High Visibility Conditions in a Sunset Environment

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Abstract

Purpose: There is no standard for high-visibility safety clothing for general pedestrians, nor is it widely used. Therefore, this study investigated visibility in order to examine the standards for high-visibility safety clothing for general pedestrians.

Methods: Twenty normal participants (mean age, 22.4 ± 4.4 years) without ocular disease, except for refractive errors, were studied. All participants had normal visual acuity in corrected vision. This study assumed sunset conditions in Japan. The light source was set up in a dark room, and the illuminance in front of the visual target was set to 300 lx. We investigated the visibility of 142 patterns of black and yellow combination samples with different spatial frequencies, pattern types, angles, and color ratios.

Results: The highest visibility was found at 5.0 cycles per degree of the stripe pattern at the spatial frequency, yellow ratio of 75%, and a stripe angle of 165° .

Conclusions: Under sunset conditions, the brightness decreased when black was combined with yellow. However, it forms a two-color pattern and becomes more conspicuous. The highest visibility was obtained by arranging black and yellow in a diagonal stripe pattern. We predict that establishing clothing standards based on the results of this study will help design safety clothing with increased visibility.

Introduction

The World Health Organization reports that approximately 1.35 million deaths occur due to traffic accidents worldwide [1]. The number of traffic fatalities is increasing worldwide, while it is decreasing in Japan. In 2019, there were 3,215 traffic fatalities in Japan (less than 317 or 9.0%, compared with the previous year), which is the lowest statistic in the post-war period. However, the number of traffic accidents remain high at 381,237 cases per year, with 461,775 people injured (decrease of 64,071 or 12.2% from the previous year) [2]. According to the 2019 statistics from Japan's National Police Agency, many pedestrians were injured in traffic accidents, with the largest number of adults aged 80 years and older (5,277) and the largest number of children aged 7–12 years (3,426). Details of the number of injured pedestrians, assorted by age group, are observable in Supplementary Figure S1. When we looked into traffic accidents involving children, we found that the largest number of traffic accidents occurred between 4 and 6 pm, which is the time when elementary and junior high school students leave from school [3]. For details on the number of injured elementary and junior high school students, assorted by time of day, please see Supplementary Figure S2.

In this study, we focused on high-visibility safety clothing to prevent traffic accidents in children. This clothing should be designed in such a way that safety through high visibility

is ensured. The color and design of the cloth and the retroreflective material used should increase the visibility of the wearer. ISO 20471 high-visibility clothing was established by the International Organization for Standardization in March 2013, and JIS T 8127 high-visibility safety clothing was established by the Japanese Industrial Standards in October 2015 [4, 5]. The current JIS T 8127 standard limits the colors that can be used and does not allow for a variety of color schemes. In addition, retroreflective materials make it difficult to design clothing, and safety is the primary concern of this standard. However, these do not cover general users such as general adults and children, but are limited to workers on highways, public roads, construction sites, parking lots, and other high-risk levels. There have been many field-based studies examining the conspicuousness of road workers and pedestrians wearing reflective materials [6-9], but to our knowledge, no studies have investigated the use of high-visibility clothing in general users. Therefore, it is necessary to create a standard for high-visibility clothing with colors and designs that can be preferred by general users. In this study, we constructed an environment assuming the time of sunset, which corresponds to the time when elementary and junior high school students leave from school, and investigated visibility in terms of spatial frequency, color ratio, and angle of the stripes.

Results

Spatial frequency conspicuity of the stripes and the checkerboard showed that the 5.0 cpd (cycles per degree) stripes were the most conspicuous (Figure 1a). Expressed on the scale graph, a checkerboard of 2.5 cpd and stripes of 2.5 cpd and 5.0 cpd were included within the estimated range, and there was no difference in the conspicuity of the three (Figure 1b). These values were significantly different from the other samples ($p < 0.05$).

Spatial frequency brightness perception of the stripes and checkerboard showed that the checkerboard at 2.5 cpd was the brightest (Figure 2a). Expressed on a scale graph, stripes of 5.0 cpd and 2.5 cpd and a checkerboard of 2.5 cpd were estimated. It was included within the width, and like conspicuousness, there was no difference in the top three brightness sensations (Figure 2b). These values were significantly different from the other samples ($p < 0.05$).

The yellow color ratio of 50% was the most conspicuous in terms of color ratio, and the yellow color ratio of 0% was the least conspicuous (Figure 3a). Expressed on the scale graph, the color ratios of 75% and 50% of the yellow color were included within the estimated range, and there was no difference in the conspicuity of the two colors (Figure 3b). These values were significantly different from the other samples ($p < 0.05$).

