IMPROVEMENT OF TRAFFIC SIGNS FOR PEOPLE WITH LOW VISION

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วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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ชิซูรุ โคงะ : การปรับปรุงเครื่องหมายจราจรสำหรับคนสายตาเลือนราง. (IMPROVEMENT OF TRAFFIC SIGNS FOR PEOPLE WITH LOW VISION) อ.ที่ปรึกษาหลัก : รศ. ดร.พิชญดา เกตุเมฆ, อ.ที่ปรึกษาร่วม : รศ. ดร.โทโมโกะ โอบามา

ผู้ที่มีสายตาเลือนรางมีความยากลำบากในการปฏิบัติงานที่เกี่ยวข้องกับการมองเห็น อย่างไรก็ตามความสามารถนี้สามารถเพิ่มขึ้นได้จากการปรับเปลี่ยนสภาพแวดล้อม เมื่อบูรณาการทักษะทางการมองเห็น ได้แก่ การกวาดสายตา, การแกะรอยและการติดตาม กับการชี้แนะทางสภาพแวดล้อมที่ส่งผลให้เกิดความปลอดภัยและความคล่องตัวอย่างมีประสิทธิภาพ งานวิจัยนี้มีจุดประสงค์ในการปรับเปลี่ยนป้ายจราจรสำหรับผู้ที่มีสายตาเลือนราง โดยคำนึงถึงรูปร่างกับสีในสภาวะสลัวและสว่าง ประเภทของเครื่องหมายจราจรที่สื่อข้อมูลจากการมองเห็น ภาพแบบพอสิทิฟและเนกาทิฟ พื้นหลังและระยะทาง งานวิจัยนี้แบ่งออกเป็น 3 ส่วน ส่วนแรกศึกษาผลกระทบของสภาวะสลัว (18.9 cd/m^2) สว่าง (255 cd/m^2) กับรูปร่าง 6 แบบ สี 4 สี และระยะทาง 6 ระยะ (ขนาดของตัวอย่างเป็นองศาเมื่อตกกระทบลงบนเรตินา) ต่อระยะเวลาในการตอบสนองเพื่อบอกรูปร่างและสีบนหน้าจอ EIZO ให้ถูกต้อง โดยผู้สังเกตการณ์สายตาปกติจำนวน 10 คน ที่ใส่แว่นจำลองสายตาเลือนราง 3 ชนิด ได้แก่ การมองเห็นแบบพร่ามัว (BV) ที่ระดับสายตา 0.06 องศา, การมองเห็นแบบพร่ามัวที่เกิดจากการอุดตันของเส้นเลือด (CV) ที่ระดับสายตา 0.08 องศาและการมองเห็นแคบกว่าปกติ (NV) ที่ลานสายตา 3 องศา จากการวิจัยพบว่าสภาวะสลัวทำให้เกิดความสับสนระหว่างรูปร่างวงกลมและแปดเหลี่ยม ส่งผลให้ระยะเวลาในการตอบสนองนานขึ้นเมื่อขนาดของสิ่งกระตุ้นเล็กกว่า 3.4 องศาสำหรับการมองเห็นแบบ BV และ CV โดยสามเหลี่ยมมีการสนองที่รวดเร็วกว่าเมื่อมีการมองเห็นแบบ BV และ CV ส่วนการมองเห็นแบบ NV ตอบสนองต่อวงกลมได้รวดเร็ว ส่วนที่สอง ข้อมูลทางการจราจรแบบรูปภาพและข้อความถูกเพิ่มเข้ามาในวงกลมและสามเหลี่ยม 4 สี ป้ายจราจรทั้งหมดถูกนำเสนอแบบพอสิทิฟและเนกาทิฟพร้อมกับพื้นหลัง 3 แบบ และขนาดตัวอย่าง 3 ขนาดถูกทดสอบจับเวลาการตอบสนองและตรวจสอบความถูกต้อง โดยใช้ผู้สังเกตการณ์สายตาปกติที่ใส่แว่นตาเช่นเดียวกับการทดลองส่วนแรก จำนวน 5 คน ผู้สังเกตการณ์จะมองสิ่งกระตุ้นบนหน้าจอ EIZO ผลการทดลองพบว่าการมองเห็นแบบ BV และ CV ให้ผลไปในทิศทางเดียวกัน แต่การมองเห็นแบบ BV จะให้ผลการตอบสนองต่อตัวแปรตามที่ด้อยกว่าในการทดสอบ ข้อมูลทางการจราจรแบบข้อความให้ความเข้าใจมากกว่าข้อมูลทางการจราจรแบบรูปภาพในการจำลองสายตาเลือนรางทั้งสามประเภท ระยะทางที่เหมาะสมที่สุดสำหรับการมองเห็นแบบ BV และ CV ในการแยกแยะป้ายจราจรแบบรูปภาพไม่ควรมากกว่า 6.7 เมตร เมื่อป้ายมีขนาด 60 เซนติเมตร หรือขนาดภาพบนเรตินาไม่น้อยกว่า 5.2 องศา ป้ายจราจรรูปสามเหลี่ยมให้เวลาการตอบสนองน้อยกว่าวงกลมสำหรับการมองเห็นแบบ BV และ CV ส่วนการมองเห็นแบบ NV สามารถแยกแยะข้อมูลทางการจราจรแบบรูปภาพได้อย่างแม่นยำโดยไม่ขึ้นกับระยะทางในการทดสอบ ส่วนระยะทางที่เหมาะสมต่อการแยกแยะข้อมูลทางการจราจรแบบข้อความควรมากกว่า 6.7 เมตรและวงกลมจะให้ผลที่มีประสิทธิภาพมากกว่ารูปร่างอื่น ในทางกลับกัน ภาพแบบพอสิทิฟและเนกาทิฟและสีไม่ใช่ปัจจัยหลักที่ส่งผลกระทบต่อเวลาการตอบสนอง เมื่อพิจารณาผลกระทบรวมระหว่างภาพแบบพอสิทิฟและเนกาทิฟและสีพบว่าป้ายจราจรภาพเนกาทิฟสีน้ำเงินจะให้เวลาในการตอบสนองเร็วที่สุดอย่างมีนัยสำคัญสำหรับการมองเห็นแบบ CV อย่างไรก็ตามสีน้ำเงินจะให้ระยะเวลาในการตอบสนองยาวนานที่สุดสำหรับการมองเห็นแบบ NV โดยความต่างของการตอบสนองอยู่ที่เพียง 200–500 มิลลิวินาทีเท่านั้น ปัจจัยที่เหมาะสมที่สุดถูกนำมารวมกันเพื่อออกแบบป้ายจราจร ภาพเนกาทิฟรูปสามเหลี่ยมสีน้ำเงินสำหรับการมองเห็นแบบ BV และ CV และป้ายจราจรภาพพอสิทิฟรูปวงกลมสีเหลืองสำหรับการมองเห็นแบบ NV ในขั้นสุดท้ายกลุ่มของป้ายจราจรจากการทดลองจะถูกประเมินโดยเปรียบเทียบกับป้ายจราจรที่มีการใช้งานจริงโดยผู้สังเกตการณ์สายตาปกติจำนวน 15 คน ที่ใส่แว่นตาจำลองสายตาเลือนราง 3 ชนิด ที่ 3 ระยะทาง จากการทดลองพบว่า ป้ายจราจรแบบรูปภาพ 2 แบบและป้ายจราจรแบบข้อความ 1 แบบ จากทั้งหมด 6 แบบที่ออกแบบใหม่ ให้ความแม่นยำมากกว่าป้ายจราจรที่มีการใช้งานในปัจจุบันสำหรับการมองเห็นแบบ BV และ CV ส่วนป้ายจราจรที่ออกแบบสำหรับการมองเห็นแบบ NV ให้ประสิทธิภาพเทียบเท่าป้ายจราจรที่มีการใช้งานอยู่ในปัจจุบัน

สาขาวิชา	เทคโนโลยีทางภาพ		ลายมือชื่อนิสิต ....
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5772811523 : MAJOR IMAGING TECHNOLOGY
KEYWORD: Low vision, Narrow vision, Occlusion vision, Blurred vision, Traffic sign, Pictogram-based traffic sign, Text-based traffic sign, Visual impairment

Chizuru Koga : IMPROVEMENT OF TRAFFIC SIGNS FOR PEOPLE WITH LOW VISION . Advisor: Assoc. Prof. PICHAYADA KATEMAKE, Ph.D. Co-advisor: Assoc. Prof. Tomoko Obama, Ph.D.

People with low vision have difficulty accomplishing visual tasks but the ability can be enhanced with the use of environment modifications. Visual skills: scanning, tracing and tracking, integrated with environmental cues can result in safer and more efficient orientation and mobility. This research aimed to optimize traffic signs for the low vision concerning shape with color in dim and bright environments, types of traffic sign carrying visual information, negative/positive presentations, backgrounds and distances. Three successive investigations were carried out. Firstly, the effect of dim (18.9 cd/m^2)/ bright (255 cd/m^2), 6 shapes with 4 colors and 6 distances (size of sample in degrees presented on retina) were examined in response to reaction time of correct answer viewed on the calibrated EIZO monitor by 10 normal color vision participants wearing 3 types of simulated low vision glasses: blurred vision (BV) with visual acuity (VA) of 0.06, occlusion vision (CV) with VA of 0.08 and narrow vision (NV) with 3 degrees of visual field. It was found that dim environment resulted in confusion of circular and octagonal shapes reflected in long reaction time when the subtended visual angle of the stimulus was less than 3.4 degrees for BV and CV. The triangular and the circular shapes show the lowest reaction time responded by BV, CV and NV respectively. Blue and green were confused in dim condition and red showed shortest reaction time. Secondly, two types of traffic information: pictogram-based and text-based were added to the triangular shape and circular shape, with 4 colors. These traffic signs along with 3 backgrounds, negative and positive presentations and 3 sizes of the subtended visual angle were tested in response to the accuracy and reaction time by 5 normal color vision participants wearing the same simulated low vision glasses as the 1st investigation. They viewed the stimulus on the calibrated EIZO monitor. It was found that BV and CV had similar trends; the BV was rather inferior in response to dependent variables in test. The text-based traffic signs were more comprehensive in short time than the pictogram-based ones for 3 types of the simulated low vision. The optimum distance for the BV and CV in recognizing the pictogram traffic signs accurately should not be longer than 6.7 m when viewed the sign size of 60 cm or the size of subtended visual angle should not be smaller than 5.2 degrees. The triangle traffic signs showed lower reaction time than the circle one for the BV and CV. The NV recognized the pictogram traffic sign accurately irrespective of distance in test. The optimum distance in recognizing the text traffic signs for the NV should be greater than 6.7 m and the circle was more effective. The negative/positive presentation and colors were not dominant factors contributing to reaction time. The combined effects of negative/positive and colors showed that blue/negative traffic sign significantly gave the lowest reaction time for the CV. However, blue gave the longest reaction time in the effective distance for the NV. The significant difference of reaction time is rather small of about 200–500 ms. The optimum factors were combined to design candidate traffic signs negative/blue/triangle for BV and CV and positive/yellow/circle for NV. Finally, the candidate traffic signs were assessed in comparison with the current ones by 15 normal color vision participants wearing the 3 types of simulated low vision glasses at 3 simulated distances. It was found that 2 pictogram and 1 text candidates out of 6 for BV and CV showed higher accuracy than the current traffic signs. The candidates for the NV gave the same performance as the current ones.

Field of Study:	Imaging Technology	Student's Signature ....
Academic Year:	2020	Advisor's Signature ....
		Co-advisor's Signature ....

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Chizuru Koga

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INTRODUCTIONS

1.1 Background and significance of research

There were approximately 2.2 billion people visual impairment around the world, which included 246 million people of low vision, estimated by WHO in 2018 (World Health Organization, 2019). The number will increase because of the ageing world's population and other causes such as diabetic retinopathy (World Health Organization, 2015). Recently, the new definition for low vision is given by WHO as "A person with low vision is someone who, after medical, surgical and/or optical intervention, has a corrected visual acuity in the better eye of less than 6/18 but equal to or better than 3/60 or a corresponding visual field loss to less than 20 degrees but who uses or has the potential to use vision for the planning and/or execution of a task" (World Health Organization, 2012). The visual acuity of the elderly falls within the range of low vision's visual acuity appeared in the given definition. In 2018, WHO added the low visual acuity classification to the categories of visual impairment (World Health Organization, 2020). In many developing countries, low vision service has not been established or difficult to reach. Low vision affects employment opportunities for adults and increases the risk of isolation for the elderly. The visual enhancement for people with low vision should be concerned for improving the quality of life and safety in addition to other assistive tools such as audio. In Thailand, low vision service is poor, they commute mostly by using public transports and walk. Some of traffic or road signs are important for their safety. Different types of low vision may have different response times to the traffic signs. There is a large diversity in both quality and quantity in vision and visual function of persons with low vision. According to American Optometric Association, common types of low vision are as follows: 1) Loss of central vision: the loss of central vision makes a blur or blind spot but person's peripheral visual field is remained. In this case, reading, recognition and distinguish most in detail in distance are difficult but peripheral vision is remained and mobility is usually unaffected; 2)

Loss of peripheral vision: people who lose their peripheral vision cannot distinguish anything to one side or both sides, or anything directly above and/or below eye level. Central vision remains making it possible to see directly ahead. Typically, loss of peripheral vision affects mobility. If it is severe, it can slow reading speed because the person can only see a few words at a time; 3) Blurred vision: with blurred vision, both near and far vision is out of focus, even with the best possible correction by eyeglasses; 4) Generalized hazel, which is called as occlusion in this research: people with occlusion have the sensation of a cloudy filter or glare that may extend over the entire viewing field; 5) Extreme light sensitivity: extreme light sensitivity occurs when standard levels of light overwhelm a person's visual system, producing a flashed-out image and/or a glare. People with extreme light sensitivity may suffer pain or discomfort from relatively normal levels of light and 6) Night blindness: people with night blindness cannot see outside at night under starlight or moonlight or in dim lighted interior areas (American Optometric Association, 2020). In many case, visual impairment is caused by eye diseases. Some common causes of low vision are macular degeneration, diabetic retinopathy, retinitis pigmentosa, amblyopia, cataract and glaucoma (Alizadeh-Ebadi, Markowitz, & Shima, 2013). Some of them are very age-related. In addition, most of symptom of low vision are complex of some symptoms, such as blur and loss of central vision, blur and loss of peripheral vision, so that research about low vision has been considered difficult (Legge, Rubin, Pelli, & Schleske, 1985; Mansfield, Legge, & Bane, 1996; Owsley, 2011; Wurm, Legge, Isenberg, & Luebker, 1993). On the other hand, main difficulty of low vision people is said to ride bus and train, to walk outside, or to detect general signs at outside, such as traffic sign (Ikeda & Obama, 2008; Wake H, 2008; 大嶋瑠美子, 2012).

In this research, we will consider about three main types of symptom of low vision, blurred, occlusion, and narrow vision which means peripheral vision loss. Simulated blurred, occlusion and narrow visual field types of low vision, with a specific visual acuity, will be tested individually using shape, size and color of the most common traffic signs that are essential for pedestrians, as stimuli.

1.2 Objectives

1.2.1 To investigate the fastest response time for shapes with color of the traffic signs seen by subjects with 3 types of simulated low vision glasses from various distance.

1.2.2 To investigate the impact of color portion in image of traffic signs on the response time seen by subjects with 3 types of simulated low vision glasses from various distance.

1.2.3 To design and to improve the traffic signs for people with low vision.

1.3 Hypothesis

1.3.1 Different types of low vision response to shape and shape with color differently.

1.3.2 Illumination levels during the daytime and at dawn or at dusk affect the response to negative and positive signs by people with different low vision types.

1.3.3 The improved traffic signs will be easily to detect in a longer distance seen by people with low vision compared with current traffic signs.

1.4 Scope of the study

1.4.1 Three types of simulated low vision glasses: blurred, occlusion and narrow vision with minimum visual acuity of the low vision defined by WHO will be used in all parts of experiment.

1.4.2 Six most common shapes of traffic sign, including circle, square, triangular, invert triangular, diamond, as well as octagon, and 4 colors of red, green, yellow, and blue are selected as stimuli in Part 1. The distances of 80 cm and 60 cm as well as 2 levels of the illumination are conditions to be tested in response to reaction time.

1.4.3 Two color portions: negative and positive applied on six traffic signs (2 of regulatory sign, 2 of warning sign and 2 of information sign), 2 shapes, 4 colors, 3 backgrounds and 3 sizes are used as stimuli in Part 2.

1.4.4 The designs of traffic signs proposed according to the results of Part 2 will be used as stimuli in Part 3 in comparison with the current traffic signs.

1.4.5 The response times will be used as a measure.

1.5 Research procedures

This research consists of 3 parts of experiments as we want to investigate if the shape and color (Part 1) as well as color portion (negative or positive) of traffic signs (Part 2) affect the response time of low vision people. If they affect the response time, the proposed design of traffic signs will be tested (Part 3)

1.5.1 Investigation of the effect of the most common shape of traffic signs with color on response time and distance.

Part 1 is aimed to investigate the effect of the most common shape of traffic signs with color on response time and distance. After the investigation, we will choose the shape and color with the shortest response time and apply to the next investigation.

Flowchart of the approach is shown in Figure 1-1.

Stimulus having 6 types of shape with 4 colors in 3 levels of size
(72 conditions)

↓ Showed on PC monitor with 2 levels of luminance.

Observers wearing 3 types of simulated low vision glasses
response from 2 levels of distance (6 conditions)

↓ Measure response time

Evaluate what type of shape, which color is reacted
in shortest response time

Figure 1-1 Flowchart of the approach of the 1st investigation.

- Subjects

Ten subjects, having normal vision and under 50-year-old, are recruited.

- Glasses

Three types of glasses with minimum level of visual acuity in definition of low vision are applied. Types of glasses are blurred, occlusion and narrow vision. Minimum of visual acuity available is 3/50 and visual angle is 3 degrees. Glasses are products of “Simulation Lens Trial (M.TAKATA)”.

- Stimuli

Six types of shape of common traffic signs (circle, square, diamond, triangular, invert triangular and octagon) are used as stimuli. They are red, green, blue and yellow. Each of them has three levels of size, these 72 types of stimulus are shown randomly on PC screen. In addition, distance from monitor is set in two levels of 60 cm and 80 cm, so that six levels of distance from 60 cm traffic sign to 3.1 m, 4.1 m, 5.0 m, 6.7 m, 10.0 m, and 13.3 m are simulated.

- Luminance

PC monitor is set for 2 levels of luminance similar to outside conditions, daytime and sunset time: bright and dim. They are set approximately, 255 cd/m^2 and 18.9 cd/m^2.

- Evaluation

Every subject is asked to state the type of shape and color when he/she sees the stimulus. The response time and right/wrong answer for each condition obtained from all 3 of glasses are recorded. Effect of shape and color is estimated with response time, and optimum distance to recognize stimuli for each color and shape will be analyzed.

1.5.2 Investigation of the effect of color portion of traffic signs on response time.

Part 2 is aimed to investigate the effect of color portion (negative and positive) of traffic signs on response time. The results of this part will be used to design the traffic signs for the low vision and they will be tested in Part 3.

- Subjects

Five subjects, having normal vision and under 30-year-old are recruited.

- Glasses

Three types of glasses with the same visual acuity as in the 1st investigation is applied.

- Stimuli

Stimuli that are 6 kinds of traffic signs, 2 of regulatory, 2 of warning and 2 of information signs, according to 2 types of shapes chosen as the result from the 1st investigation for each type with 4 colors and 2 types of color portion (positive or negative) are prepared. Each of them has three levels of size, and three kinds of background. These 864 stimuli are shown randomly on PC monitor to observers. Distance from monitor is set in 80 cm, so that three levels of distance from 60 cm traffic sign to 6.7 m, 13.3 m, and 26.6 m are simulated.

