecting information to the periphery of the driver's visual field can reduce cognitive load without interfering with their primary task of driving (Hess et al., 1994). Additionally, studies have found that human perceptual processing with peripheral vision can be faster than eye movements, allowing drivers to gain a basic understanding of a scene within 100 ms (Andersen et al., 2011; Greene & Oliva, 2009). Drivers can receive messages without shifting their gaze, enabling them to keep their attention on the road (Li et al., 2002; Ng-Thow-Hing et al., 2013). Recent research has also found that using peripheral vision to display messages does not negatively impact the primary task of message interpretation (Makoto et al., 2014; Svärd et al., 2021). In conclusion, peripheral vision can be a useful tool for delivering information to drivers without distracting them from their primary task of driving. While most studies have found that drivers can perceive information with peripheral vision, further research is needed to confirm whether drivers can read information with peripheral vision.

Furthermore, previous studies have shown that messages perceived through peripheral vision are less disruptive to driving. However, a common definition of the range of peripheral vision has not been established. Previous studies combining peripheral vision theory with light-emitting diodes (LEDs) as stimuli for detection tasks have mostly concluded that drivers have good and stable peripheral vision within 20° (van Winsum, 2018; Yang et al., 20-22). The visual crowding theory (Strasburger et al., 2011) mainly affects peripheral vision for reading. Experimental evidence suggests that words can be detected in peripheral vision but not as clearly or quickly as in central vision (Bouma, 1970; Levi et al., 1984). Stuart M Anstis (1974) studied peripheral vision in text perception and reading by asking subjects to fixate at the center of the screen and read the text with their peripheral vision without moving their gaze. He then measured the threshold required for recognition and obtained a graph of the function change of letter size versus eccentricity, as shown in Figure 5. Chanceaux and Grainger (2012) found that peripheral vision can recognize alpha characters in strings, which is beneficial for HUDs because drivers usually pay attention to the hundreds and tens of numbers to maintain a safe driving speed. However, they also reported that the triple interaction between letters (numbers) and symbols (shapes), eccentricity, and visual field is significant.

Since 2010, cars have explored the provision of driver safety information for traffic signs and lanes through an interface that superimposes data on the real-world environment at locations that match the driver's field of view (Jablonski, 2010). However, providing visual information through the HUD still requires the driver to move their central gaze, which may distract their visual attention and impair their reaction time to road hazards.

Therefore, this study aims to evaluate the ability of AR-HUDs to recognize messages using peripheral visual perception and explore the possibility of constructing human-machine interfaces with AR-HUDs in the future. Specifically, the study focuses on the effects of reading HUD message display position (eccentricity) and stimulus size (height) on peripheral visual perception.

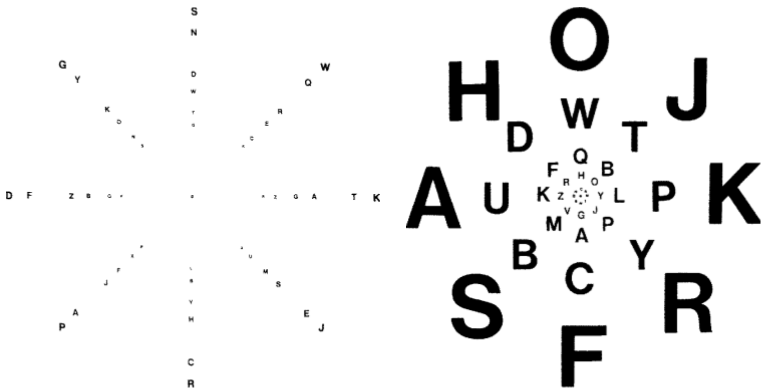


*Figure 1. All letters should lie at threshold when centre of this chart is fixated. Threshold letter size increases linearly with increasing distance from fixation point. (Stuart M Anstis, 1974)*