The yellow color ratio of 100% was the brightest in terms of brightness perception, and the yellow color ratio of 0% was the least bright (Figure 4a). Expressed on the scale graph,

the color ratios of 75% and 100% of the yellow color were included within the estimated range, and there was no difference between the two brightness values (Figure 4b). These values were significantly different from the other samples ($p < 0.05$).

The conspicuousness in terms of angles was most noticeable at 165° and least noticeable at 90° (Figure 5a). Expressed on the scale graph, 165° , 150° , 30° , 135° , 45° , and 60° were within the estimated range, and therefore, no differences were found (Figure 5b). These values were significantly different from the other samples ($p < 0.05$).

Regarding the brightness in terms of angles, 165° appeared to be the brightest (Figure 6a); however, 180° , 120° , 30° , 45° , 105° , 15° , 150° , 90° , 75° , 60° , and 165° were within the estimated range. Therefore, there was no difference, and the change in angle did not significantly affect the brightness perception (Figure 6b).

Discussion

The main purpose of this research was to investigate visibility in terms of spatial frequency characteristics, color ratios, and stripe angles in order to create high-visibility clothing for general users. The final goal was to create a standard for high-visibility clothing and to spread it among the general public, as it is necessary to use colors and designs that are preferred by general users.

Spatial frequency

In terms of spatial frequency, the stripe pattern of 5.0 cpd had the highest visibility, considering the average degree of preference for conspicuousness and brightness. These results are consistent with previous reports of spatial frequency characteristics using grating patterns and are almost equivalent to the peak sensitivity of spatial frequency in humans, between 3.0 and 5.0 cpd [11]. Both stripes and checkerboard patterns are common in clothing designs, but we found that stripes were slightly more visible in terms of visibility points of view.

Color ratio

In terms of the color ratio, the higher the yellow ratio, the brighter was the result in terms of preference. This is consistent with Ricco's Law, which states that the sense of brightness is proportional to the product of the color illuminating the retina and the intensity of the light; therefore, it is thought that objects with a higher luminance are brighter and more visible. The sense of brightness of the pattern was the same for stripes and checkerboards. In addition, combining them with black color created a contrast and made them more conspicuous, which may have improved their visibility. Therefore, considering the average degree of preference for conspicuousness and brightness, a color ratio of 75% resulted in the highest visibility.

Angle of stripes

In terms of the angle of the stripes, visibility was higher in the oblique direction than in the horizontal and vertical directions, and among the oblique directions, 165° had the highest visibility. The other oblique directions, 150° , 30° , 135° , 45° , 60° , and 15° , had similar visibility, and the difference between 180° and 90° was obvious. According to Appelle's research [12], humans perceive vertical and horizontal stimuli better than oblique stimuli, and this phenomenon, called the "oblique effect," occurs. This "oblique effect" is a phenomenon caused by visual cognition derived from the primary visual cortex [13], and in this study, it is thought that it did not affect the results because the more conspicuous angle was selected as the preference after recognizing the samples. In the natural world, most of the things we see are horizontal or vertical, and we may feel uncomfortable with things that are tilted; therefore, we thought that visibility in the oblique direction has increased.

In this study, we investigated the effects of two colors, yellow and black, on clothing visibility. We found that the two colors, yellow and black, had the highest visibility when placed in a diagonal 165° -degree stripe pattern, with a spatial frequency of 5.0. This study provides information pertaining to visibility for the study of base standards that may be considered for clothing, and provides a first step in the research concerning this study. To

our knowledge, no previous studies have examined high visibility clothing for the general public, but one study has assessed field-based high visibility clothing in fluorescent colors for road-workers [14], reporting that distance drivers observed no difference in visibility between road workers in fluorescent yellow-green and fluorescent red-orange colors. This is because both fluorescent colors are more luminous than normal colors, and the brightness effect due to luminance is considered to play a significant role in visibility. Since no study has used normal colors that are not fluorescent, the next step would be to study the difference in visibility using normal colors that ordinary people prefer, and whether normal colors have the same visibility as fluorescent colors, based on the results of this study. Finally, we would like to evaluate the visibility of pedestrians wearing various colored clothes, and to thus devise and disseminate a standard for high visibility clothes.