- Luminance

PC monitor is set for the luminance which is similar to outside dim conditions. It is set approximately, 18.9 cd/m^2.

- Evaluation

Every subject will be asked to state the name of traffic sign when he/she sees the stimulus. The observers will be explained about the traffic signs used in this part of the experiment. The response time and right/wrong answer including 'I cannot see' for each condition obtained from all 3 of glasses will be recorded. Effect of colors and positive as well as negative stimuli on response time will be analyzed. The summary of this part of the experiment is shown in Figure 1-2.

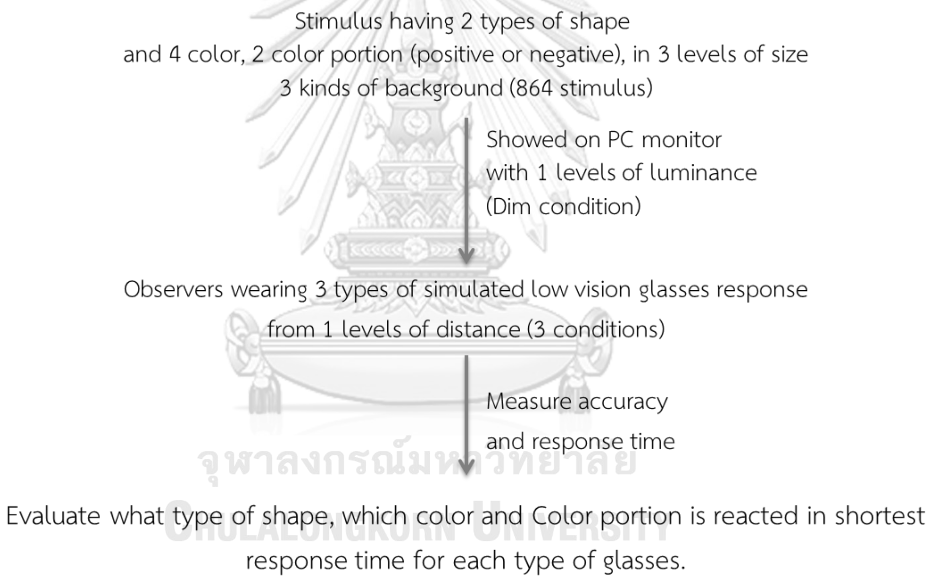

Figure 1-2 Flowchart showing the summary of the 2nd investigation.

1.5.3 Investigation of the farthest distance required to response on the improved traffic signs compared with the current traffic signs by normal vision subjects wearing three types of simulated low vision glasses.

Part 3 is aimed to investigate the farthest distance required to response on the improved traffic signs compared with the current traffic signs by normal vision subjects wearing three types of simulated low vision glasses (blur, occlusion and narrow vision)

- Subjects

Subjects having normal vision are recruited.

- Glasses

Three types of glasses; They are the same ones as in the 1st and 2nd investigations, occlusion vision, blurred vision and narrow vision with minimum visual acuity of low vision.

- Stimuli

The optimized traffic signs obtained from the 2nd investigation will be used in this investigation. The optimized traffic signs will be showed to observers on the monitor. The normal vision observers with simulated low vision glasses will see them and answer what kind of sign. The same procedure will be tested using the current traffic signs. The new design of traffic signs will be made based on the results obtained from the 2nd investigation. The criterion of judgement of the new design and the current traffic signs is the answering time.

- Luminance

PC monitor will be set for the luminance similar to outside dim conditions. It is set approximately, 18.9 cd/m^2.

- Evaluation

Every subject will be asked to state the name of traffic sign when he/she sees the stimulus. The observers will be explained about the traffic signs used in this part of the experiment. The response time and right/wrong answer including ‘I cannot see’ for each condition obtained from all 3 of glasses for each level of visual acuity will be recorded. The summary of this part of the experiment is shown in Figure 1-3.

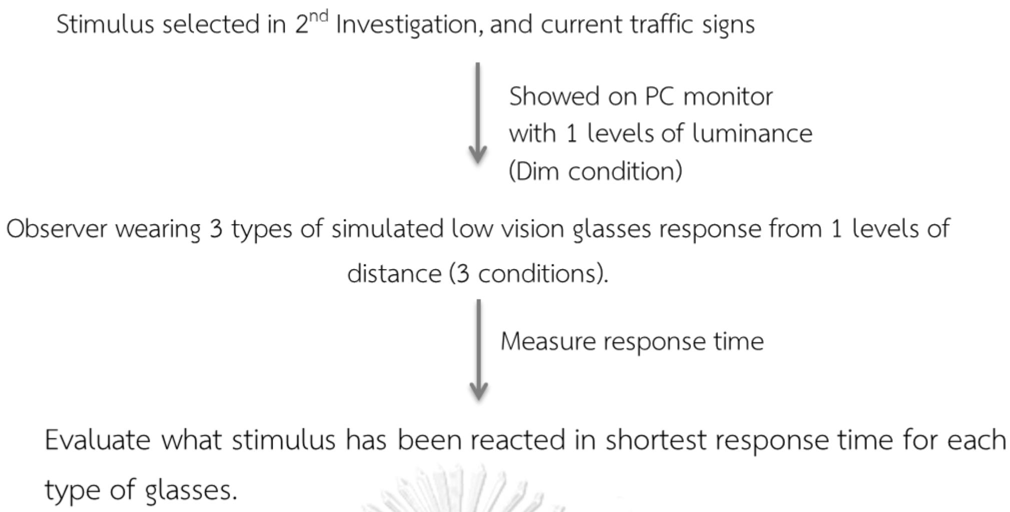

Figure 1-3 Flowchart showing the summary of the 3rd investigation.

1.6 Analysis

Data analysis is based on descriptive statistics that include a measure of central tendency (mean) and a measure of dispersion (standard deviation). Statistical comparison between populations is made by Student's *t*-test. For categorical data analysis, the binomial test is used. Differences would be considered statistically significant at p value of less than 0.05.

CHAPTER 2
THEORETICAL CONSIDERATION AND LITERATURE REVIEWS

2.1 Theories

This research investigated the response by subjects wearing simulated low-vision glasses. They participated in the sequences of psycho-physical experiments to see some traffic signs: pictogram-based and text based as stimulus, then the results were analyzed statistically. Corresponding theories including low vision, psychophysical methods, traffic signs and safety colors, and Taguchi method will be explained.

2.1.1 Low vision

The new definition for low vision is given by WHO as "A person with low vision is someone who, after medical, surgical and/or optical intervention, has a corrected visual acuity in the better eye of less than 6/18 but equal to or better than 3/60 or a corresponding visual field loss to less than 20 degrees but who uses or has the potential to use vision for the planning and/or execution of a task." There were approximately 246 million people with low vision around the world, estimated by WHO in 2019 (World Health Organization, 2019). In 2018, The International Classification of Diseases 11 (2018) of WHO classifies vision impairment into two groups, distance and near presenting vision impairment (Table 2-1). In this research, we consider about only distance presenting vision impairment (World Health Organization, 2020). In this research, three kinds of low vision, occlusion vision, blur vision, and narrow vision were focused.

Table 2-1 Classified visual impairment and blindness based on the International Classification of Diseases 11 (World Health Organization, 2020)

Presenting distance visual acuity		
Category	Worse than	Equal to or better than
Mild visual impairment	6/12*	6/18
Moderate visual impairment	6/18	6/60
Severe visual impairment	6/60	3/60
Blindness	3/60	

* If a person has a visual acuity of 6/12, he is said to see detail from 6 meters (20 ft) away the same as a person with normal eyesight would see it from 12 meters (39 ft) away.

2.1.1.1 Occlusion vision

Occlusion vision is the condition that clouding interferes vision with light. Cataract is known to cause this symptom. Clouding interferes with light reaching the retina at the back of the eye, resulting in a general loss of vision (American Optometric Association, 2020). Cataract is caused by aging, long-term exposure to the sun's ultraviolet radiation, injury, disease, and inherited disorders. If the eye is healthy, a cataract can be surgically removed. Usually, an intraocular lens implant is inserted in the eye, and vision is restored. Cataract surgery has a high success rate in otherwise healthy eyes (American Optometric Association, 2020). Cataract eyes are also known as less sensitive for chroma and brightness than normal vision (Ikeda & Obama, 2008).

2.1.1.2 Blurred vision

Blurred vision is the condition that both near and far vision is out of focus, even with the best possible correction with eyeglasses (American Optometric Association, 2020). Amblyopia is known to cause this symptom, a developmental abnormality that results from physiological alterations in the visual cortex and impairs form vision (Levi, Knill, & Bavelier, 2015; Levi & Li, 2009). Amblyopia is a neurodevelopmental disorder of the visual system that is associated with disrupted binocular vision during early childhood, and an important condition that can affect up to 5% of the general population (Carlton & Kaltenthaler, 2011; Hamm, Black, Dai, & Thompson, 2014).

2.1.1.3 Narrow vision

Narrow vision is the condition that people lose their peripheral vision cannot distinguish anything to one side or both sides, or anything directly above and/or below eye level. Central vision remains, however, making it possible to see directly ahead, read and see faces. Typically, loss of peripheral vision affects mobility. If it is severe, it can slow reading speed because the person can only see a few words at a time (American Optometric Association, 2020). Glaucoma is known to cause this symptom. Glaucoma damage to the optic nerve. Most commonly, this occurs due to increasing internal pressure in the eye because of problems with the flow or drainage of fluid within the eye. It can also occur when the internal pressure of the eye does not increase, but there is not enough blood flow to the optic nerve. There are no early symptoms in the most common form of glaucoma, but the first signs of damage are defects inside vision and difficulty with night vision (American Optometric Association, 2020).

2.1.1.4 Simulated low vision glasses

To experience how the world are seen by people with low vison, there are some tools used to simulate the vision. The tools include application of smartphone and simulated glasses, such as the simulated low vision glasses required for this research. We required “the simulation lens trial”, product of TAKATA, Japan and they are 3 kinds of simulated low vision, blurred vision, occlusion vision, and narrow vision. The ranges of visual acuity for individual type are from 0.01 to 0.3. the visual angle is from 3 degrees to 10 degrees. The effect of common causes of visual impairments can be simulated. However, the visual effects of eye conditions vary from person to person, the effects and acuity losses can be only approximate. The six most common causes of visual impairments are cataract, macular degeneration, tunnel vision, hemianopia, and diabetic eye disease.

2.1.2 Psychophysical methods

The word “psychophysics” comes from Gustav Theodor Fechner’s “Elemente der Psychophysik” in 1860 (Gescheider, 2013; Solomon, 2013). Fechner describes research intended to relate physical stimuli to the consciousness such as sensation, taste, smell, touch, hearing, and sight. According to Fechner, all sensory processes are amenable to psychophysics examination. Sight is the most important and more than 50% of the cerebral cortex of the human brain is involved with processing of visual input. When people see the object, the visual stimulus, such as color, shape, is processed by visual system and they recognize the image of the object, becomes “sight”.

2.1.2.1 Visual system

The visual system is composed of the eye as the sensor and the part of cerebral cortex of the brain (Bruce, Green, & Georgeson, 2003; Solomon, 2013). In the bran, the neural circuitry of the retina transforms a fluctuating pattern of light into a pattern of neural activity in retinal ganglion cells, which is then transmitted along the optic nerve to the brain. Once we received some stimulus at the eye, it goes on to the visual pathway and reach the primary visual cortex and we get the sight (Bruce et al., 2003; Snowden, Snowden, Thompson, & Troscianko, 2012). The primary visual cortex is located at the back of the head, as far from the eyes as you can get, in the occipital lobe of the brain (Figure 2-1).

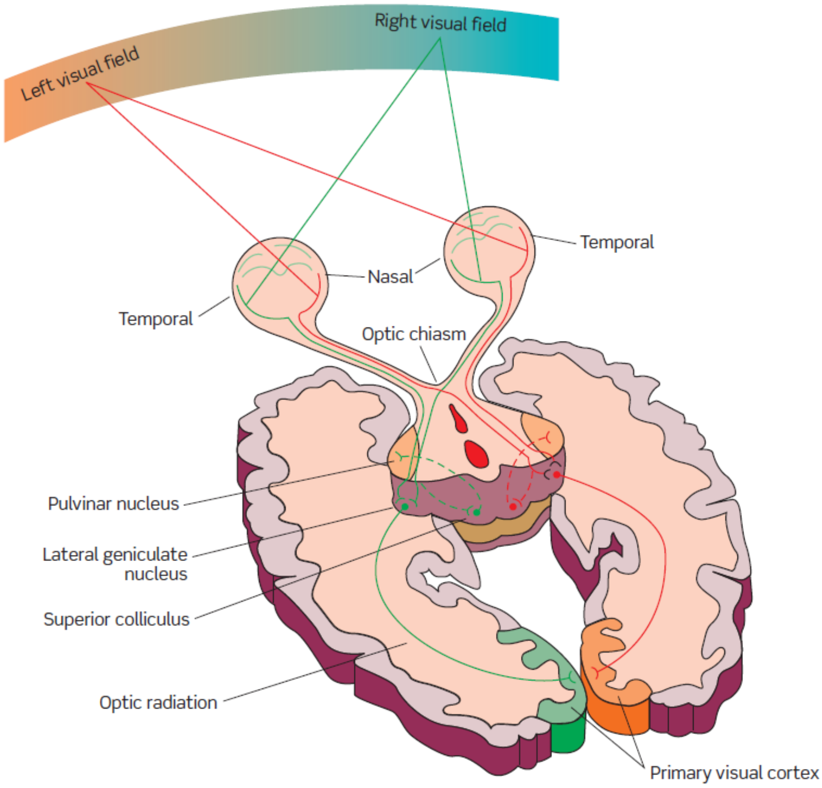

Figure 2-1 The visual pathways from the eyes to the primary visual cortex, also known as striate cortex and V1 (Snowden et al., 2012)

2.1.2.2 Aging related visual loss

Aging causes the declining in vision. It can have a major impact on the health and well-being of an elderly population. The declines occur at multiple levels of the visual system including optics, sensory processing, and perceptual processing and are not likely due to a systemic change in brain function as a result of normal aging (Andersen, 2012). However, some age-related diseases, cataract which causes occlusion vision and AMD (age-related macular degeneration) which causes narrow vision, cause visual loss. The prevalence of abnormal vision changes caused by disorders of the visual system, and the anticipated incidence and impact of visual impairment are considered and discussed globally (Dagnelie, 2013).

2.1.2.3 Visual acuity

Visual acuity is the measure of the spatial resolution of the visual processing system, determined by using optotypes such as Snellen chart. The

Snellen eye chart is shown in Figure 2-2. High-contrast letters of progressively smaller size allow us to determine the resolution limit of the visual system. To have 20:20 vision means that you can see at 20 feet what a 'normal' person can see at 20 feet. The metric equivalent is 6:6 vision—20 feet is about 6 meters. Someone with 20:200 vision can see at 20 feet what a normal person can see at 200 feet. Such a person would be legally blind (Snowden et al., 2012).

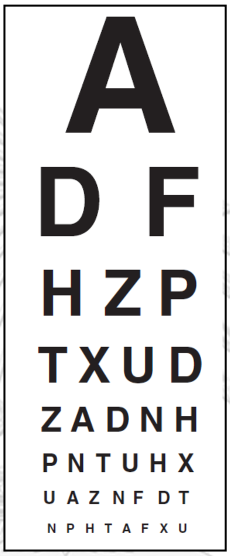

Figure 2-2 Snellen chart

2.1.3 Traffic signs

Traffic signs are at the side of roads to give information, guidelines and warnings to road users. They are not always comprehended correctly. A pictogram is an ideogram that lets people know the meaning through its pictorial resemblance to a physical object. Sometimes, pictograms are applied to the traffic signs with or without some characters. There are some international conventions to help to achieve the uniformity in traffic signing. Majority is the categorize by Annex 1 of the Vienna Convention on Road Signs and Signals (1968) as shown in Table 2-2, entered in force 30 November 1995 (United Nations. Economic Commission for Europe. Transport Division, 2007), Thailand also is signatory to the Vienna Convention on Road Signs and Signals.

Table 2-2 Eight categories of Traffic Sign by Vienna Convention on Road Signs and Signals (United Nations. Economic Commission for Europe. Transport Division, 2007)

Category	
A	Danger warning signs
B	Priority signs
C	Prohibitory or restrictive signs
D	Mandatory signs
E	Special regulation signs
F	Information, facilities or service signs
G	Direction, position, or indication signs
H	Additional panels

2.1.4 Safety color

Colors of traffic signs are basically following to the "Safety Color". ISO 3864 is the international standards for Safety Signs Markings in workplaces and public facilities. Colors provided in this rule are called "Safety Color". Definitions, conditions, and requirement for safety color is included in Annex A of ISO 3864-1984, as shown in Table 2-3 and Table 2-4. Japanese Industrial Standards (JIS)Z-9103 used to be adjusted in same color with ISO 3864, and changed target Munsell number of safety color consider with color blind people in 2018 (Itoh & Sagawa, 2018). Although all colors are in the area which limited in ISO 3864-1984, green and blue are considered for the people with low vison and new colors are a little brighter than previous safety colors. Other colors are considered mainly for some kinds of people with color blind. For new colors, the target Munsell values are different from previous target Munsell values.

Table 2-3 The range of safety colors (International Organization for Standardization, 1984)

Color		x, y value on the corner of area (Light source: D65, 45/0°geometory)			
		1	2	3	4
Red	x	0.690	0.595	0.569	0.655
	y	0.310	0.315	0.341	0.345
Blue	x	0.078	0.150	0.210	0.137
	y	0.171	0.220	0.160	0.038
Yellow	x	0.519	0.468	0.427	0.465
	y	0.480	0.442	0.483	0.534
Green	x	0.230	0.291	0.248	0.007
	y	0.754	0.438	0.409	0.703

Table 2-4 The Target Munsell number for safety colors in JIS Z 9103-2018 and JIS Z 9103-1955 (ISO 3864-1984)

Color	JIS Z 9103-1955 (ISO3864-1984)		JIS Z 9103-2018	
	Munsell	Color	Munsell	Color
Red	7.5R 4/15		8.75R 5/12	
Yellow	2.5Y 8/14		7.5Y 8/12	
Green	10G 4/10		5G 5.5/10	
Blue	2.5PB 3.5/10		2.5PB 4.5/10	

2.1.5 Statistical Analysis

For the results of every investigation, statistical analysis is applied to analyze if there is any statistically significant difference between the groups, or if there is any interaction between 2 or more variants. Popularly, one-way ANOVA (Analysis of variance) or two-way ANOVA is recruited to the analysis. ANOVA was developed by Sir Ronald A. Fisher, a statistician, to avoid loss function from the theory. While Taguchi methods are statistical methods, sometimes called robust design methods, including loss function, developed by Genichi Taguchi to improve the quality of manufactured goods at first. Nowadays, Taguchi methods are applied not only to manufacturing but also to engineering, biotechnology, marketing and advertising (Fei, Mehat, & Kamaruddin, 2013; Mahapatra & Patnaik, 2009; Roy, 2010; Selden, 1996). Taguchi methods based on understand including loss function and robustness, so that to design parameter by Taguchi method can achieve stable effect. To apply to reasonable orthogonal allays, more variants can be investigated their effect as parameters with less trial stimulus or sample.

2.2 Literature review

To improve the quality of life of people with visual impairment is a major theme from the aspect of public health, the construction industry, infrastructure, and transport. Especially, according to increase of elderly population, the people with low vision will also be increased because the aging is the cause of major diseases, such as cataract, glaucoma and AMD. Dagnelie considered vision changes that are a part of normal aging, the prevalence of abnormal vision changes caused by disorders of the visual system. Then he discussed and considered how to promote improved quality, availability and acceptance of low vision care to lessen the impact of visual impairment (Dagnelie, 2013). Mansfield et al. discussed the effect of "Font" for people with low vision and with normal vision to make their recognition easier (Mansfield et al., 1996). Peli et al., also contributed to the research on the effect of image enhancement for the people visual impairment (Peli, 1992; Peli, Goldstein, Young, Trempe, & Buzney, 1991; Peli & Peli, 1984).