## 1.1 Peripheral vision & eccentricity

Perimetric vision has been used for decades to study elements of road safety. It has been shown to help drivers detect important and unexpected events that occur in front of the vehicle. When peripheral vision theory is combined with LED detection response tasks, it is mostly assumed that drivers gain good and stable peripheral vision within 20° (van Winsum, 2018; Yang et al., 2022). In an experiment, Kruijff et al. (2018) combined augmented reality with the dynamic behavior of the subject in terms of stimulus location, type, color, and motion state to provide a new range of peripheral vision in this state, as shown in Figure 2 (Kruijff et al., 2018). The definition of the range of peripheral vision may be more consistent with the visual state of the driver, who is faced with the overlap of reality while driving. In the graph of the variation of vision with retinal position proposed (e.g. Figure 1) by Stuart M Anstis (1974), letters of 10 times threshold size were drawn at each eccentricity. In this experiment, all letters at that eccentricity appeared to have the same legibility. Notably, this most widely discussed and applied research on peripheral vision reading proposes the benefits of peripheral vision and font design.

The timing of the message while driving affects the driver's reaction and is directly related to traffic safety. Meanwhile, the study by Stuart M Anstis (1974) did not examine the temporal aspects of message perception by drivers. Chung et al. (1998) investigated the effect of different eccentricities on reading speed and found that reading speed increased with stimulus size but remained constant after reaching a threshold of 0 (central concave) to 20 degrees. Maximum reading speed remained constant after a critical threshold was reached. These studies provide insight into how peripheral vision can transmit and read messages.

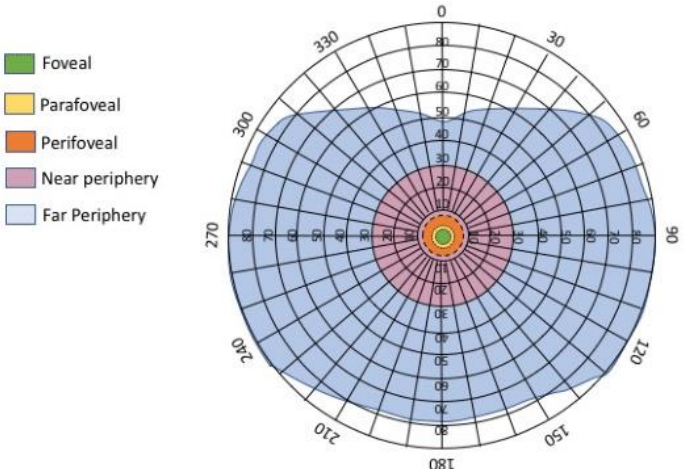


*Figure 2. The different areas in central and peripheral vision (Kruijff et al., 2018; Traquair, 1946; Wolfe et al., 2017).*

# 2 Method

## 2.1 Stimuli

The stimuli for the experiment were selected as speed limit figures of the road. According to the Australian driving safety model, the safe speed limit is the most crucial element in maintaining driver safety, as it enables drivers to react appropriately to unexpected traffic accidents (Council, 2011). To balance the driver's criteria for perceiving speed limit numbers, we excluded easily identifiable numbers like 1, 2, and 4 and chose circular line numbers of 30, 50, 60, 80, and 90 as numerical stimuli.

The FHWA fonts were developed by the Federal Highway Administration (FHWA) of the U.S. Department of Transportation as a set of sans serif fonts and are used for road signs in the U.S., Canada, China, Taiwan, New Zealand, and many other countries. The fonts are designed with high legibility in mind. The E and F series of fonts are most commonly used for speed limit signs in the United States. In the experiments, the FHWA F-series fonts were used to address the theoretical requirement, where peripheral vision crowds text and visual crowding (Bouma, 1970; Levi et al., 1984; Strasburger et al., 2011). The stroke width of the F-series letters is approximately 13-18% of the height, while the height-to-width ratio of the fonts is close to 1:1. Rosen et al. (2014) modified Bouma's law by proposing that the critical spacing is equal between the edges of each object, rather than the center of the object. This proposal facilitated the recognition of glyph strings for peripheral vision (Dudek, 1991; Garvey & Mace, 1996; Lay, 2004; Slattery et al., 2016). The number spacing of 0.26-0.30 times the height of the letters is probably the easiest design to read (e.g., Figure 3).