Methods

Participants

Twenty normal participants without ocular disease, except for refractive errors, were studied. There were 10 men and 10 women with a mean age (SD) of 22.4 ± 4.4 years, ranging from 20–30 years. All participants had a corrected visual acuity of $> 20/20$. This

study was conducted in accordance with the Declaration of Helsinki. The procedures used were approved by the Ethics Committee of the School of Allied Health Sciences of Kitasato University (2018-012), and informed consent was obtained from all participants, and the study was conducted in accordance with guidelines and regulations related to informed consent. In addition, we have obtained informed consent from the participants to submit their research scenes for open access publications, which may lead to personal identification.

Experimental system

A black curtain (approximately 2.5 m) was set up around the participants to prevent distraction and uneven distribution of luminance in the visual field. The light source was set up in a dark room, and the illuminance in front of the visual target was set to 300 lx. This study assumed sunset conditions in Japan, and the study environment is shown in Figures 7a and 7b below.

The light source was SFX-502 (Panasonic), which is a dimmable LED with a warm white. The color temperature was approximately 2,700 K. Two samples were placed 5 m away from the line of sight, and two light sources were placed in front of the samples. The angle of placement of the light source from a straight line connecting the line of sight

to the sample was set at 45° to the left and right.

Experimental sample

The samples used in this study were made of 100% polyester fabric, manufactured by Sakai Obex Co., Ltd. These were a combination of yellow ($x = 0.445$, $y = 0.497$, $\beta = 0.49$) and black ($x = 0.314$, $y = 0.326$, $\beta = 0.02$) colors, which are used to warn against potential hazards [10].

A polyvinyl chloride pipe 70 mm in height $\times$ 25 mm in diameter was covered by the samples. There were 29 samples in total. Spatial frequencies were evaluated in six different checkerboards and stripes of 2.5 cpd, 5.0 cpd, 7.5 cpd, 10.0 cpd, 12.5 cpd, and 15.0 cpd, respectively. The color ratio of yellow was evaluated as 0%, 25%, 50%, 75%, and 100%. The angles were evaluated at 180°, 15°, 30°, 45°, 60°, 75°, 90°, 105°, 120°, 135°, 150°, and 165° for a total of 12 types. A total of 142 combinations of these patterns were compared (Figure 7c).

Procedure

The participant was seated, and the head position was fixed using a chinrest and forehead rest. A shading cylinder was placed in front of the participant with a 4° field of view. Next, a liquid crystal shutter film (Koyo Co.) was placed in front of the eyes, and a

control signal generator AWG10K (Elmos Co., Ltd.) and a semiconductor relay AC100SSR (Asakusa Giken Co., Ltd.) were connected to the PC and software. The signal was controlled by using a Ver. 1.1 (Elmos Co., Ltd.). As shown in Figure 7d, the parallel transmittance was 74% when the liquid crystal shutter was opened and 5% when it was closed. This principle can instantly change from an impermeable vision to a transparent vision by applying a voltage. Impermeable to transparent vision is approximately 1/1000 s, and transparent to impermeable vision is approximately 1/100 s. The sample viewing time was set at 0.5 seconds. This time is based on the amount of time a vehicle driving at 50 km/h can recognize a person 50 m away, brake suddenly, and stop approximately 10 m in front of it. Visual acuity and refraction measurements were performed at approximately 500 lx, basic data were acquired, and visibility was evaluated for brightness under sunset conditions.

To assess brightness, two samples were randomly presented to the front of the research participants, left and right. Then, as shown in Figure 7e, the sample on the left or right side was marked with a circle to indicate which sample was brighter. The respondents were asked to indicate the degree of brightness of the samples as "very bright" or "somewhat bright." If the left and right samples appeared to be equally bright or it was impossible to determine which was brighter, the participants were asked to choose

"neither." The visibility of the samples was assessed using the same method.

As mentioned above, the time at which the two samples can be viewed is approximately 0.5 s when the light is transmitted, but during the evaluation, there was plenty of time.

Statistical analysis

Statistical analysis was performed using the statistical sensory evaluation method, Scheffé's (Nakaya) paired comparison method. This method is a grading method in which any two objects are taken out and compared one-to-one, and the results of all comparisons are combined for evaluation. Excel 2016 (Microsoft Co.) and BellCurve for Excel (Social Survey Research Information Co., Ltd.) were used to calculate the analysis of variance table, average degree of preference, difference in the average degree of preference, and the analysis of the scale graph and estimated range of the sample's average degree of preference on a number line. The estimated range in this scale graph was interpreted as significantly different if the samples were further apart from each other. The level of significance was set at $P < 0.05$.

Data Availability:

The datasets generated and/or analysed during the current study are available from the

corresponding author on reasonable request.