For the traffic signs, there are many investigations have been done for driving for the people with low vision (Bahlmann, Zhu, Ramesh, Pellkofer, & Koehler, 2005; De la Escalera, Armingol, & Mata, 2003; De La Escalera, Moreno, Salichs, & Armingol, 1997; Sermanet & LeCun, 2011; Strong, Jutai, Russell-Minda, & Evans, 2008; Vincent, Lachance, & Deaudelin, 2012). Strong et al., reviewed the effectiveness of driver rehabilitation and trainings for elderly and visual impairment drivers. They also review the low vision devices for driving. Vincent et al., investigated the effect of Bioptic

Telescope on driving by the people with low vision. Bahlmann et al., tried to detect the traffic sign from images to apply the data for automatic driving. Sermanet and LeCun also tried to apply image processing measure to recognize and classify traffic Signs for driving.

While for pedestrians, some research has been reported (Geruschat, Fujiwara, & Emerson, 2011; Van Houten, Blasch, & Malenfant, 2001; Wang, Pan, Zhang, & Tian, 2014). Houten et al., investigated the recognition distance with traffic signals for the people with low vision. Geruscnhat et al., tried to find out how to detect the traffic gap to across the street for the people with low vision, especially with narrow vision caused by AMD. Wang et al., tried to support the people with low vision by image analysis to detect gap and traffic signs to guide them walking safety.

Zwalen et al., studied on nighttime recognition for shape by using 3 different materials having luminance of 1,130 cd/m^2, 336 cd/m2 and 11,625 cd/m^2 and found that the longest recognition distance was for the triangular shape. The subtended visual longest angle of the stimulus was 0.22–0.20 degrees, viewed by normal color vision. The shortest recognition distance was for the circle and the octagon (Zwahlen, Gardner-Bonneau, Adams Jr, & Miller, 1988).

Ikeda et al., demonstrated the color appearance through foggy lenses simulated the elderly eyes. The cloudy lenses desaturated color patches greatly when the size was small. They suggested that, for the elderly, to maintain the same color appearance to the original color, the size of the color paten should be greater than 6 degrees (Ikeda, Pungrassamee, & Obama, 2009).

In this research, we employed 3 types of simulated low vision glasses to investigate how pedestrians with low vision recognize the factor of traffic signs such as color, shape and color portion, and tried to propose optimized traffic signs for people with low vision.

CHAPTER 3
METHODS

3.1 Materials and equipment

3.1.1 Investigation of the effect of the most common shape of traffic signs with color on response time and distance.

3.1.1.1 Three types of simulated low vision glasses, M. Takata Optical Company Limited, Japan

- Occlusion vision, CV (VA = 0.08), the lens is cloudy.
- Blurred vision, BV (VA = 0.06)
- Narrow vision, NV (visual angle=3 degrees)

3.1.1.2 Konica Minolta CS-100A chroma meter, Japan

3.1.1.3 Konica Minolta CL500A illuminance spectrophotometer, Japan

3.1.1.4 EIZO monitor display model ColorEdge CX271, Japan

3.1.1.5 Color Calibration program Color Navigator 6, Japan

3.1.1.6 Farnworth-Munsell 100-hue test, USA

3.1.1.7 Adobe Illustrator CC 2017, USA

3.1.1.8 Experimental booth

3.1.2 Investigation of the effect of color portion of traffic signs on response time.

The equipment shown in Section 3.1.1, from Items 3.1.1.1 to 3.1.1.8 were used in this experiment. In addition, the following items were used.

3.1.2.1 Canon EOS 7D, Digital Camera, Japan

3.1.2.2 Ginichi Silk Gray Card, Japan

3.1.2.3 Adobe Photoshop CC 2017, USA

3.1.2.4 X-Rite I1 Eye-One Pro spectrophotometer, USA

3.1.3 Investigation of the farthest distance required to response on the improved traffic signs compared with the current traffic signs by normal vision subjects wearing three types of simulated low vision glasses.

The equipment shown in Section 3.1.1, from Items 3.1.1.1 to 3.1.1.8 were used in this experiment. In addition, the following items were used.

3.1.3.1 Adobe Photoshop CC 2017, USA

3.1.3.2 Google form, USA

3.2 Experimental procedure

3.2.1 Investigation of the effect of the most common shape of traffic signs with color on response time and distance.

This first part of research was to optimize the shape and the color based on time of recognition by simulated low vision. The stimuli that were combined six types of shape and four colors, used in common traffic signs, were shown on monitor. The normal vision observers wearing 3 types of the simulated low vision glasses: narrow vision, occlusion vision and blurred vision, participated in the experiment under dim and bright conditions. The experimental room was at Shizuoka University of Arts and Culture, Japan.

3.2.1.1 Participants

The participants were 10 students from Shizuoka University of Arts and Culture. There were 9 females and 1 male aged between 19 to 35 years old and all participants in the group have visual acuity between 20/14–20/20 with corrective lenses, and they have normal color vision, tested by using Munsell 100-Hue test. The visual acuity was tested in the laboratory using the Snellen chart with 6 m calibration. The walk-up acuity or reducing distance by bringing participant to the chart was used. Subsequently the distance was converted to 20 ft Snellen equivalent.

3.2.1.2 Experimental set up and stimulus

Stimuli were presented on a 27 inches LED screen, EIZO Color Edge CX271, 2560×1440 pixels (16:9). The monitor was calibrated using the Color Navigator 6. The observers sat at 0.6 m and 0.8 m from the monitor in a brightness-controlled booth. Viewing was binocular with simulated low vision glasses. The maximum stimulus size was 11 degrees at 60 cm viewing distance. This simulated the real distance of 3.1 m when viewed the traffic sign with the size of 60 cm by setting each stimulus image with same visual angle according to the calculation method showed in Figure 3-1. The conditions that were used in the experiment are shown in Table 3-1.

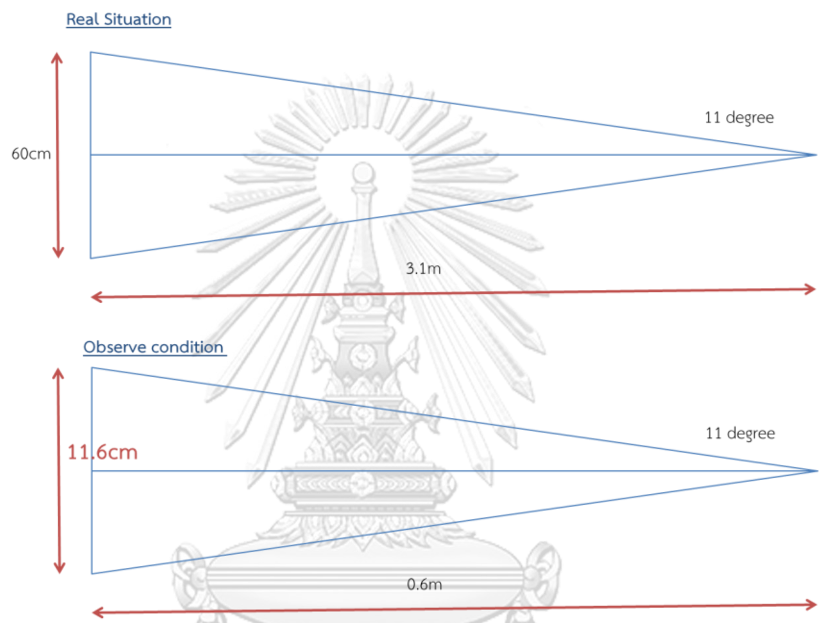

Figure 3-1 Calculation of simulated distance between monitor and observers

Table 3-1 Visual angle of each combination of image size and distance.

		Distance between observers and monitor	
		60 cm	80 cm
Image size on monitor	11.6 cm	11.0 degrees/ 3.1 m	8.3 degrees/ 4.1 m
	7.2 cm	6.8 degrees/ 5.0 m	5.1 degrees/ 6.7 m
	3.6 cm	3.4 degrees/ 10.0 m	2.6 degrees/ 13.3 m

The visual angles were selected according to the previous research (Ikeda et al., 2009). Our selection was within the range of visual angle that they tested the color perception of participants wearing cloudy simulated glasses.

The brightness controlled experimental booth of 1.75 m x 1.70 m x 2.10 m (W x L x H) was set up. Participants, wearing simulated low vision glasses, sat at a table of 0.77 m height and looked at the stimulus on the monitor for individual session as shown in Figure 3-2.

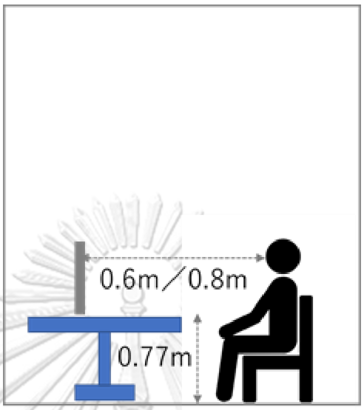

Figure 3-2 Experimental booth from cross view.

Stimuli were conducted for four color Munsell patches by using Adobe Illustrator CC2017. The Munsell Patches, according to ISO 3864-1 (Graphical Symbols – Safety colors and safety signs - part 1), were 7.5R 4/15, 2.5Y 8/14, 10G 4/10 and 2.5PB 3.5/10. Stimuli also were shaped into six types of common traffic sign, square, circle, diamond, octagon, and inverted triangular (Figure 3-3), according to standard of United Nation (convention on road signs and signals of 1968), Triangular shape is according to Japanese Government Ordinance about Traffic sign. Furthermore, stimuli having the combination of six shapes and four colors were showed in 3 sizes with N5 grey background on monitor randomly.

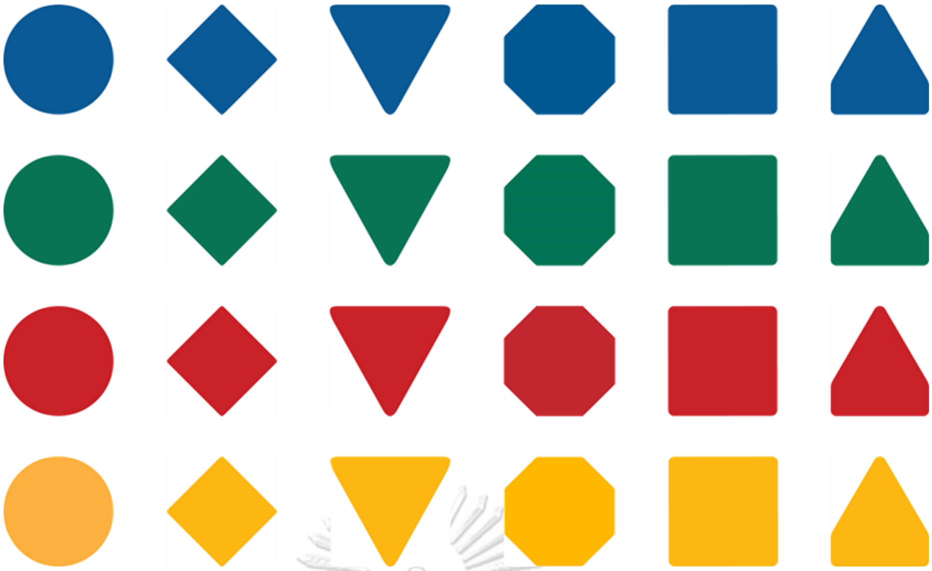

Figure 3-3 Stimulus images

3.2.1.3 Lighting conditions

Experimental light booth was set into two brightness conditions, “Bright” and “Dim” as shown in Table 3-2. The luminance of the bright and dim conditions was set at the maximum and minimum of the monitor’s luminance respectively. These 2 conditions, ‘Dim’ and ‘Bright’, were selected to simulate dusk/dawn and sunrise/midday/sunset of the day respectively. The illuminance of the experimental light booth was measured by using the illuminance spectrophotometer Konica Minolta CL-500A, located at the face of table in front of monitor. The luminance of the monitor was measured at white image on center of monitor using luminometer Konica Minolta CS-100A, at the distance of 20 cm.

Table 3-2 Lighting conditions of “Bright” and “Dim”.

Brightness condition of experimental booth	Illuminance of room (lx)	Luminance of monitor (cd/cm^2)
Bright	400	255
Dim	10	18.9

3.2.1.4 Procedure

3.2.1.4.1 100 Hue test: Each subject participated in testing color vision using Munsell 100-hue test at the outside of experimental booth, under light booth having D65 illumination.

3.2.1.4.2 Trial with simulated low vision glasses: Each subject was asked to answer the shape and color for each image showed on monitor while wearing the simulated low vision glasses, and the time from showing image to finish answering correctly was recorded for each image. The HTML codes were written to show stimulus one by one randomly. The time was recorded by the program once the experimenter clicks to show stimulus and the recording time stopped immediately when the experimenter clicked after hearing the right answer. The experimenter explained the instructions to the participants that “In the experiment you are about to see the stimuli randomly. They have 6 shapes including square, rectangle, triangular, flip triangular, diamond and circle. Each shape has colors that are red, yellow, green and blue. After the stimulus appears on the screen, you shall state the shape and color of the stimulus. If it is correct, the next stimulus will appear and you do the same. If it is not correct, the experimenter will announce ‘try again’ then you shall state the shape and color of the stimulus again. This will repeat until you state it correctly. Then the next stimulus will appear on monitor.” The participants were trained for about 10 stimuli covered all visual angles in test. Each sequence for a participant took about 30–40 minutes for each type of glass. They did each sequence in different day. One sequence has three trials or three repetitions and in each trial 72 images were shown under dim and bright conditions from 0.8 m and 0.6 m distances (72 images x 4 conditions x 3 repetitions). To keep the fixed distance, each subject was set their shoulder to back of chair and chair’s legs were set on the floor mark which was measured to have correct distance between eyes of subjects and monitor.

The summary of experimental parameter of the 1st investigation is shown in Table 3-3.

Table 3-3 Summary of parameters used in the 1st investigation.

Low vision glasses	Lighting conditions (cd/m^2)	Distance (m)	Stimulus		
			Color	Shape	Size
Narrow vision Occlusion vision Blurred vision	Dim (18.9)	60	4 (see Fig.3-2)	6 (see Fig.3-2)	3 (see Table3-1)
		80	4	6	3
	Bright (255)	60	4	6	3
		80	4	6	3

3.2.1.5 Data collection

The judgements on every stimulus was answer of “shape & color” by participants and the time when the samples appeared until the participants made decision, for 3 types of simulated low vision glasses, 2 distances and 2 brightness conditions were examined. These results would be used to determine which color and shape is quickest recognized by analysis of reaction time.

3.2.1.6 Analysis

Analysis for recorded reaction time had done by applying repeated 2-way ANOVA and common statistical methods.

3.2.2 Investigation of the effect of color portion of traffic signs on response time.

3.2.2.1 Participants

The participants were 5 students from Chulalongkorn University participated in the experiment. There were 2 females and 3 males aged between 20 to 28 years old and all participants in the group have visual acuity between 20/15–20/20 measured while wearing the corrective glasses (if any) and they have normal color vision after Munsell 100-Hue test.

3.2.2.2 Experimental set up and stimulus

Stimuli were presented on a 24 inches LED screen, EIZO Color Edge CS2420, 1920×1200 pixels (16:9). The monitor was calibrated using the Color Navigator 6 and X-Rite I1 Eye-One Pro spectrophotometer. The observers sat at 0.8 m from the monitor in a brightness-controlled room. Viewing was binocular with the simulated low vision glasses. The maximum stimuli size were 5.2 degrees and minimum stimuli size were 1.3 degrees as shown in Table 3-4. The choice of observing distance and image sizes was resulted from the 1st investigation that the maximum visual angle affected the response time significantly was 3.4 degrees. Therefore, in this investigation visual angle ranges were chosen above and below 3.4 degrees.

Table 3-4 Visual angle of each image size and distance, distance between observers and monitor: 80 cm

		Visual angle/simulated distance
Image size on monitor	7.2 cm	5.1 degrees/6.7 m
	3.6 cm	2.6 degrees/13.3 m
	1.8 cm	1.3 degrees/26.6 m

Participants, wearing simulated low vision glasses, sat at a table of 0.85 m height and looked at the stimulus on the monitor for individual session.

Stimuli were conducted for 4 color Munsell patches by using Adobe Illustrator CC 2017. The Munsell patches, according to ISO 3864-1 (Graphical

Symbols – Safety colors and safety signs - part 1), were 7.5R 4/15, 2.5Y 8/14, 10G 4/10, and 2.5PB 3.5/10. Stimuli also were shaped two types of common traffic sign, “Circle” and “Triangular”, according to standard of United Nation (convention on road signs and signals of 1968), Triangular according to Japanese Government Ordinance about Traffic sign. These 2 shapes were selected as the results from the 1st investigation. Six kinds of sign: 2 of regulatory, 2 of warning and 2 of informative signs were chosen and showed in Figure 3-4. Furthermore, stimuli having the combination of 2 shapes and 4 colors with 2 levels of color portion were shown in 3 sizes with 3 patterns of background on monitor randomly as shown in Figure 3-5 for blue as example. The total numbers of stimuli were 864.

Three patterns of background are N5 gray, white building, and the road with trees. Last 2 patterns were taken in Chulalongkorn University campus, using Canon EOS 7D digital camera, with ISO:100, f = 6.3 and exposure time 1/80 seconds. White balance was set by using Ginichi Silk Gray card.

Figure 3-4 Stimulus samples, 6 kinds of traffic signs with 2 shapes, with 2 levels of color portion (Blue).

Figure 3-5 Background samples, road with trees, white building, and N5 Gray.

3.2.2.3 Lighting conditions

According to the results of the 1st investigation, lighting condition was limited only to “Dim” condition. This was because the Dim condition in the 1st investigation gave higher response time in many conditions and showed significant difference when observed in longer simulated distances from 10 m onward. It is clear that ‘Dim’ condition influences response time more than Bright condition. If the traffic sign is easy to recognize in Dim condition, it should be better recognized in Bright condition. Furthermore, Jenkins and Cole (Jenkins & Cole, 1979) suggested that color supports in conveying information if the luminance decreases. In this investigation, color and color portion were factors to be tested. The illuminance of the experimental booth was measured by using the illuminance spectrophotometer Konica Minolta CL-500A, at the face of table in front of monitor. The luminance of the monitor was measured by using luminometer Konica Minolta CS-100A, at the white image patch on monitor.

Table 3-5 Lighting conditions of the room (Dim).

Brightness condition of experimental room	Illuminance of room (lx)	Luminance of monitor (cd/cm^2)
Dim	10	18.9

3.2.2.4 Procedure

3.2.2.4.1 100 Hue test: Each subject participated in testing color vision by using Munsell 100-hue test.

3.2.2.4.2 Trial with simulated low vision glasses: Each subject was asked to answer the “Kind” of sign for each image showed on monitor while wearing simulated glasses, and accuracy and the time from showing image to finish answering was recorded for each image. "Accuracy" means the rate of correct answer. One sequence has 864 images, which are shown under dim conditions from 0.8 m distance. One sequence took about 45–70 minutes for each type of glasses. They were allowed to have a break at any time. To keep the fixed distance, each subject was set their shoulder to back of chair and chair's legs are set on the floor mark which is measured to have correct distance between eyes of subjects and monitor. For the 2nd investigation, Google form was recruited as a questionnaire format different from HTML format at 1st investigation. The summary of experimental parameters of the 2nd investigation is shown in Table 3-6.

Table 3-6 Summary of experimental parameters of the 2nd investigation.