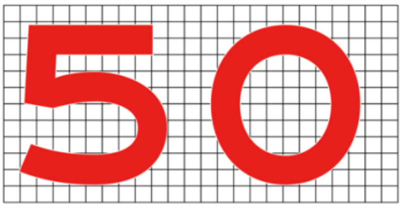


*Figure 3. The letter length-to-width ratio of the experimental numbers is close to 1:1, and the letter spacing is 0.26 times the letter height.*

## 2.2 Stimulus size and position

The stimuli size and location were adopted from Chung et al. (1998). In the experiment, stimulus locations were set at 20° to the left, 10° to the left, 5° (above the fovea), 10° to the right, and 20° to the right. The size of the stimulus appearing at 5° (above the fovea) was considered the standard baseline for detection. The size of the stimulus was measured as the reciprocal of the visual angle of the eye, which is measured in minutes of arc or seconds of arc. Sanders and McCormick (1998) proposed the concept of angle of view to calculate the angle of view versus distance and stimulus height, as depicted in Figure 4.

$VA = (360 \times D) / 2\pi S$ or $VA = 3438 \times H / D$

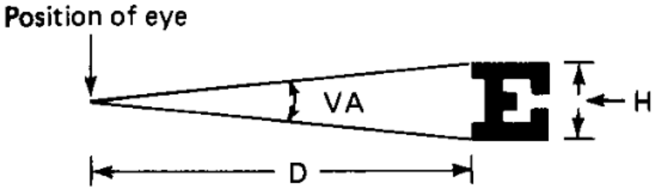


*Figure 4. The concept of visual angle, H = height of eye stimulus (font height), D = distance between eye and stimulus (font) (Sanders & McCormick, 1998).*

The size of the stimuli was based on Chung et al. (1998) experimental visual angles of 0.16°, 1.4°, and 2.22°. Their results suggest that a 2.5 times larger visual angle size would improve reading speed and recommend excluding the less effective 0.16° visual angle. Therefore, 0.4°, 1.4°, 2.22°, 3.5° (From 1.4° x 2.5), and 5.55° (From 2.22° x 2.5) visual angles were used as the experimental stimulus sizes in our experiment. The distance between the simulator screen and the subject was 55 cm; Figure 5 shows the size of the stimuli displayed on the screen based on the equation of visual angle and distance to stimulus height. For the purpose of speed limit reminder, red was selected as the stimulus color attributed to a warning; R35 G24 B21 (#231815) was used as the sample color in this experiment. A total of 50 stimuli were used in each formal experiment.

*Figure 5. Five view sizes of the stimuli and the colors shown in the experiment.*

## 2.3 Instruments

The experiments were performed in the Carnetsoft driving simulator environment movie. The desktop simulator consists of a computer with a GeForce GTX 770 GPU, i7-4790 CPU, Windows 7 PRO operating system, and 16 GB of RAM, connected to a display with a resolution of 1680 × 1050. Images were rendered within a 210-degree horizontal field of view: 70 degrees for the front view and 70 degrees each for the left and right views out the window. A Logitech G29 steering wheel and pedal set, brake, clutch, and gas pedals were used, and the steering wheel had a gear shift lever and response buttons. The experimental screen and the state of the left-hand drive.

## 2.4 Experimental procedure

We set our standard correct reading rate, estimated from condition-specific psychometric functions (i.e., eccentricity x stimulus size) within 4.0 s after 2.0 s of stimulus exposure. As long as the observer correctly reported the vehicle speed, the task was scored as a correct reading. Each psychometric function for eccentricity and stimulus size was based on a total of 10 sets of speed limit numbers presented in computerized order. Each subject used the same stimulus size and presentation to exclude additional variables.

Before starting each experiment, subjects were required to read the task description. The practice video allows subjects to practice keeping their eyes focused on the white cross and to practice perceiving the location of the stimuli and the speed and manner of verbal responses after perception. In all experiments and practice sessions, subjects were instructed to look at a white cross drawn in the center of the display.

In the formal experiment, a small white fixation cross was drawn in the center of the display, and subjects were instructed to look at the fixation cross instead of the stimuli, not to turn their gaze toward the stimuli, and to place their hands on the steering wheel and respond to the perceived number of stimuli as soon as they were perceived and read by peripheral vision. The duration of each stimulus presentation was fixed at 2.0 seconds.