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Author Contributions

TI wrote the main manuscript and created Figures 1-7. TK, CT, HT, HK, and HS assessed the construction of the environment for the experiment. All authors reviewed the manuscript.

Figure Legends

Figure 1. (a) In terms of spatial frequency conspicuity between the stripes and checkerboard patterns, the 5.0 cpd stripes were the most conspicuous results. (b) There was no significant difference between the 5.0 cpd stripes and the 2.5 cpd stripes, and the 2.5 cpd checkerboard pattern.

Figure 2. (a) In terms of spatial frequency brightness perception between the stripes and the checkerboard pattern, the 2.5 cpd checkerboard pattern was the brightest result. (b) There was no significant difference between the 5.0 cpd stripes and the 2.5 cpd stripes, and the 2.5 cpd checkerboard pattern.

Figure 3. (a) In terms of yellow color ratio conspicuity, the 50% color ratio was the most conspicuous result. (b) There was no significant difference between the 50% and 75% yellow color ratios.

Figure 4. (a) In terms of yellow color ratio brightness perception, the color ratio of 100% was the brightest result. (b) There was no significant difference between the 100% and 75% yellow color ratios.

Figure 5. (a) In terms of stripe angle conspicuity, angle 165° was the most conspicuous result. (b) There was no significant difference in stripe angles of 165° , 150° , 30° , 135° , 45° , and 60° .

Figure 6. (a) In terms of stripe angle brightness perception, angle 165° was the brightest result. (b) There was no significant difference in stripe angles of 165° , 60° , 75° , 90° , 150° , 15° , 105° , 45° , 30° , 120° , and 180° .

Figure 7. (a) Research environment. Two evaluation samples are placed 5 m away from the participants.

(b) Experimental scene. The sunset environment is recreated by covering the participants' surroundings with a blackout curtain.

(c) Evaluation samples. A total of 29 different patterns.

(d) Liquid crystal shutter. Electronically controlled to open (left side) and close (right side).

(e) Evaluation items (English Version). Compare the two samples and circle the item for brightness and conspicuity.

Supplementary Figure Legends

Figure S1. Number of injured pedestrians by age group in 2019 by Japan's National Police

Agency. Most children are 7~12 years old, and most adults are over 80 years old.

Figure S2. Number of elementary and junior high school students injured in traffic

accidents in 2019 by Japan's National Police Agency. Traffic accidents are most

common between 4:00 p.m. and 6:00 p.m.

Figures

Figure 1.

Figure 1

(a) In terms of spatial frequency conspicuity between the stripes and checkerboard patterns, the 5.0 cpd stripes were the most conspicuous results. (b) There was no significant difference between the 5.0 cpd stripes and the 2.5 cpd stripes, and the 2.5 cpd checkerboard pattern.

Figure 2.

Figure 2

(a) In terms of spatial frequency brightness perception between the stripes and the checkerboard pattern, the 2.5 cpd checkerboard pattern was the brightest result. (b) There was no significant difference between the 5.0 cpd stripes and the 2.5 cpd stripes, and the 2.5 cpd checkerboard pattern.

Figure 3.

Figure 3

(a) In terms of yellow color ratio conspicuity, the 50% color ratio was the most conspicuous result. (b) There was no significant difference between the 50% and 75% yellow color ratios.

Figure 4.

Figure 4

(a) In terms of yellow color ratio brightness perception, the color ratio of 100% was the brightest result. (b) There was no significant difference between the 100% and 75% yellow color ratios.

Figure 5.

Figure 5

(a) In terms of stripe angle conspicuity, angle 165° was the most conspicuous result. (b) There was no significant difference in stripe angles of 165°, 150°, 30°, 135°, 45°, and 60°.

Figure 6.

Figure 6

(a) In terms of stripe angle brightness perception, angle 165° was the brightest result. (b) There was no significant difference in stripe angles of 165°, 60°, 75°, 90°, 150°, 15°, 105°, 45°, 30°, 120°, and 180°.

Figure 7.

Figure 7

(a) Research environment. Two evaluation samples are placed 5 m away from the participants. (b) Experimental scene. The sunset environment is recreated by covering the participants' surroundings with a blackout curtain. (c) Evaluation samples. A total of 29 different patterns. (d) Liquid crystal shutter. Electronically controlled to open (left side) and close (right side). (e) Evaluation items (English Version). Compare the two samples and circle the item for brightness and conspicuity.

Supplementary Files

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- [SupplementaryFigureS1.pdf](#)