Low vision glasses	Environment	Stimuli				
	Background	Traffic signs	Color	Shape	Size	Color portion
3	3 (see Fig.3-5)	6 (see Fig.3-4)	4	2 (see Fig.3-4)	3 (see Fig.3-4)	2 Negative/ Positive

The experimenter explained the following instruction to the participants. "In this experiment, you will be presented images randomly on the screen one by one. Individual image comprises traffic sign in an environment. The type of traffic sign, background and size will be different. You shall name the traffic sign after you recognize it. If you cannot recognize it or you cannot see it, please state 'I cannot see'" Then the experimenter shows the traffic signs and the name of traffic sign as shown In Table 3-7. The participants were trained for 6–7 images. The experimenter controlled the image presentation showed to the participants. Once the image was shown, the time was recorded and after the participant answered, the experimenter stopped time recording.

Table 3-7 Examples of traffic sign (in blue-positive) and names.

Traffic signs	Name of traffic sign
	Pedestrian and bicycle only “คนเดินเท้าและจักรยานเท่านั้น”
	Caution for slip “ระวังลื่น”
	Under construction “ระหว่างก่อสร้าง”
	School “เขตโรงเรียน”
	STOP “หยุด”
	SOS “ขอความช่วยเหลือ”

3.2.2.5 Data collection

Eight hundred sixty-four images were shown on monitor randomly. The judgements on every stimulus were answer of “kind of sign” by participants and the time when the samples appeared until the participants made decision, for 3 types of simulated low vision glasses were examined. These results would be used to determine which color, color portion, and shape is quickest recognized by analysis of decision time.

3.2.2.6 Analysis

Analysis for recorded answering time had done by applying repeated 2-way ANOVA and common statistical methods. For this investigation, the questionnaire included the option “I cannot see”. If the participant answered this option or incorrect answer, recorded reaction time was added 10,000 msec then analyzed. Consider with the result of 1st investigation, when each observer cannot see the stimulus and provide incorrect answers sometimes it took 8,000 to 9,000 msec approximately until provide correct answer. In this part, observer was allowed to choose the answer “I cannot see” or incorrect answer, so that we add 10,000 msec for weighting.

3.2.3 Investigation of the farthest distance required to response on the improved traffic signs compared with the current traffic signs by normal vision subjects wearing three types of simulated low vision glasses (blur, occlusion and narrow vision)

3.2.3.1 Participants

The participants were 7 students from Chulalongkorn University participated in the experiment. There were 5 females and 2 males aged between 20 to 38 years old and all participants in the group have visual acuity between 20/15–20/20 and they have normal color vision after testing with Munsell 100-Hue test.

3.2.3.2 Experimental set up and stimulus

Stimuli were presented on a 24 inches LED screen, EIZO Color Edge CS2420, 1920×1200 pixels (16:9). The monitor was calibrated using the Color Navigator 6 and X-Rite I1 Eye-One Pro spectrophotometer. The observers sat at 0.8 m from the monitor in a brightness-controlled room. Viewing was binocular with simulated low vision glasses. The maximum stimuli size were 5.2 degrees and minimum stimuli size were 1.3 degrees. For 3rd investigation, Google form was recruited as a questionnaire format different from HTML format in the 1st investigation. From the results of the 2nd investigation, one design was chosen for individual type of low vision and applied to 6 kinds of sign. In addition to these 12 signs, 6 current designs for individual sign, total 18 designs (Figure 3-6) of signs were showed on monitor with 3 kinds of background and 3 levels of distance same as the 2nd investigation.

3.2.3.3 Lighting conditions

The illuminance of the experimental room was measured by using the illuminance spectrophotometer Konica Minolta CL-500A, at the face of table in front of monitor. The luminance of the monitor was measured by using luminometer Konica Minolta CS-100A, at the white image on monitor. Lighting conditions of the room is the same as 2nd investigation showed in Table 3-5.

3.2.3.4 Procedure

3.2.3.4.1 100 Hue test: Each subject participated in Munsell 100-hue test.

3.2.3.4.2 Trial with simulated low vision glasses: Each subject was asked to answer the Kind of sign for each image showed on monitor while wearing simulated glasses, and the time from showing image to finish answering was recorded for each image. One sequence has 3 trials and in each trial 162 images were shown under dim conditions and viewed at 0.8 m distance. One sequence took about 40–45 minutes for each type of glasses. The participants were allowed to stop at any time. They did each sequence in different day. To keep the fixed distance, each subject was set their shoulder to back of chair and chair's legs are set on the floor mark which is measured to have correct distance between eyes of subjects and monitor. The summary of parameters of used in this investigation is shown in Table 3-8. The instructions given to the participants was similar to the 2nd investigation.

Table 3-8 The summary of the parameters used in the 3rd investigation.

Low vision glasses	Environment	Stimuli		
3	Background	Type of traffic signs	Design	Size
	3	6	3 (including current design)	3

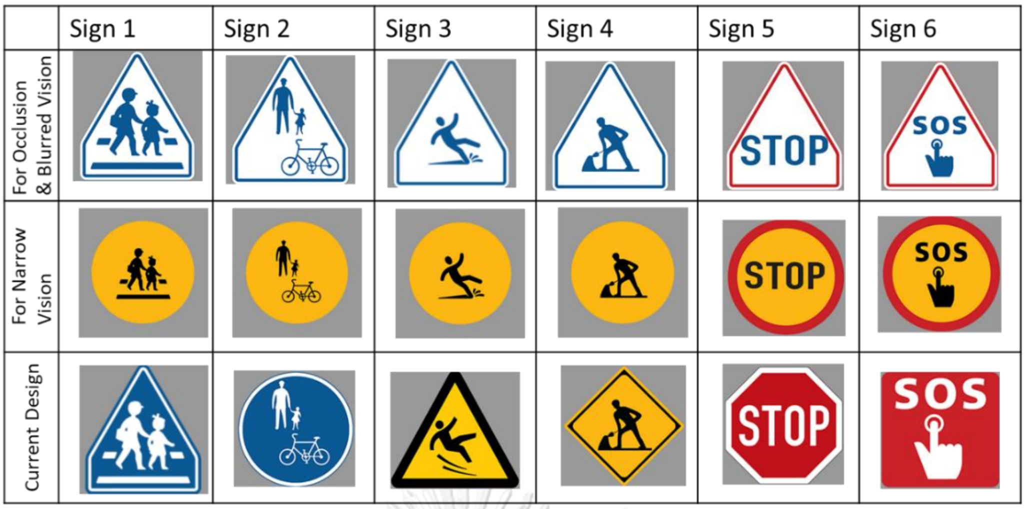

Figure 3-6 Stimuli for the 3rd investigation, 18 kinds of designs.

3.2.3.5 Data collection

The judgements on every stimulus were answer of “kind of sign” by participants and the time when the samples appeared until the participants made decision, for 3 types of simulated low vision glasses were examined. These results would be used to determine which sign is the quickest recognized by analysis of decision time.

3.2.3.6 Analysis

Analysis for recorded reaction time was carried out by applying repeated 2-way ANOVA and common statistical methods. For this investigation, the questionnaire included the option, “I cannot see”, same as 2nd investigation. If the participant answered this option or incorrect answer, recorded reaction time was added 10,000 msec then analyzed.

CHAPTER 4
RESULTS AND DISCUSTIONS

4.1 Investigation of the effect of the most common shape of traffic signs and with color on response time and distance

At first, the difference between "Dim" and "Bright" conditions was investigated. Octagon and circle shapes were confused and difficult to be recognized, at the most 2 far distances of 10 m and 13 m or size of visual angle of 3.4 degrees and 2.6 degrees in our test range, under dim condition than bright condition by blurred vision and occlusion vision significantly ($p \leq 0.05$), as shown in Table 4-1 and Table 4-2 respectively. For all of 4 colors, observers had wondered to answer which shape between circle and octagon were shown on monitor, so that the results of each color of circle or octagon is shown significant longer reaction time under dim condition. They had blue and green confusion sometimes but it did not show the significant difference in other shapes. This can be certain that 'Dim' condition has a stronger effect to circle and octagon confusion than blue and green confusion. On the other hand, there are no significant difference of reaction time between dim and bright condition for narrow vision statistically, as showed in Table 4-3. However, in short distance, the size of visual angle 11 degrees, it seems to be difficult to be recognized their shape under dim condition.

For the distance, we had obtained some clear tendency. Circle and octagon were more difficult to be distinct when distance became farther, especially over 10 m (less than 3.4 degrees of visual angle in our study) for blurred vision and occlusion vision. However, longer distance made to recognize shape easier for narrow vision. In Table A-2, Table A-3, and Table A-4 in the Appendix, reaction time and its statistics obtained from blurred, occlusion and narrow vision simulated glasses are shown, respectively.

Figures 4-1 to 4-72 show average of response time, and standard deviations of 10 observers against the simulated distance. Overall, average of reaction time is around 2 seconds for all conditions, and maximum reaction time is around 2–3 seconds while minimum reaction time is just under 2 seconds. Figures 4-1 to 4-24 show comparison of the reaction time between “Dim” and “Bright” conditions for simulated occlusion vision. Figures 4-25 to 4-48 show for simulated blurred vision and Figures 4-49 to 4-72 show for simulated narrow vision. For blurred vision and occlusion vision, the longer the distance is, the longer the reaction time shows. Some shapes showed obvious difference between “Dim” and “Bright” conditions. Especially, circle and octagon seem difficult to be distinguished from long distance. On the other hand, for narrow vision, the longer the distance is, the shorter the reaction time is recorded for each color and shape. In addition, these results show there are small difference in reaction time between blurred vision and occlusion vision under the “Dim” and “Bright” conditions.

Statistical analysis using 2-way ANOVA (Table A-1, Appendix) showed that color, shape, distance, types of simulated low vision glasses, as well as “Dim” and “Bright” conditions significantly affect the reaction time ($p < .01$). The combined effects of these variables also affect the reaction time ($p < .01$) except for color and shape ($p = .09$). We then need to analyze for individual conditions. Table 4-1, 4-2, 4-3 show the *p*-value of *t*-test for individual conditions including color, shape, distance as well as “Dim” and “Bright” conditions.

For blurred vision and occlusion vision, there are significant difference between “Dim” and “Bright” conditions for circle and octagon of each color under 3.4 degrees subtended by the image sizes, which means over 10 m distance for the traffic sign’s size of 0.6 m. These results are considered that octagon’s corners are difficult to be detected from circle; therefore, every observer took longer time to answer for them. Similar study (Zwahlen, Yu, Xiong, Li, & Rice, 1989) found that circle and octagon shapes could not be recognized in longer distance, greater than the average of about 115 meters at night time compared to square, rectangle and triangular having the maximum size of at least one side of 46 cm. They used 3 different high intensities of prismatic reflective materials as stimuli and found that different intensities: 1,130 cd/m^2, 3,336 cd/m^2, 11,625 cd/m^2 did not give significant difference on recognition distance at night time. We could see that even people with normal vision found it difficult to recognize circle and octagon shape, people with blurred and occlusion vision in our study experienced the similar results, in that, they took longer time to name these 2 shapes correctly. This can be confirmed by the road application in computer vision (Madani & Yusof, 2018) that the red circle traffic sign was wrongly classified as red octagon traffic sign due to similarity between circle and octagon in shape. In our study, the observers with blurred and occlusion glasses did the same as the classification method of Madani and Yusof.

For narrow vision, there are some significant differences between "Dim" and "Bright" conditions for yellow-square, yellow-diamond and green-octagon for 11 degrees subtended by the image sizes, which means 3.1 m distance for traffic sign's size of 0.6 m. These results are considered that they are too large, for narrow vision having visual angle of 3 degrees, to detect the shape of each stimulus. Also, under dim condition seems to be more difficult than under bright condition.

As conclusions of the 1st investigation for the simulated low vision, we confirmed that under "Dim" condition is more difficult to detect traffic signs than under "Bright" condition in longer distance, as in our study, over 10 meters.

In addition, to confirm better condition for each type of simulated low vision, 1-way-ANOVA is applied for the reaction time. To choose the condition that we can obtain shorter reaction time, we standardized the data of reaction time and put opposite sign, so that the shorter reaction time was obtained. Table 4-4 and Table 4-5 show the results of 1-way ANOVA. In terms of shapes, with 3 types of the simulated low vision, circle shape is the easiest to be detected by narrow vision; whereas the triangular shape is easiest to be detected by the blurred vision and occlusion vision. Zwahlen et al., mentioned that triangular has the longest average recognition distance followed by the rectangle, which means the triangle is the easiest shape to detect (Zwahlen et al., 1988; Zwahlen et al., 1989). This confirmed by our results done by the simulated blurred and occlusion visions. They suggested that the numbers of sides of a sigh should be kept as small as possible and length of the shortest side should be greater than 1/5 of the length of the longest side. (Table 4-4) In terms of colors, with 3 types of the simulated low vision, red seems to be easier to detect than other colors, although *p*-value is bigger than those with shapes (Table 4-5).

Table 4-1 Results of *p*-value of t-test between dim and bright conditions with simulated blurred vision for individual shape. The angles shown are the angles subtended by the size of the sample to the eyes

Shape	Color	The size of the sample to the eyes. (degrees)					
		11	8.2	6.8	5.2	3.4	1.3
Square	Blue	0.532	0.913	0.743	0.961	0.433	0.314
	Green	0.343	0.527	0.760	0.805	0.808	0.679
	Red	0.071	0.624	0.929	0.641	0.106	0.729
	Yellow	0.384	0.964	0.573	0.475	0.198	0.764
Circle	Blue	0.181	0.297	0.271	0.444	0.297	0.008**
	Green	0.433	0.756	0.531	0.683	0.196	0.094
	Red	0.944	0.805	0.172	0.246	0.042*	0.617
	Yellow	0.181	0.446	0.153	0.391	0.013*	0.017*
Diamond	Blue	0.568	0.189	0.940	0.524	0.678	0.784
	Green	0.358	0.225	0.510	0.815	0.188	0.730
	Red	0.113	0.343	0.889	0.879	0.633	0.226
	Yellow	0.112	0.347	0.784	0.927	0.162	0.423
Invert Triangular	Blue	0.663	0.820	0.217	0.863	0.917	0.671
	Green	0.727	0.816	0.257	0.380	0.507	0.528
	Red	0.183	0.771	0.845	0.114	0.729	0.513
	Yellow	0.412	0.426	0.939	0.777	0.884	0.560
Triangular	Blue	0.727	0.292	0.132	0.594	0.974	0.959
	Green	0.172	0.492	0.949	0.423	0.349	0.300
	Red	0.398	0.793	0.853	0.107	0.962	0.282
	Yellow	0.709	0.709	0.699	0.712	0.349	0.557
Octagon	Blue	0.593	0.559	0.312	0.769	0.044*	0.041*
	Green	0.432	0.932	0.972	0.739	0.027*	0.108
	Red	0.612	0.267	0.647	0.223	0.126	0.001**
	Yellow	0.123	0.738	0.748	0.616	0.011*	0.018*

Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”,

Table 4-2 Results of *p*-value of t-test between dim and bright conditions with simulated occlusion vision for individual shape. The angles shown are the angles subtended by the size of the sample to the eyes

Shape	Color	The size of the sample to the eyes. (degrees)					
		11	8.2	6.8	5.2	3.4	1.3
Square	Blue	0.341	0.752	0.349	0.169	0.267	0.802
	Green	0.265	0.973	0.951	0.919	0.147	0.389
	Red	0.176	0.833	0.596	0.530	0.677	0.734
	Yellow	0.305	0.980	0.205	0.750	0.221	0.865
Circle	Blue	0.156	0.453	0.147	0.270	0.356	0.636
	Green	0.113	0.131	0.710	0.719	0.214	0.683
	Red	0.627	0.391	0.404	0.595	0.501	0.006**
	Yellow	0.173	0.969	0.185	0.939	0.266	0.852
Diamond	Blue	0.244	0.501	0.471	0.685	0.407	0.544
	Green	0.426	0.777	0.542	0.508	0.349	0.414
	Red	0.932	0.670	0.881	0.713	0.213	0.893
	Yellow	0.893	0.935	0.256	0.732	0.262	0.196
Invert Triangular	Blue	0.745	0.309	0.017*	0.905	0.153	0.471
	Green	0.136	0.866	0.507	0.699	0.011*	0.480
	Red	0.933	0.211	0.348	0.419	0.317	0.976
	Yellow	0.585	0.952	0.477	0.900	0.836	0.862
Triangular	Blue	0.505	0.329	0.528	0.657	0.600	0.499
	Green	0.718	0.793	0.148	0.798	0.534	0.805
	Red	0.221	0.682	0.833	0.698	0.303	0.611
	Yellow	0.300	0.946	0.894	0.738	0.867	0.282
Octagon	Blue	0.454	0.439	0.689	0.839	0.073	0.661
	Green	0.180	0.478	0.789	0.357	0.018*	0.704
	Red	0.148	0.258	0.334	0.383	0.037*	0.296
	Yellow	0.426	0.922	0.168	0.246	0.134	0.361

Signif. Codes: 0.001< "***", 0.01< "**", 0.05< "*",

Table 4-3 Results of *p*-value of t-test between Dim and Bright conditions with simulated narrow vision for individual shape. The angles shown are the angles subtended by the size of the sample to the eyes

Shape	Color	The size of the sample to the eyes. (degrees)					
		11	8.2	6.8	5.2	3.4	1.3
Square	Blue	0.276	0.948	0.377	0.899	0.672	0.953
	Green	0.292	0.310	0.592	0.229	0.186	0.989
	Red	0.753	0.501	0.171	0.355	0.745	0.827
	Yellow	0.036*	0.114	0.405	0.368	0.797	0.339
Circle	Blue	0.267	0.611	0.210	0.848	0.389	0.780
	Green	0.552	0.198	0.693	0.309	0.721	0.483
	Red	0.952	0.929	0.585	0.969	0.606	0.522
	Yellow	0.944	0.194	0.450	0.778	0.916	0.407
Diamond	Blue	0.275	0.274	0.209	0.576	0.543	0.591
	Green	0.289	0.742	0.649	0.390	0.834	0.776
	Red	0.117	0.575	0.102	0.033*	0.746	0.442
	Yellow	0.039*	0.567	0.734	0.959	0.702	0.585
Invert Triangular	Blue	0.558	0.560	0.851	0.733	0.473	0.692
	Green	0.457	0.981	0.052	0.996	0.382	0.380
	Red	0.303	0.772	0.261	0.821	0.984	0.945
	Yellow	0.476	0.609	0.978	0.940	0.270	0.466
Triangular	Blue	0.340	0.957	0.569	0.832	0.113	0.460
	Green	0.614	0.651	0.109	0.307	0.694	0.404
	Red	0.444	0.346	0.240	0.177	0.601	0.913
	Yellow	0.261	0.508	0.550	0.936	0.087	0.268
Octagon	Blue	0.332	0.471	0.953	0.317	0.508	0.397
	Green	0.031*	0.996	0.541	0.950	0.637	0.548
	Red	0.781	0.558	0.947	0.568	0.531	0.847
	Yellow	0.173	0.852	0.256	0.652	0.881	0.414

Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”,

Table 4-4 Individual color’s results of *p*-values of 1-way ANOVA for reaction time with simulated 3 types of the simulated low vision.

	Occlusion vision	Blurred vision	Narrow vision
Blue	0.0016**	<0.00001***	<0.00001***
	Triangular	Triangular	Circle
Green	0.0003**	<0.00001***	0.0081**
	Triangular	Triangular	Circle
Red	0.0359*	<0.00001***	0.0003**
	Triangular	Circle	Circle
Yellow	<0.00001***	<0.00001***	0.0016**
	Triangular	Triangular	Circle

Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”

Table 4-5 Individual Shape’s results of *p*-value of one-way ANOVA for reaction time with simulated 3 types of simulated low vision.