We measured reading effectiveness for five stimulus sizes in central vision (Figure. 5) and retinal eccentricity for left and right visual angles of 20°, 10°, and 5° (above the fovea) in the visual field (Fig. 6). For each eccentricity, 10 stimuli appeared in two sets of computer-ordered, speed-limited numbers with five sizes.

*Figure 6. The location where the stimulus will appear, eccentricity left and right 20°, 10°, and 5° (above the fovea).*

## 2.5 Participants

Thirty young adult participants with normal corrected vision were recruited for the study, with an equal gender distribution (Male and Female, 1:1). The mean age of the participants was 24.8 years (SD = 3.43, range 20 to 35 years). All participants provided informed consent prior to participating in the study and underwent more than one practice session to minimize the potential effect of unfamiliarity with the experimental setup.

## 2.6 Data collection and analysis

The average perceptual rate of each eccentricity for the stimuli (digits), the perceived message correctness of the two stimuli with different eccentricities, and the difference in the overall eccentricity benefit and the gender effect of different stimulus sizes were measured. Finally, the eccentricity X stimulus size interaction effect status was examined. A verbal response time of 4.0 s was given after 2.0 s of stimulus onset. If the time feedback exceeded, the message was considered lost. During each trial, the perceived rate and the number of correct rates were calculated separately for each eccentricity. The performance of each group of digits at different eccentricities was compared to examine the effect of the digit display phenomenon on the subject. This study repeated measures of binary logistic regression analysis of eccentricity x stimulus size data using Excel version 16.69.1.

Binary logistic regression is a widely used method to determine whether participants correctly perceive numerical messages. The dependent variable is dichotomous, with 1 representing correct perception and 0 representing incorrect perception (including unperceived and incorrectly perceived messages). This model is commonly used to identify relationships between categorical dependent and explanatory variables (Nasri & Aghabayk, 2021; Samerei et al., 2021) and has been extensively applied in driving and road safety research, where the dependent variable is dichotomous (Jones & Whitfield, 1988; Kadilar, 2016; Shibata & Fukuda, 1994; Simončič, 2001; Valent et al., 2002). This study employed Rogers' binary regression to examine the effects of display position and message size on the accurate recognition of digital messages, and to explore the differences and interactions between them. We set the experimental significance at $P < 0.05$ to reject null hypotheses and determine the statistically significant effect of the independent variable on the dependent variable. The model's correct prediction rate and odds ratio were analyzed to assess its accuracy. Following the methodology of Al-Ghamdi (2002), insignificant factors were sequentially excluded from the cross-tabulation model to determine their effect on the dependent variable.

# 3 Results

## 3.1 Perceived rates

Table 1 summarizes all feedback for each eccentricity and stimulus size. The mean of the majority response is 1.00, and the SD of the stimulus perception is 0.0, which means that no message was missed and the subject was mostly able to perceive the presence of the stimulus. Therefore, the rate of perception could not be statistically analyzed.

*Table 1. The total perceived rate is the sum of the subject's perceived information, the correct rate effect of the stimulus for each eccentricity, and the subject's lost rate of the message in parentheses.*

| Stimulus | 20° left | 10° left | 5° above the fovea | 10° right | 20° right |
|---|---|---|---|---|---|
| **0.4°** | 0.966666667 (0.033333333) | 1.000 (0.000) | 0.966666667 (0.033333333) | 1.000 (0.000) | 1.000 (0.000) |
| **1.4°** | 1.000 (0.000) | 1.000 (0.000) | 1.000 (0.000) | 1.000 (0.000) | 1.000 (0.000) |
| **2.2°** | 1.000 (0.000) | 1.000 (0.000) | 1.000 (0.000) | 1.000 (0.000) | 1.000 (0.000) |
| **3.5°** | 1.000 (0.000) | 1.000 (0.000) | 1.000 (0.000) | 1.000 (0.000) | 1.000 (0.000) |
| **5.55°** | 1.000 (0.000) | 1.000 (0.000) | 1.000 (0.000) | 1.000 (0.000) | 1.000 (0.000) |

## 3.2 Effectiveness of perceptual speed limit messages

### 3.2.1 Effectiveness of perceptual speed limit messages with different stimulus sizes at different eccentricities

To investigate the effectiveness of reading speed limit messages of different sizes at various eccentricities and central visual fields, we present the effect of two sets of speed limit figures for different eccentricities in Figure 7. The 5° (above the fovea) visual angle is considered the baseline for all data in the experiment to assess the recognizability of stimuli.

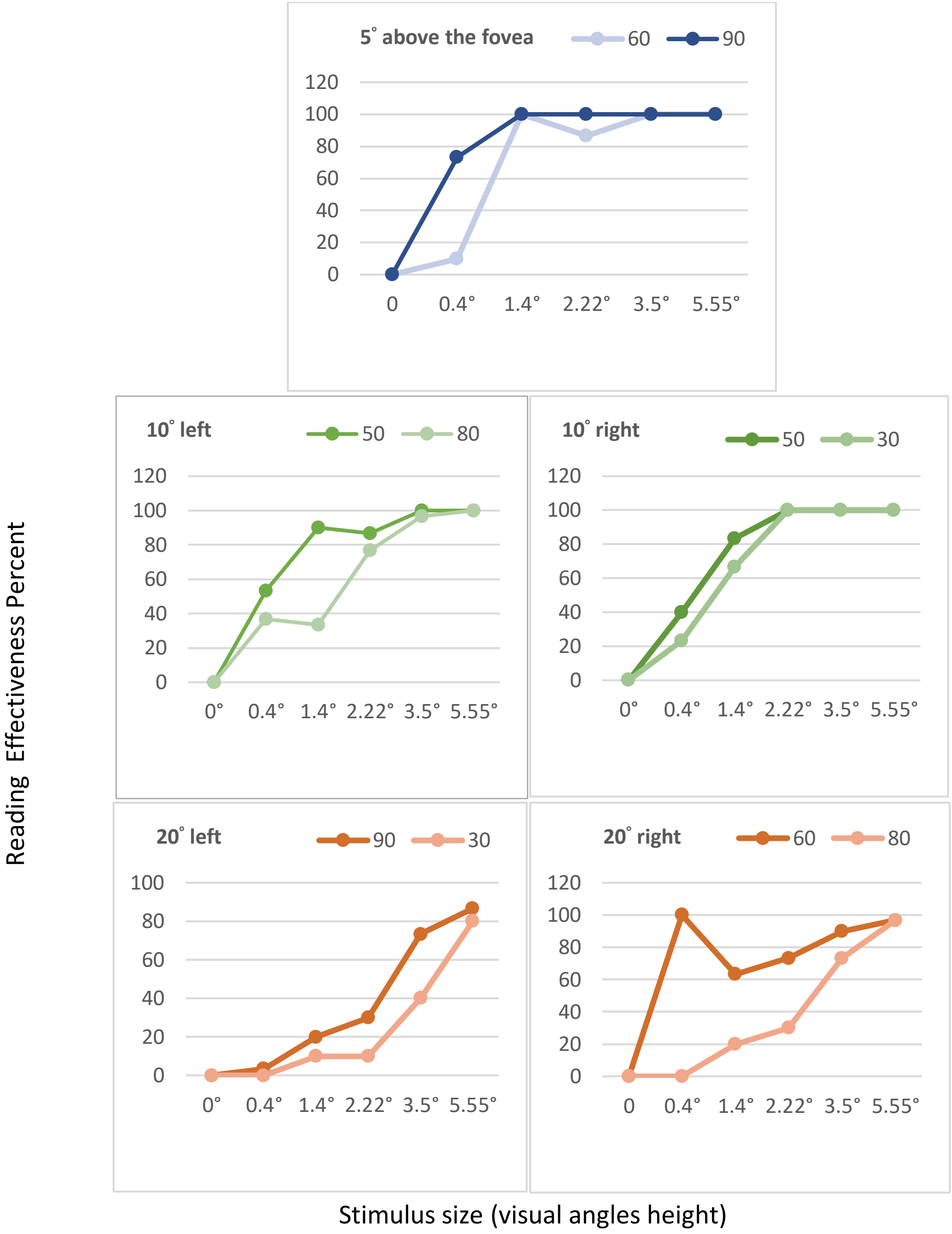