	Occlusion vision	Blurred vision	Narrow vision
Square	0.4978	0.8025	0.0493* (Red)
Circle	0.2976	0.0267* (Red)	0.0183* (Red)
Diamond	0.0831	0.5955	0.5474
Invert Triangular	0.0049**(Red)	0.0721	0.8552
Triangular	0.2668	0.2641	0.9829
Octagon	0.2870	0.9699	0.4726

Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”

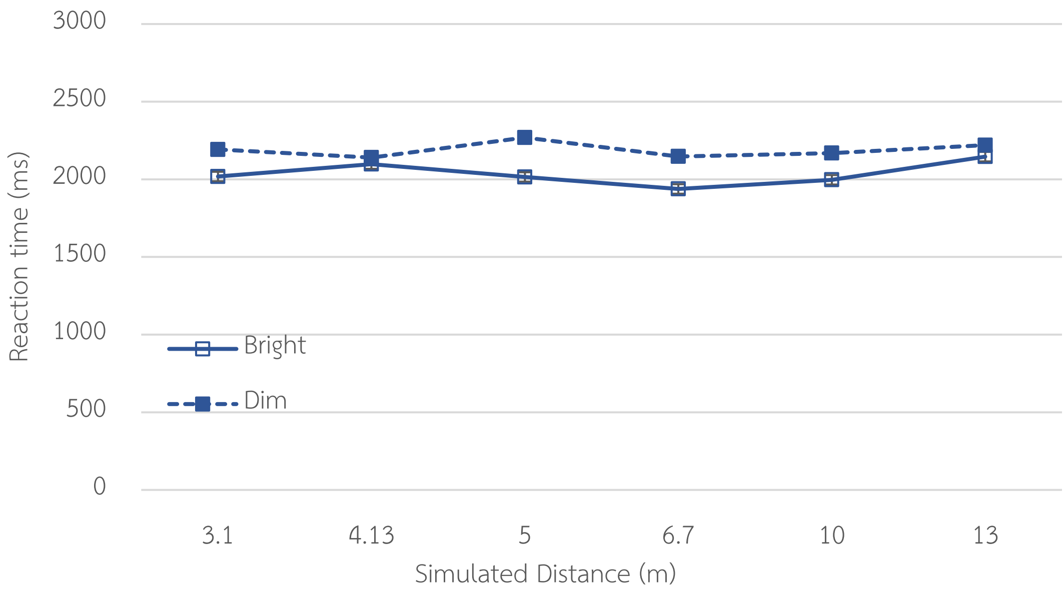

Figure 4-1 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for square shape/ blue color

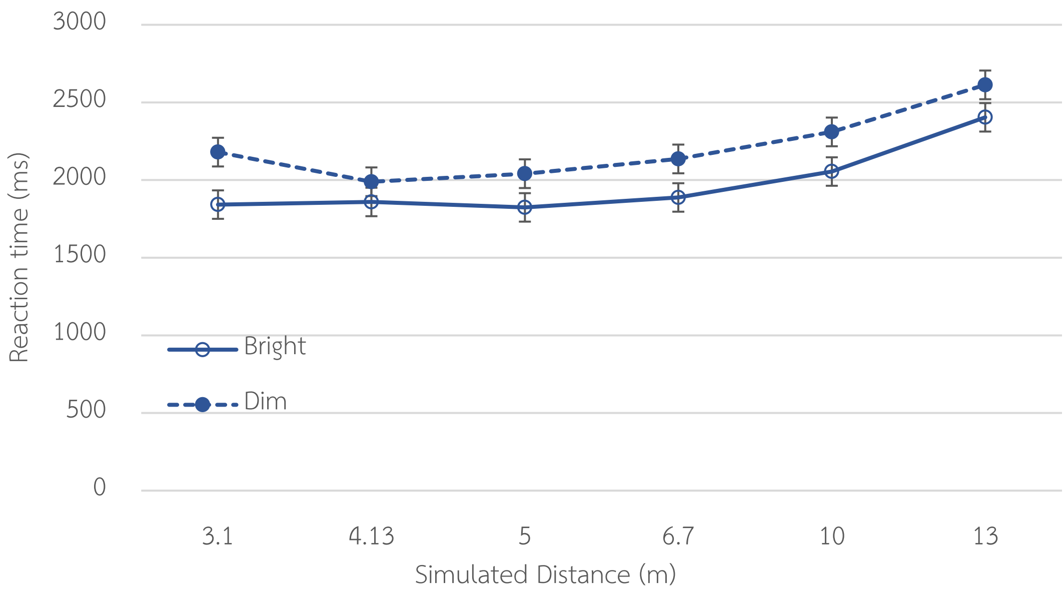

Figure 4-2 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for circle shape/blue color

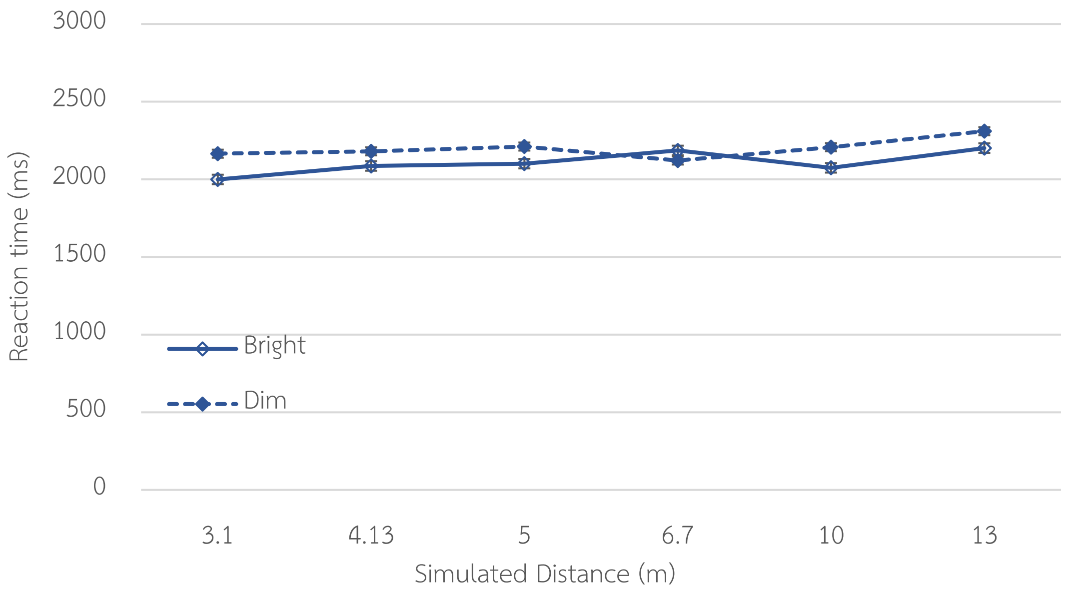

Figure 4-3 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for diamond shape/blue color

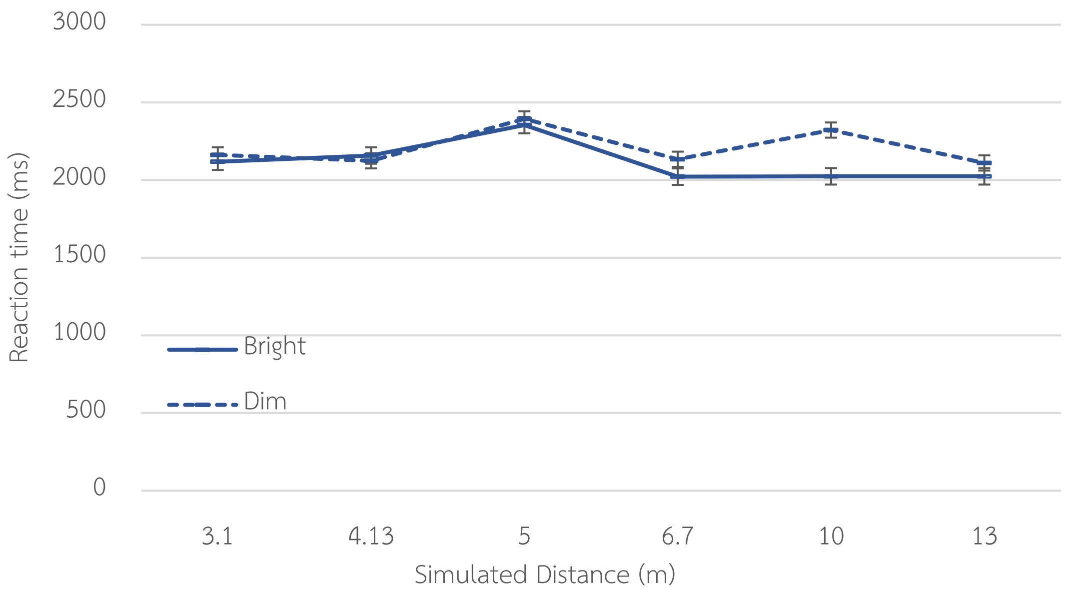

Figure 4-4 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for invert triangular shape/blue color

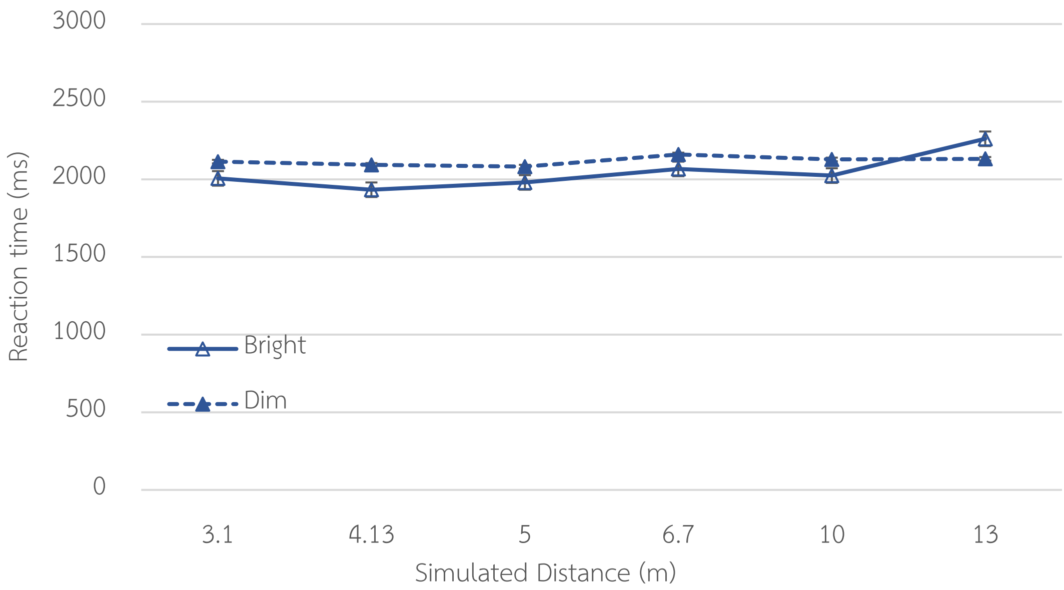

Figure 4-5 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for triangular shape/blue color

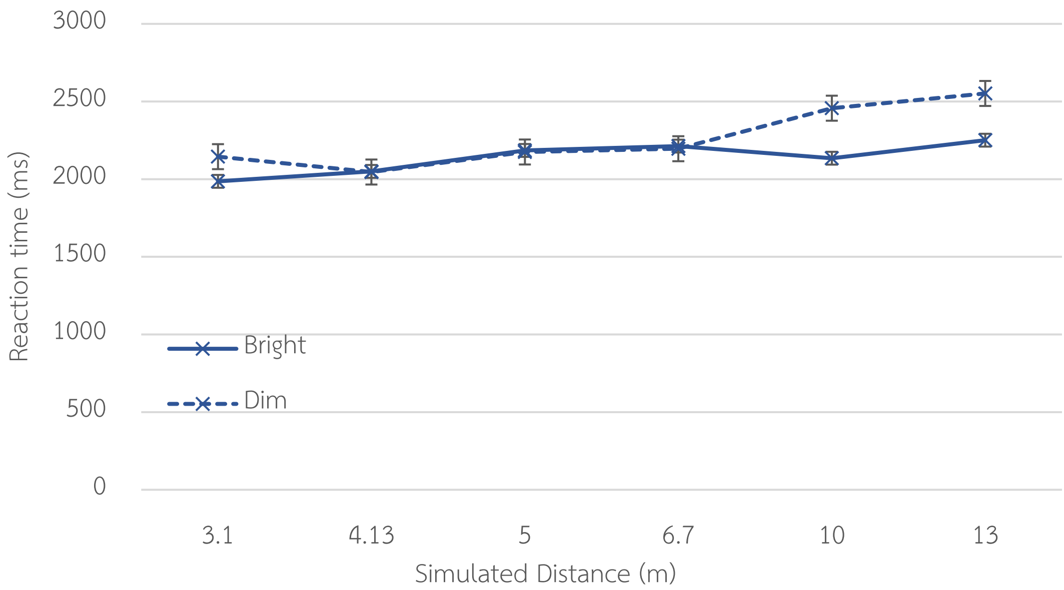

Figure 4-6 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for octagon shape/blue color

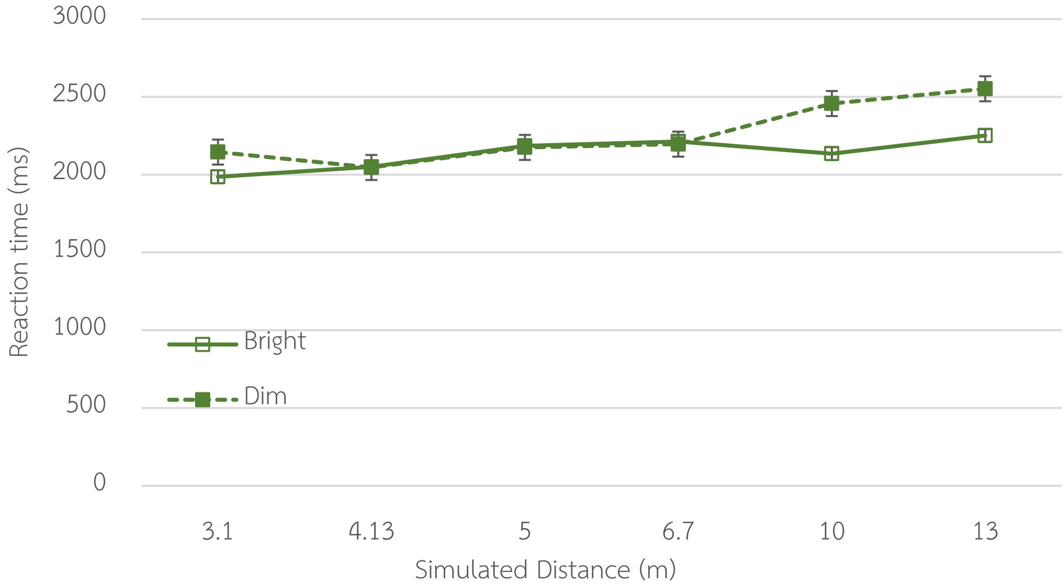

Figure 4-7 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for square shape/green color

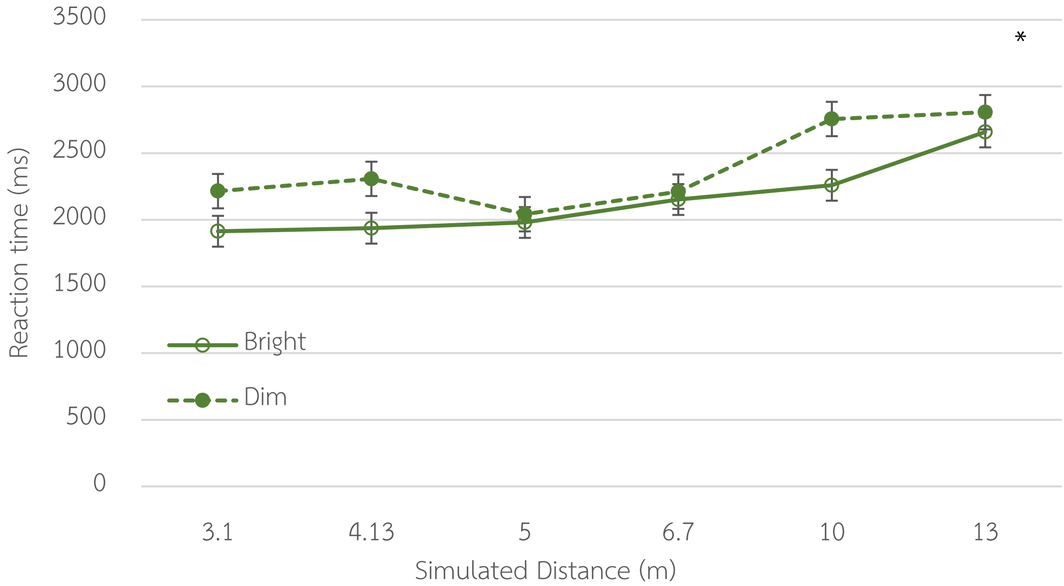

Figure 4-8 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for circle shape/green color

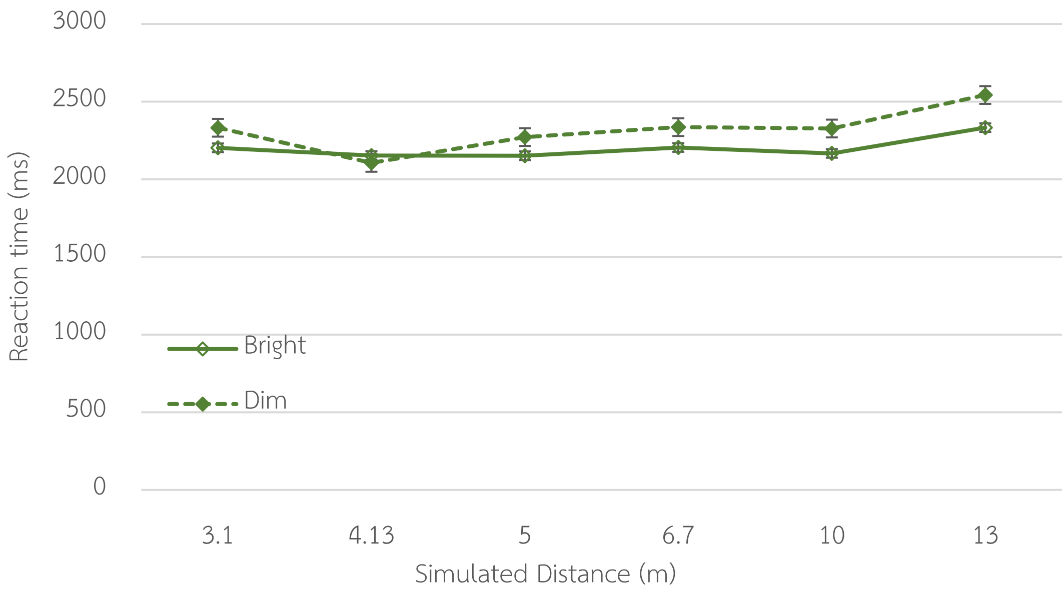

Figure 4-9 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for diamond shape/green color