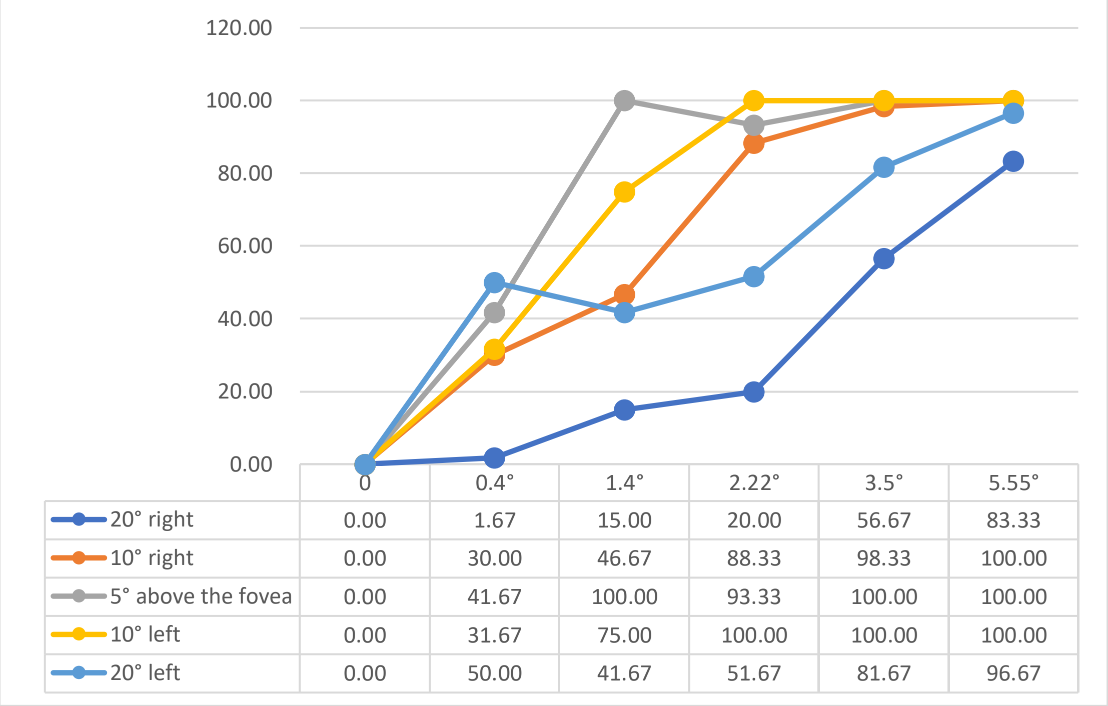