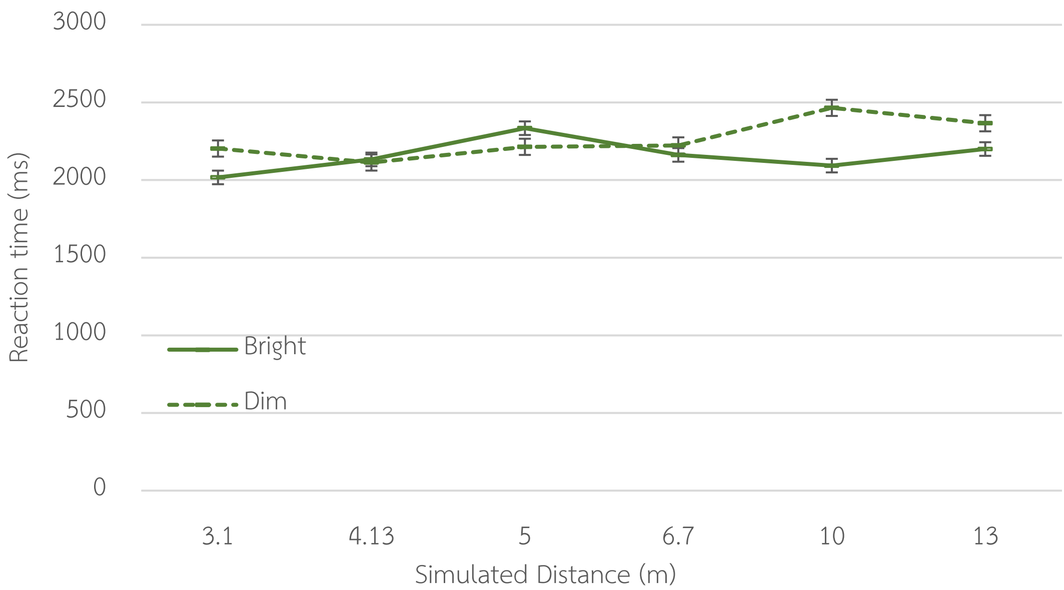

Figure 4-10 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for Invert triangular shape/green color

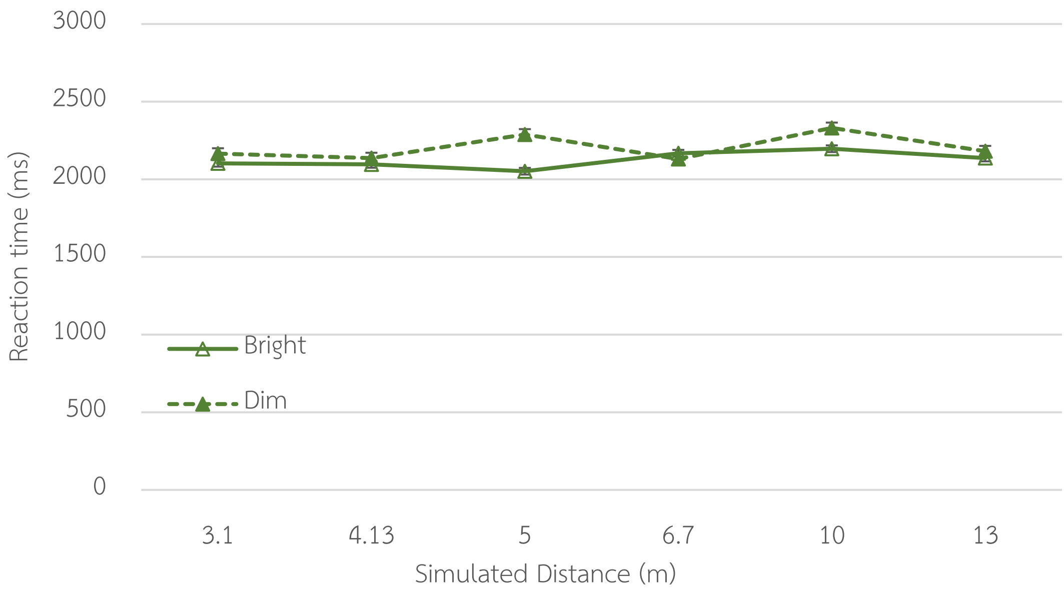

Figure 4-11 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for triangular shape/green color

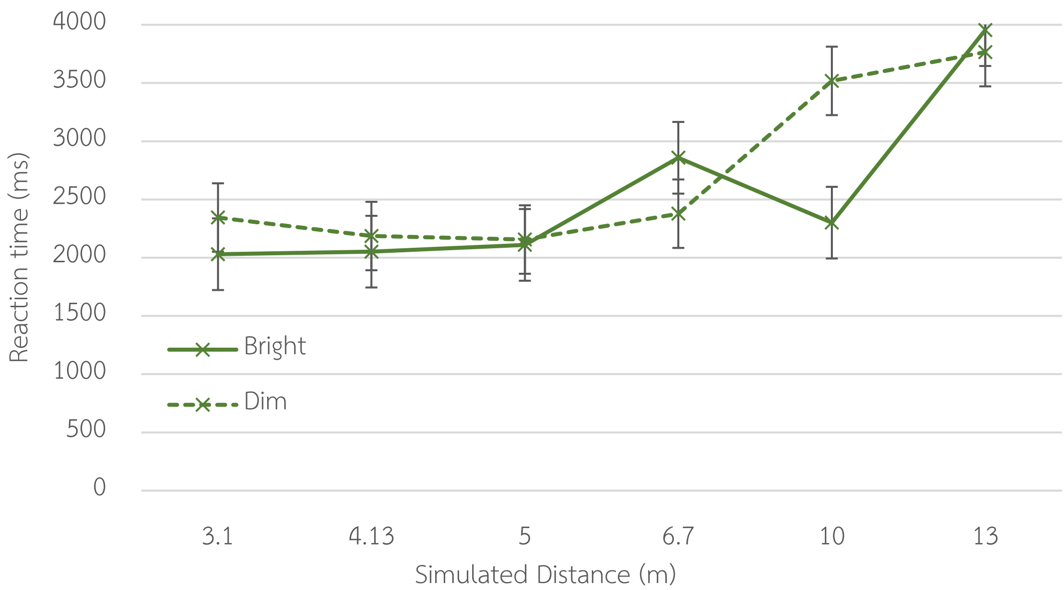

Figure 4-12 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for octagon shape/green color

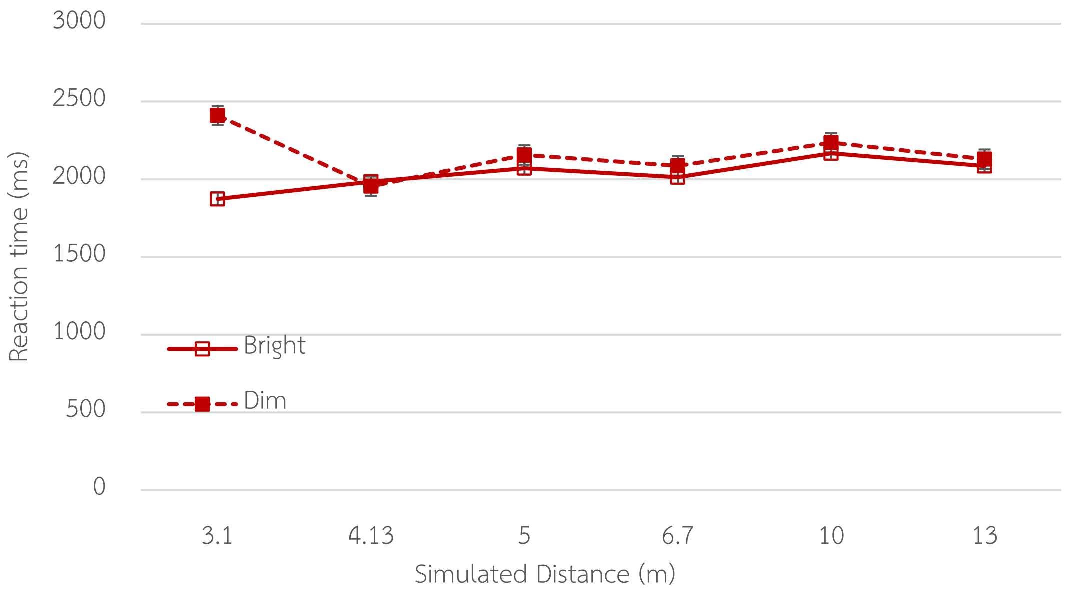

Figure 4-13 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for square shape/red color

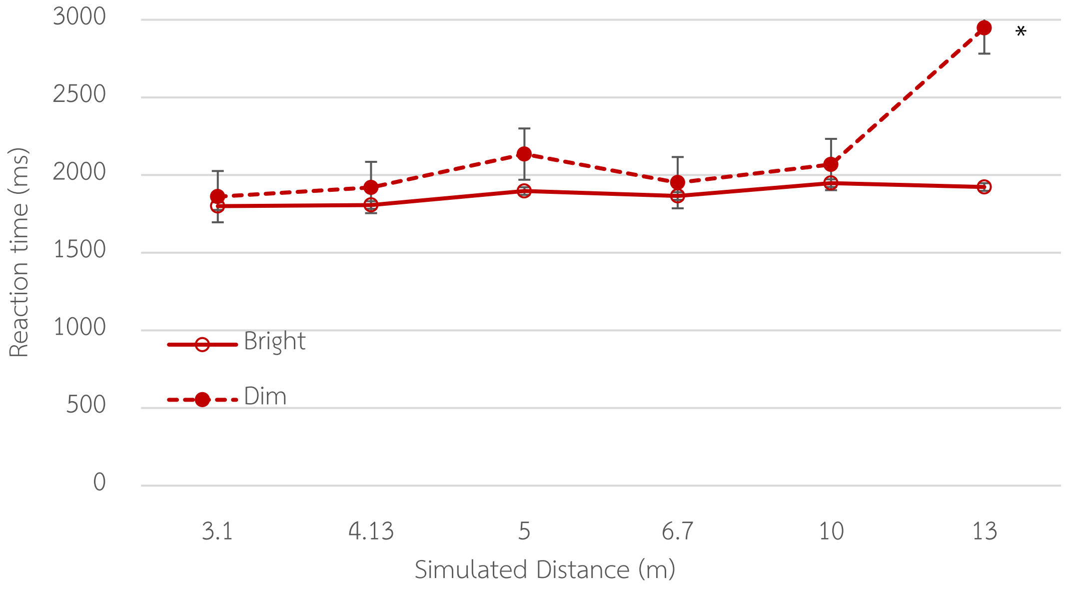

Figure 4-14 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for circle shape/red color

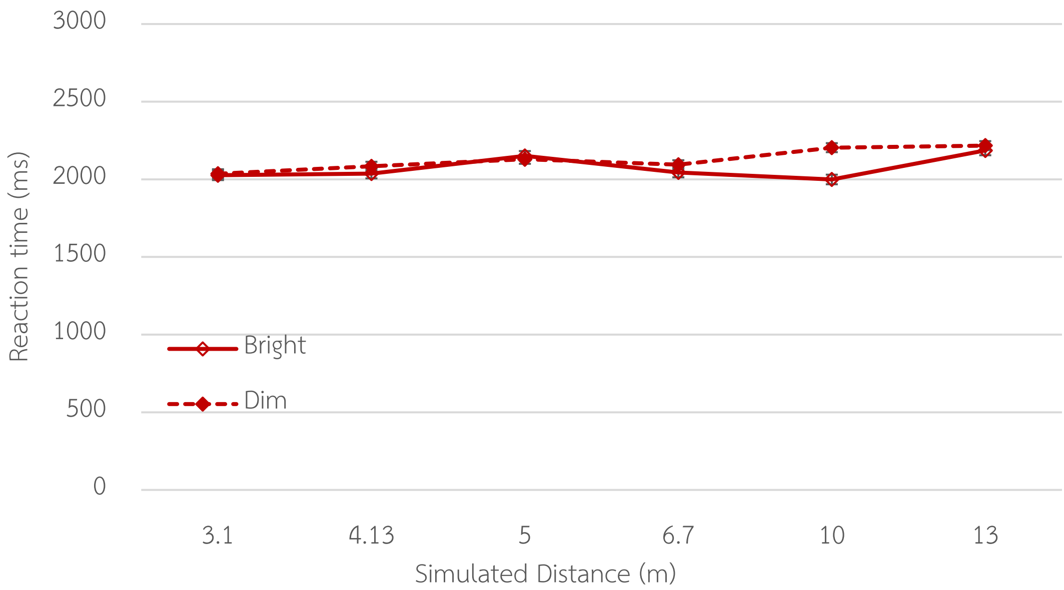

Figure 4-15 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for diamond shape/red color

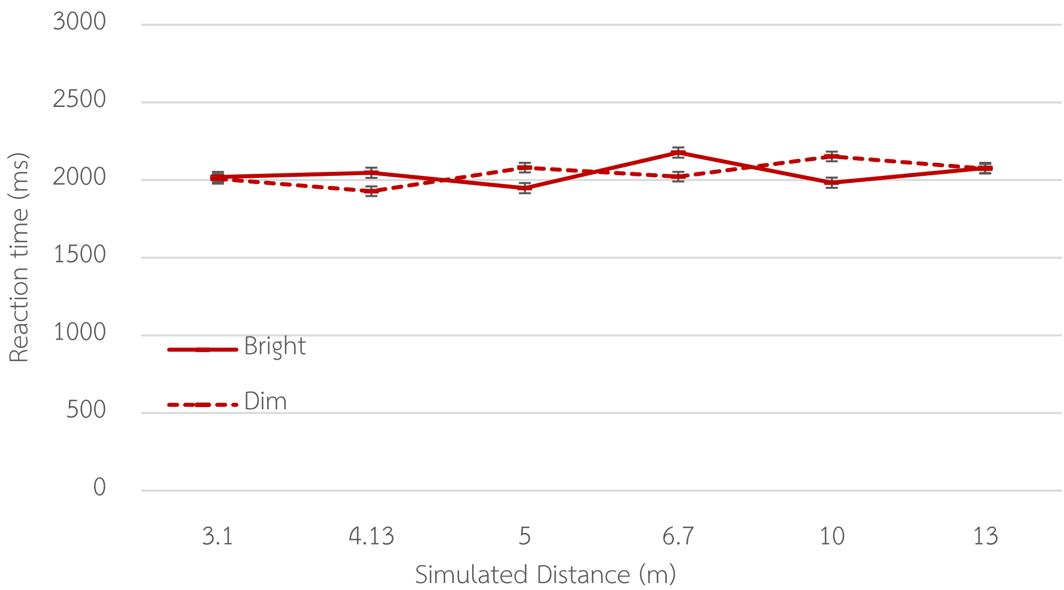

Figure 4-16 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for Invert triangular shape/red color

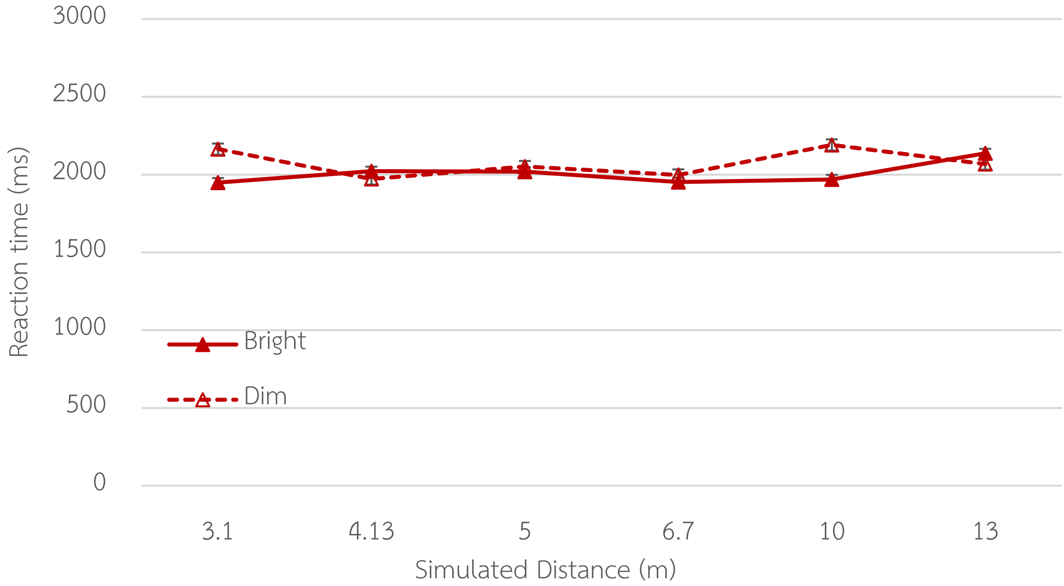

Figure 4-17 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for triangular shape/red color

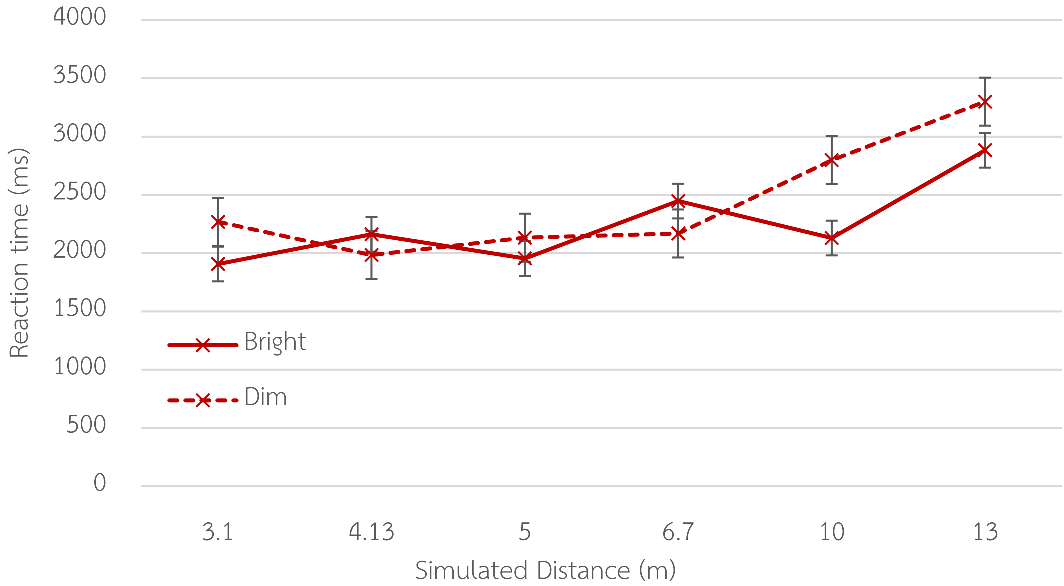

Figure 4-18 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for octagon shape/red color

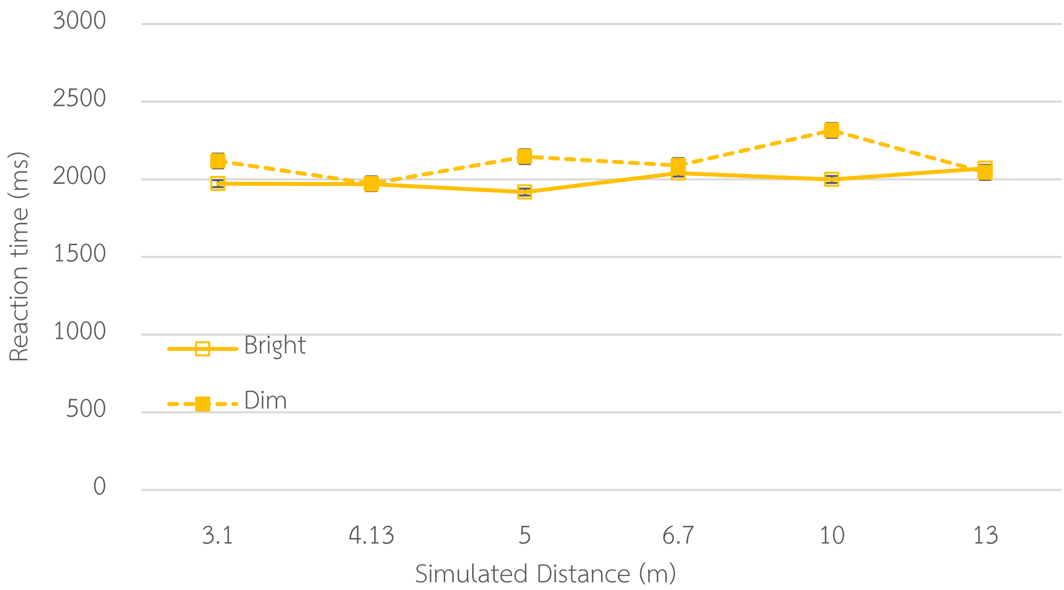

Figure 4-19 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for square shape/yellow color

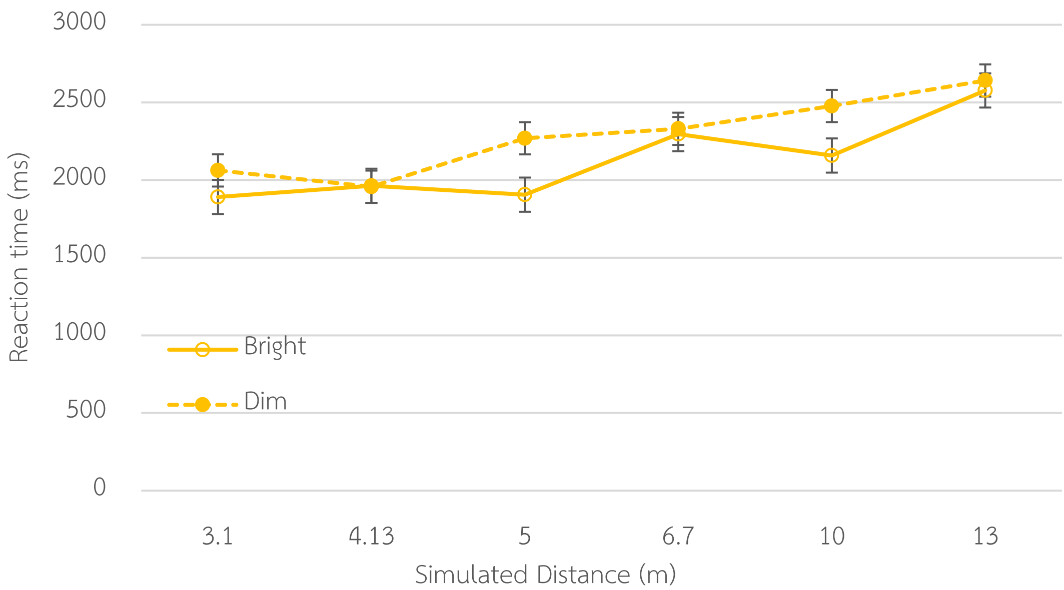

Figure 4-20 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for circle shape/yellow color

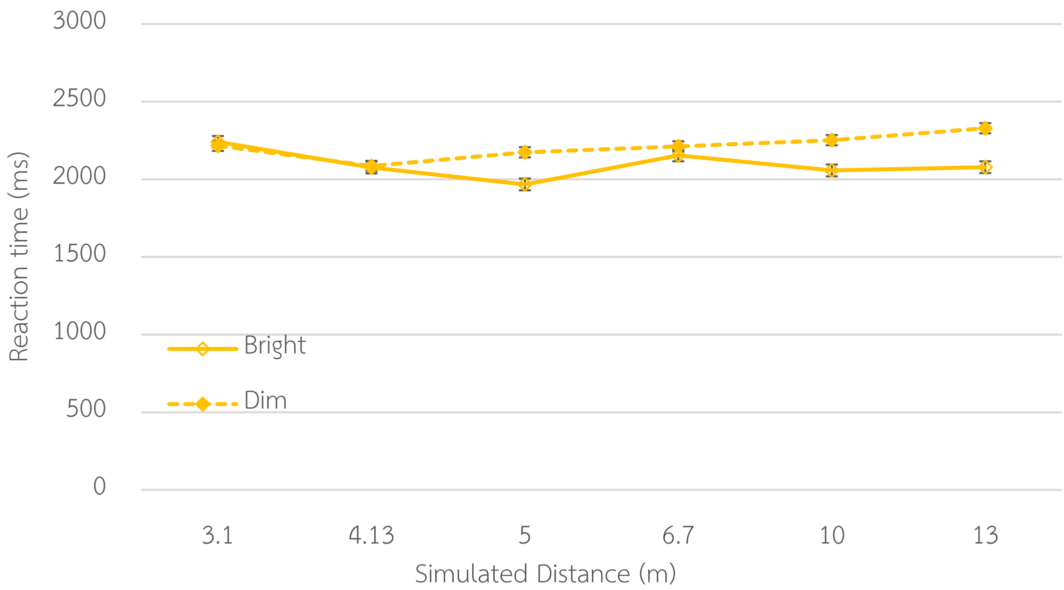

Figure 4-21 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for diamond shape/yellow color

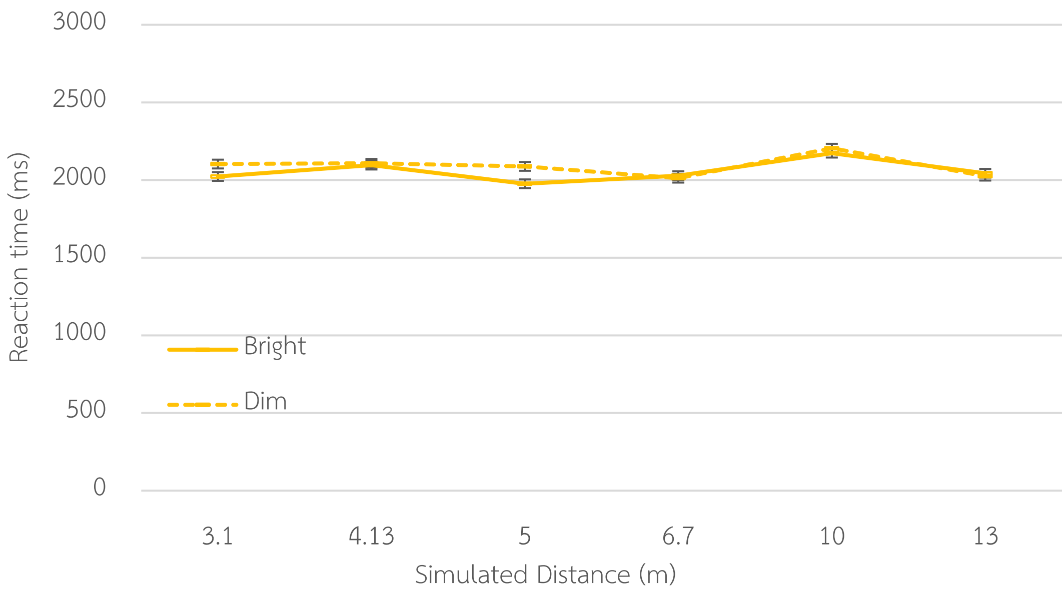

Figure 4-22 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for Invert triangular shape/yellow color

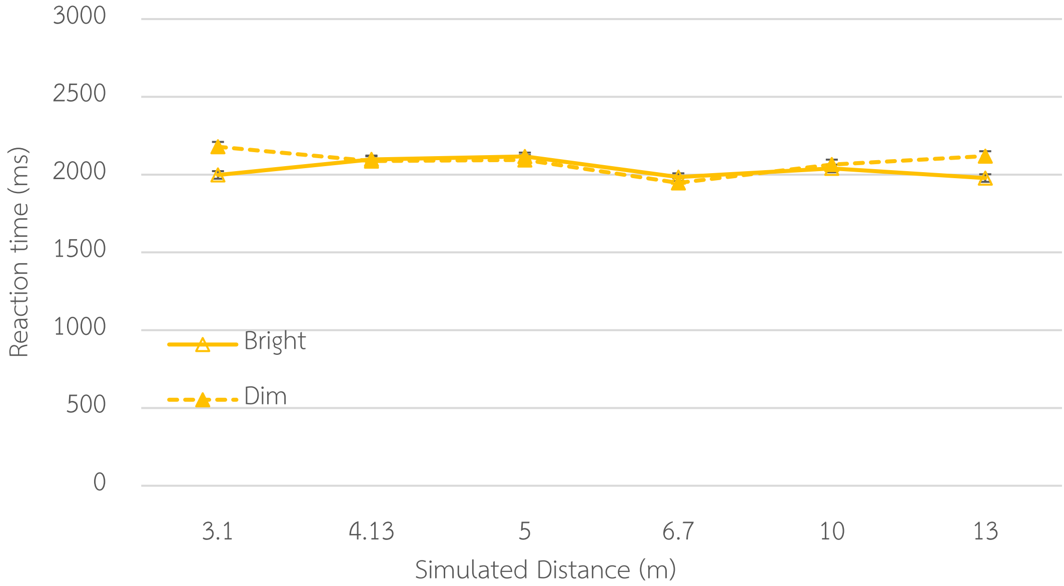

Figure 4-23 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for triangular shape/yellow color

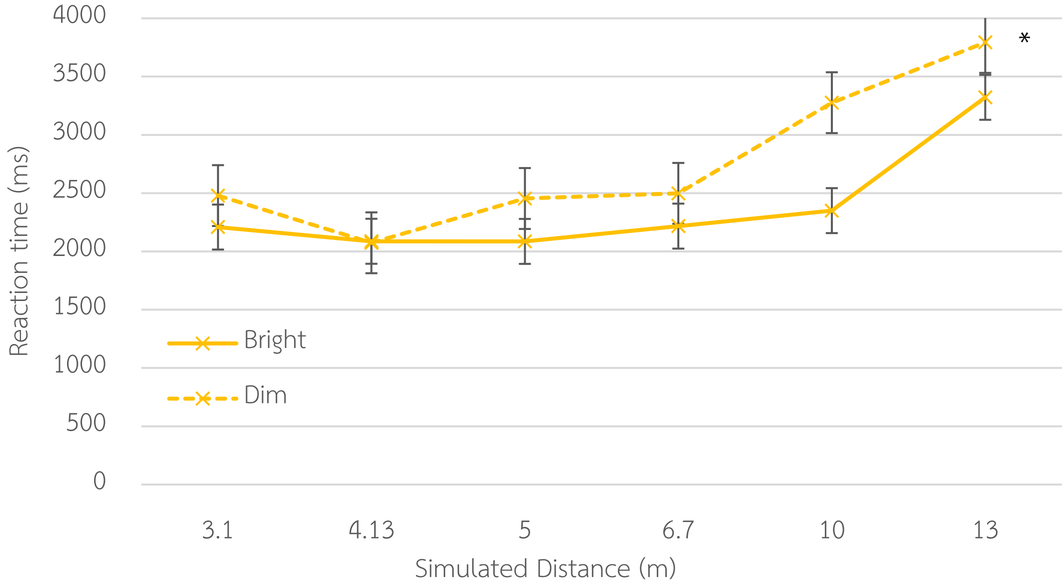

Figure 4-24 Reaction time under “Dim” and “Bright” conditions with simulated occlusion vision for octagon shape/ yellow color

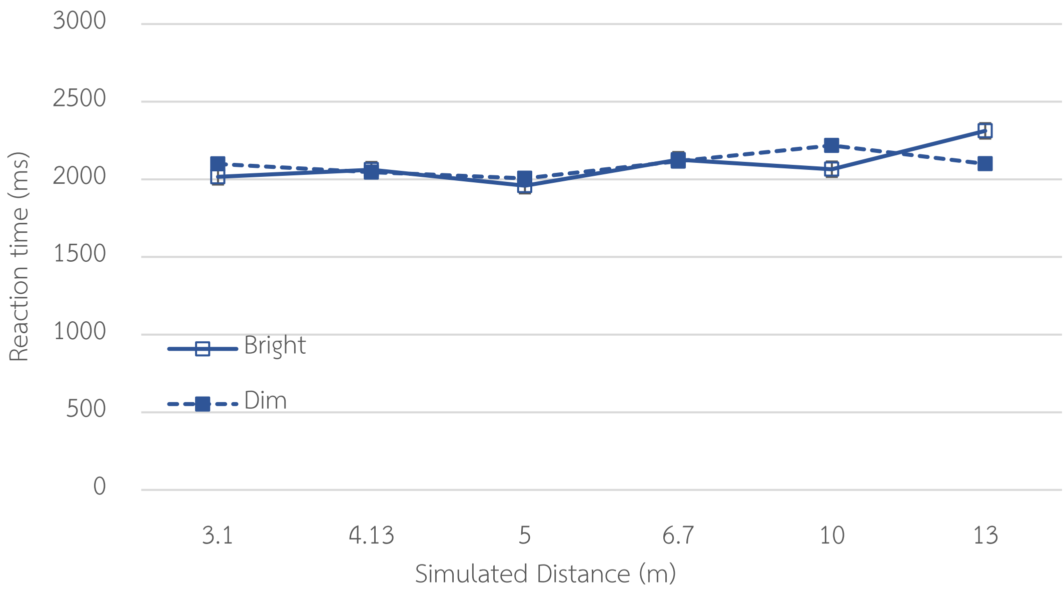

Figure 4-25 Reaction time under "Dim" and "Bright" conditions with simulated blurred vision for square shape/blue color

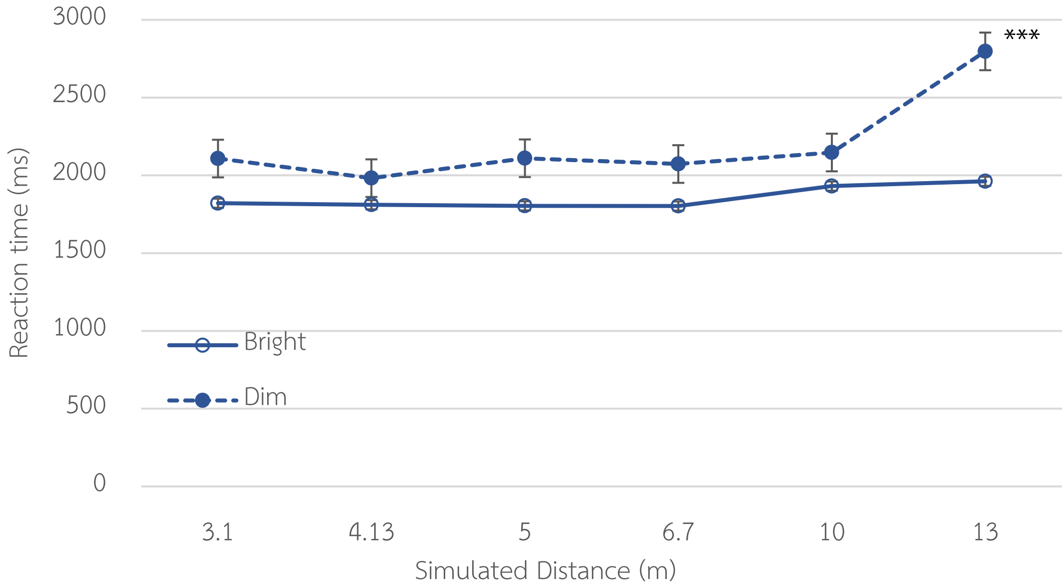

Figure 4-26 Reaction time under "Dim" and "Bright" conditions with simulated blurred vision for circle shape/blue color

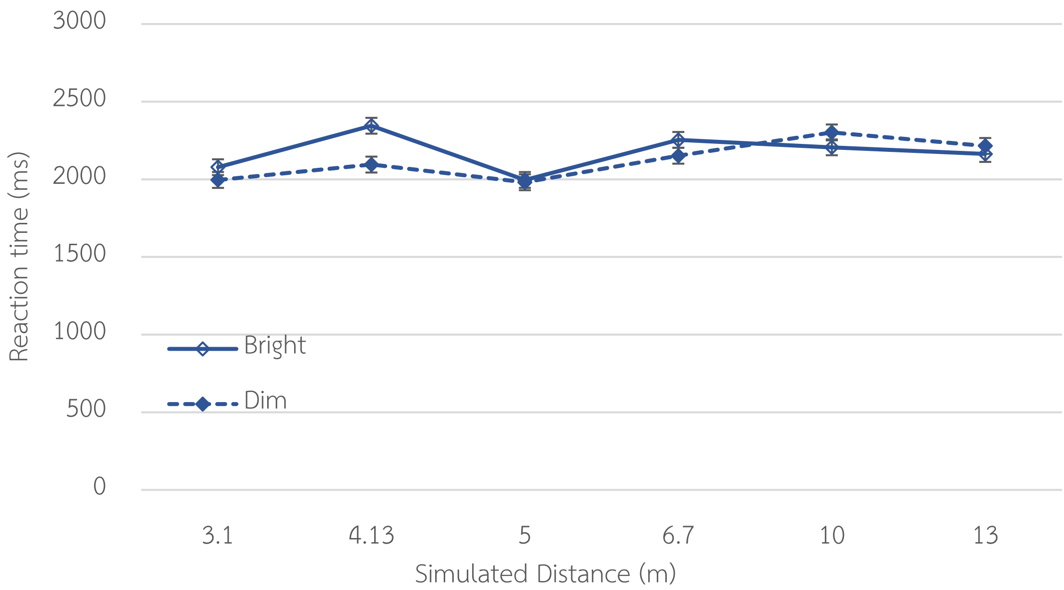

Figure 4-27 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for diamond shape/blue color

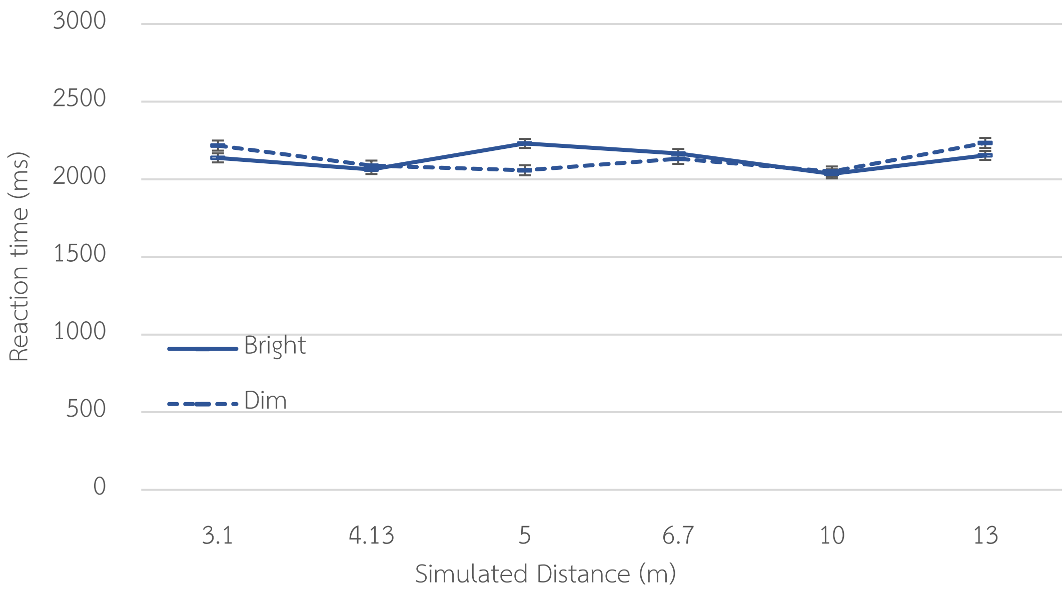

Figure 4-28 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for invert triangular shape/blue color