*Figure 7. The baseline for stimulus size in the experiment was established using stimuli appearing 5° above the fovea visual field. At a visual angle of 0.4°, stimulus digit 60 and stimulus digit 90 at the same location showed a discrepancy in the correct rate of perceptual speed-limiting messages. However, both stimulus sizes remained close to the maximum correct rate at a visual angle of 1.4° and beyond.*

Figure 7 illustrates that the stimulus size gradually increased with increasing retinal eccentricity during a controlled fixed reading time for stimuli observed at each viewing angle (Chung et al., 1998). In the present study, the effectiveness of message perception reached a stable level with increasing stimulus size. However, it was observed that the effectiveness of peripheral visual recognition is influenced by the numbers and is not directly related to eccentricity. For the 5° visual field above the fovea, the correct rate of perceived speed-limited messages for sample 90 was 73.33% and 10% for sample 60, with a difference of 63.33% between the two correct rates. A similar phenomenon was observed for the 10° left (1.4°) and 20° right (0.4° and 1.4°), with the lowest perceptual effectiveness for speed limit messages being 60 and 80.

### 3.2.2 Performance differences in total eccentricity and gender effects for different stimulus sizes

A stimulus size of 1.4° yields significant correctness at most eccentricities; as the stimulus size increases, the rate of correctness also increases. A stimulus size of 3.5° yields over 56% message correctness at all eccentricities. The worst performance for all stimuli was observed at the 20° left eccentricity, which necessitates a larger size for compensation, as depicted in Figure 8. The 20° right eccentricity was the second-worst performance. Apart from the standard 5° above the fovea, the left and right 10° positions are ideal for message display. The influence of gender is not significant in the performance of perceived speed limit message accuracy. However, in this experiment, the effect of stimulus height 1.4° in the eccentric 10° left visual field was better for females than males. The overall perceived message effectiveness rate showed a positive slope line growth with stimulus size.



| | 0 | 0.4° | 1.4° | 2.22° | 3.5° | 5.55° |
|---|---|---|---|---|---|---|
| 20° right | 0.00 | 1.67 | 15.00 | 20.00 | 56.67 | 83.33 |
| 10° right | 0.00 | 30.00 | 46.67 | 88.33 | 98.33 | 100.00 |
| 5° above the fovea | 0.00 | 41.67 | 100.00 | 93.33 | 100.00 | 100.00 |
| 10° left | 0.00 | 31.67 | 75.00 | 100.00 | 100.00 | 100.00 |
| 20° left | 0.00 | 50.00 | 41.67 | 51.67 | 81.67 | 96.67 |

*Figure 8. The difference in the overall eccentricity benefit of different stimulus sizes, where larger stimulus sizes corresponded to higher reading effectiveness. The figure reveals that the 20° left eccentricity is a relatively unsuitable position for reading the message with peripheral vision.*

### 3.3 Interaction between eccentricity and stimulus size

Based on our data, we observed that both eccentricity and stimulus size had a direct effect on the correct rate of perceived speed-limited messages. Initially, we hypothesized that there would be an interactive relationship between eccentricity and stimulus size, and we set the significant interaction at $p<.005$. In order to investigate the effects of eccentricity, stimulus size, and gender on the correctness of perceived messages, this study conducted binary logistic regression by dividing eccentricity into left and right. Experimental stimulus size and location were considered and set as continuous variables. The statistical results confirmed that gender ($p=0.44$ and 0.428, $p>0.05$) had no significant effect and was therefore ruled out as an effector in the interaction test. The model demonstrated a percentage of correct predictions of perceived messages of 83.3%, as shown in Table 2, and 82%, as shown in Table 3, which indicates its reference reliability. Both stimulus size and eccentricity significantly influenced the correctness of perceived information on both the left and right sides ($p=0.000$, $p<0.05$). However, the effect of eccentricity on the correctness of perceived information on the right side was not significant ($p=0.115$, $p>0.05$). Furthermore, there was a significant interaction effect between right and left visual field eccentricity and stimulus ($p=0.000$, $p<0.05$).

*Table 2. Effects of self-deviations in the left visual field (eccentricity and stimulus size and gender) on perceiving the correct signal and Eccentricity X Stimulus Size Interactions*

| Independent variable | Regression coefficient | Standard error | Wald statistics | P (Sig.) | Odds ratio |
|---|---|---|---|---|---|
| Gender | -0.411 | 0.204 | 4.061 | 0.44 | 0.663 |
| Stimulus size | 2.267 | 0.308 | 54.291 | 0.000* | 9.650 |
| Eccentricity | -0.175 | 0.030 | 33.35 | 0.000* | 0.839 |
| Stimulus size X Eccentricity | -0.068 | 0.17 | 16.161 | 0.000* | 0.935 |

Cox & Snell $R^2$ sig.=0.449 Nagelkerke $R^2$ sig.= 0.624 Forecast accuracy=83.3% H&L test=0.106

*Table 3. Effects of self-deviations in the right visual field (eccentricity and stimulus size and gender) on perceiving the correct signal and Eccentricity X Stimulus Size Interactions*

| Independent variable | Regression coefficient | Standard error | Wald statistics | P (Sig.) | Odds ratio |
|---|---|---|---|---|---|
| Gender | -0.157 | -0.198 | 0.627 | 0.428 | 1.170 |
| Stimulus size | 3.413 | 0.412 | 68.732 | 0.000* | 30.351 |
| Eccentricity | 0.042 | 0.027 | 2.482 | 0.115 | 1.043 |
| Stimulus size X Eccentricity | -0.139 | 0.022 | 41.328 | 0.000* | 0.870 |

Cox & Snell $R^2$ sig.=0.317 Nagelkerke $R^2$ sig.= 0.484 Forecast accuracy 82 % H&L test=0.110

## 4 Discussion

The performance and effects of eccentricity and stimulus height on the correct reading effectiveness of messages perceived by peripheral vision were investigated. The performance of five stimulus samples of five stimulus size (height) at five eccentricities was tested by fixing the time of message appearance. The results showed that (1) stimuli were perceived at all eccentricities in the experiment. (2) The correct rate of perceived message was found to be related to eccentricity and stimulus size, respectively. Compared to central vision, peripheral vision requires a larger stimulus size to achieve maximum message reading effectiveness. (3) In addition, gender had no significant effect on perceived message accuracy, but women had higher perceived message effectiveness than men for smaller stimuli. (4) There was a significant interaction between eccentricity and stimulus size. However, the effect of stimulus size on the correctness of the perceived message is more pronounced.

Furthermore, in the experiment we used stimuli that were 2 numbers side by side and adjusted their spacing with reference to other studies. We found that the size of the stimuli still contributed to the effectiveness of reading messages with peripheral vision, which is consistent with the teaching of peripheral vision reading (S. M. Anstis, 1974; Stuart M Anstis, 1974; Chung et al., 1998; Ku et al., 2019; Sanders & McCormick, 1998; Summala et al., 1996). We also found that sufficiently large letters can improve the effectiveness of peripheral vision for reading messages but are not recognized by the subject's response to a certain size range. Since the stimuli in the experiment were perceived almost at any eccentricity, it was impossible to confirm whether the visual field sensitivity was related to the size of the stimuli.

In addition, the main reason for choosing the road speed limit as a stimulus is to maintain the appropriate speed so that the driver has enough time to react to sudden traffic accidents. The F-series, the most legible of the FHWA fonts, was chosen for the stimuli, which is also the widened font suggested by Oderkerk and Beier (2021). However, a significant performance gap exists in the 5° (above the fovea) and left-right fields. As previous studies have shown, peripheral vision can detect fonts in peripheral vision but not clearly or quickly enough (Bouma, 1970; Levi et al., 1984). The effectiveness of reading messages with peripheral vision may be affected by the background color or other factors. Related studies have suggested that dynamic background, background color, motion stimuli, color, and luminance can affect the recognition of central objects in peripheral vision (Mairena Flores, 2019; Murata et al., 2000; Noorlander et al., 1983; Tripathy & Cavanagh, 2002). In the present experiment, it is evident that the effect of stimulus size on the correct rate of message recognition was more substantial. Another possibility is that it may take more time for peripheral vision to recognize text messages, thus, necessitating the observation of response time to messages at different eccentricities. Further, more in-depth studies should be conducted to explore font characteristics that are suitable for peripheral vision.

Further, this study also has some limitations. In addition to the explicit statement that only a computer camera lens was used to monitor the subject's eye movements, no experimental device control mechanism (e.g., an eye tracking device) was implemented to check whether the subject was actually looking at the gaze cross. However, the study by Fotios et al. (2016) – which used eye tracking to check whether subjects could be instructed to focus on the cross – concluded that subjects maintained a high level of gaze at the gaze cross during the peripheral test task. Another limitation of this study is that this experiment used a simulator movie, and subjects did not drive the vehicle. Hence, their visual and cognitive load on the correct rate of perceiving and reading messages – as well as the workload when actually operating the simulator for driving and the difference in reaction time – were not discussed. This case will be investigated in the next experiment.

Despite these limitations, our results quantified the performance of normal peripheral vision on perceptual message reading. Noteworthily, these measurements provide some suggestions for developing future applications, shedding light on how AR-HUD messages are delivered and how drivers might read them.

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**Acknowledgement:** This research experiment is thanks to all the participating subjects, Professor Chun-Heng Ho and all the researchers in the Cognition and Perception Laboratory, as well as Dr. Wim van Winsum of Carnetsoft for technical support and partial sponsorship from the Taiwan Ministry of Education Research Grant Program.