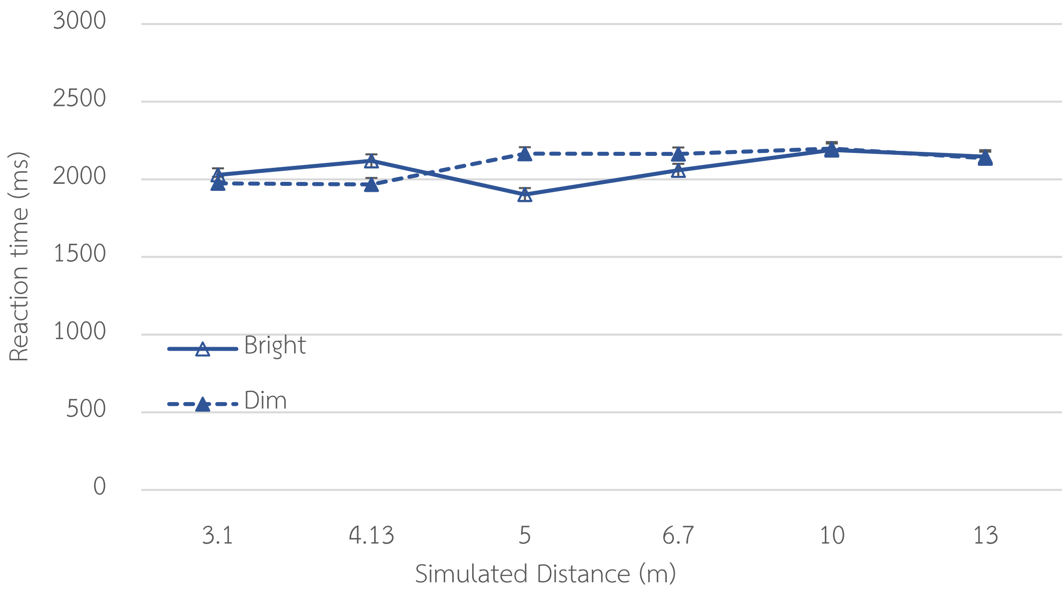

Figure 4-29 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for triangular shape/blue color

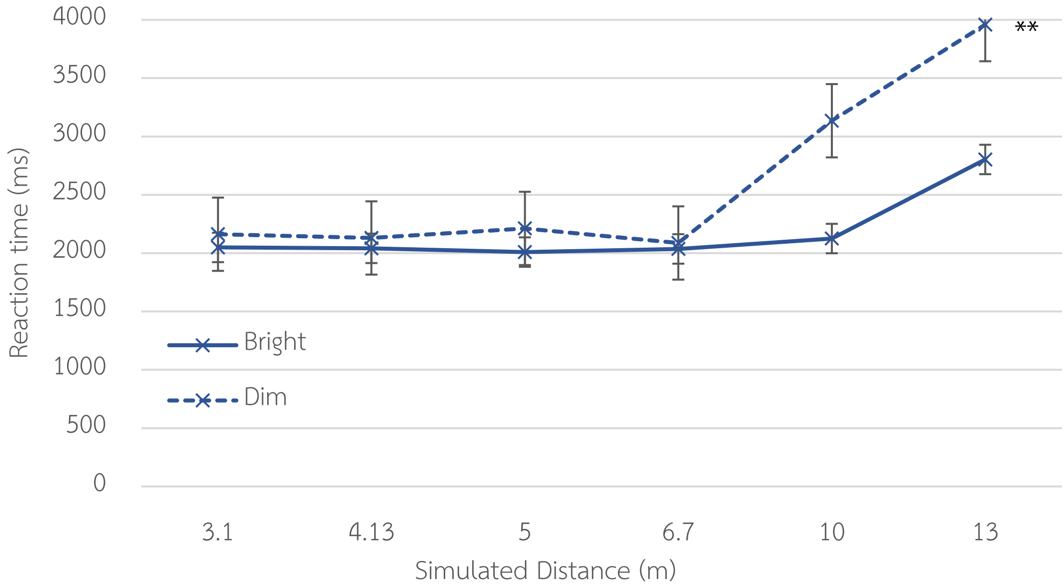

Figure 4-30 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for octagon shape/blue color

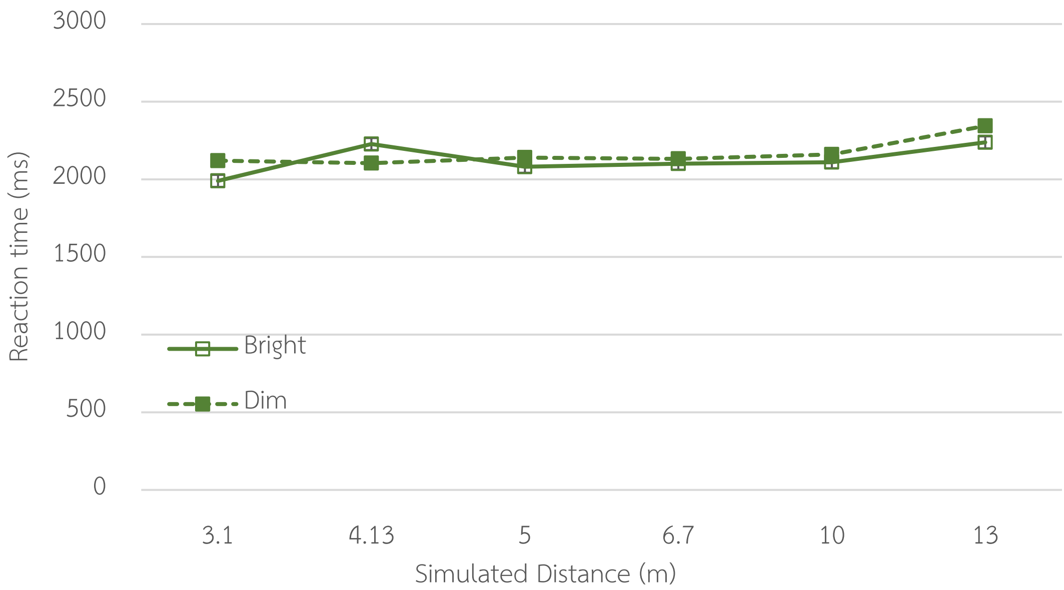

Figure 4-31 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for square shape/green color

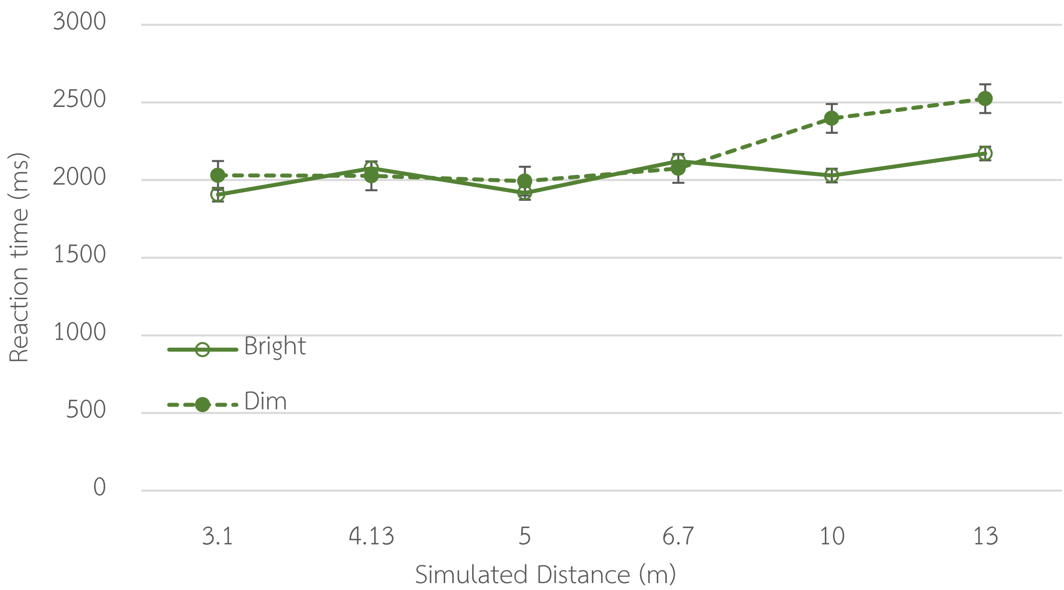

Figure 4-32 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for circle shape/green color

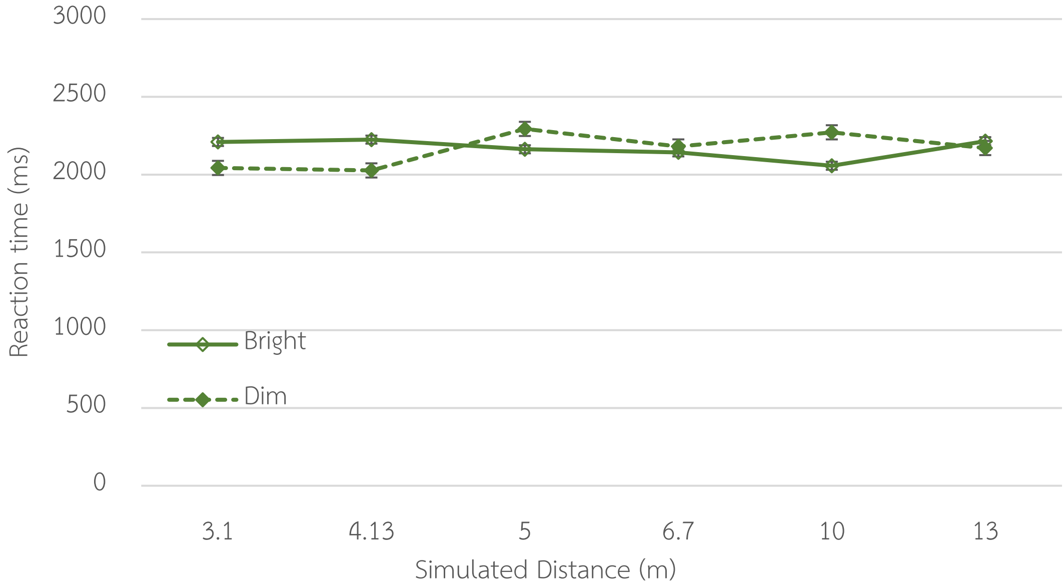

Figure 4-33 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for diamond shape/green color

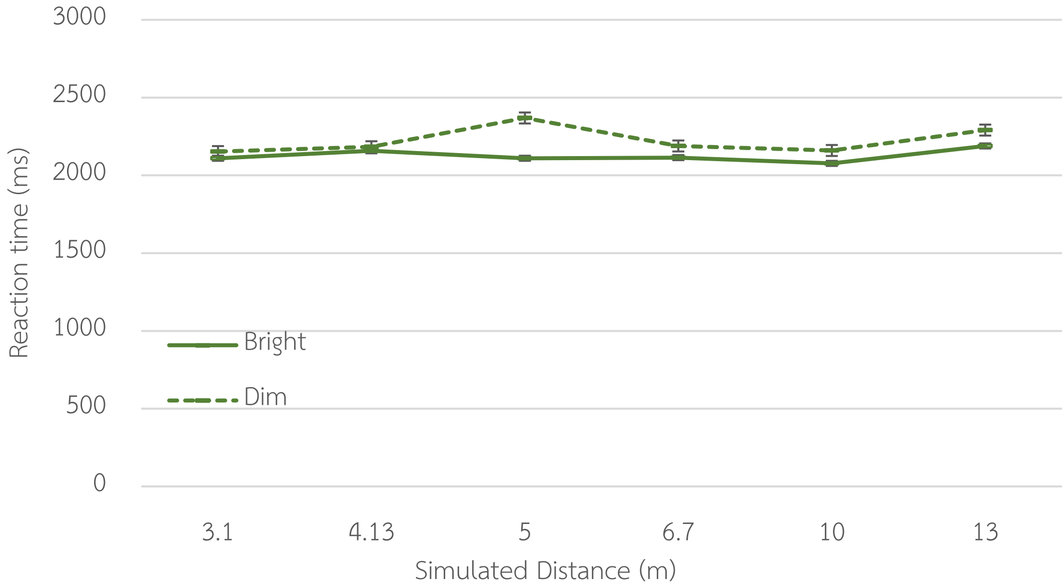

Figure 4-34 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for invert triangular shape/green color

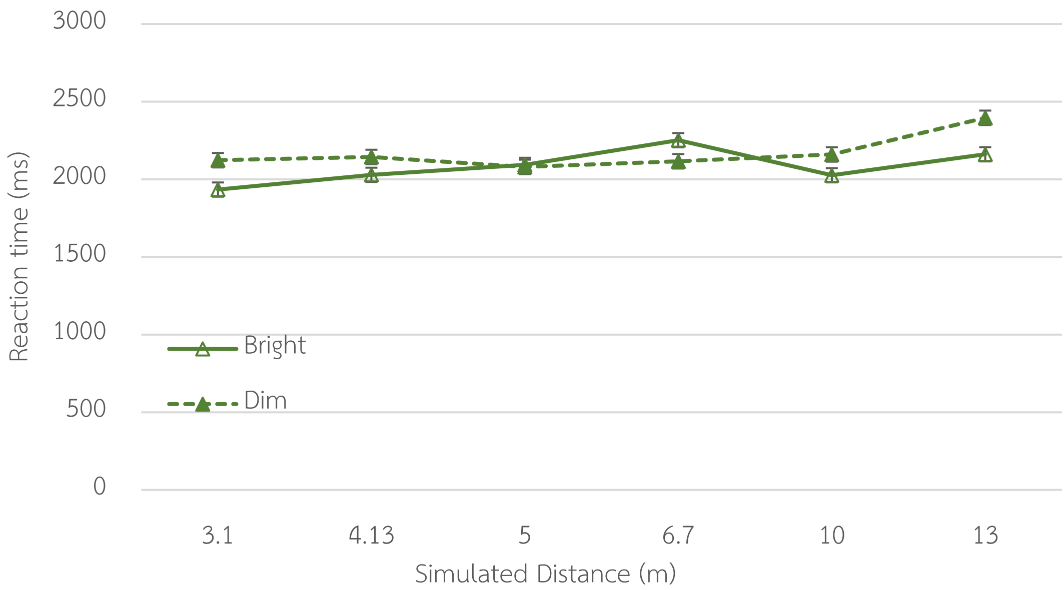

Figure 4-35 Reaction time under "Dim" and "Bright" conditions with simulated blurred vision for triangular shape/green color

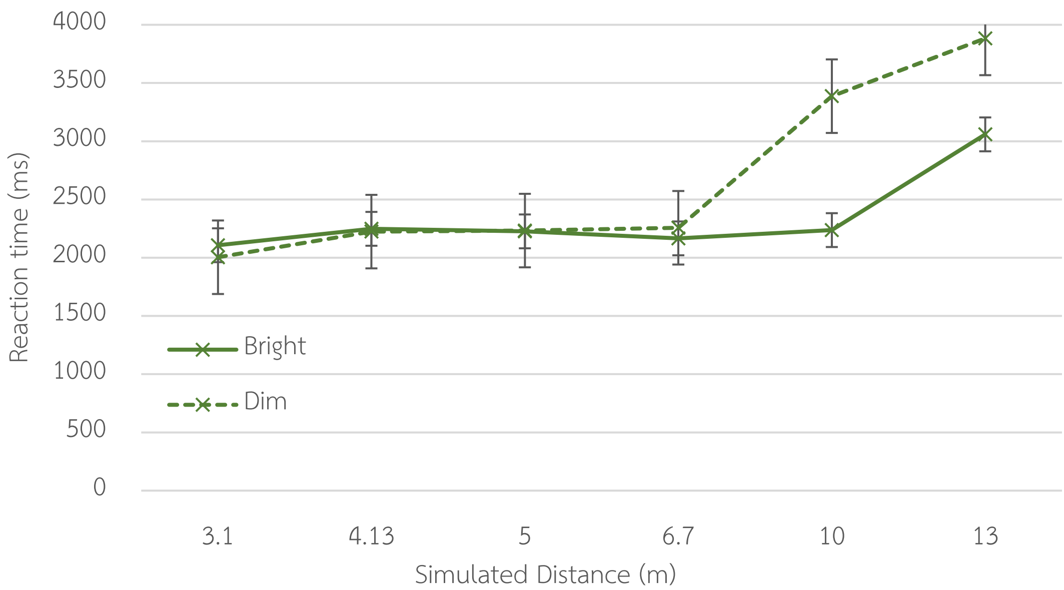

Figure 4-36 Reaction time under "Dim" and "Bright" conditions with simulated blurred vision for octagon shape/green color.

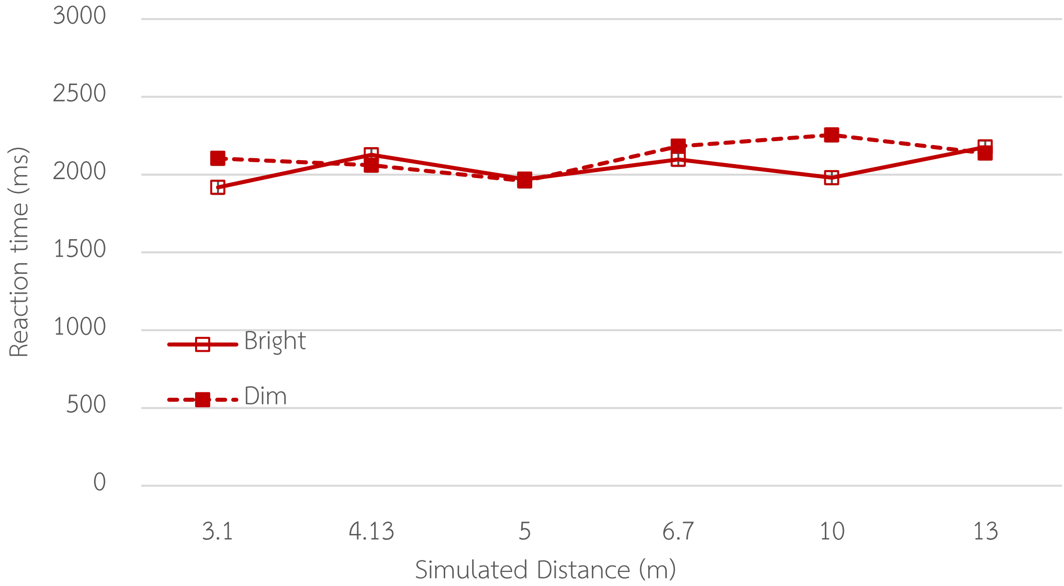

Figure 4-37 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for square shape/red color

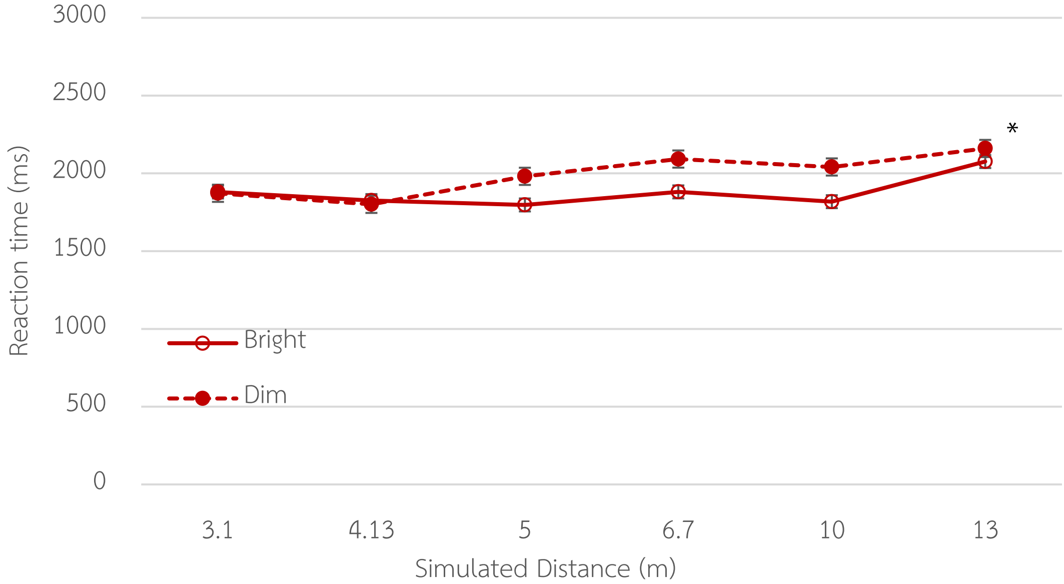

Figure 4-38 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for circle shape/red color.

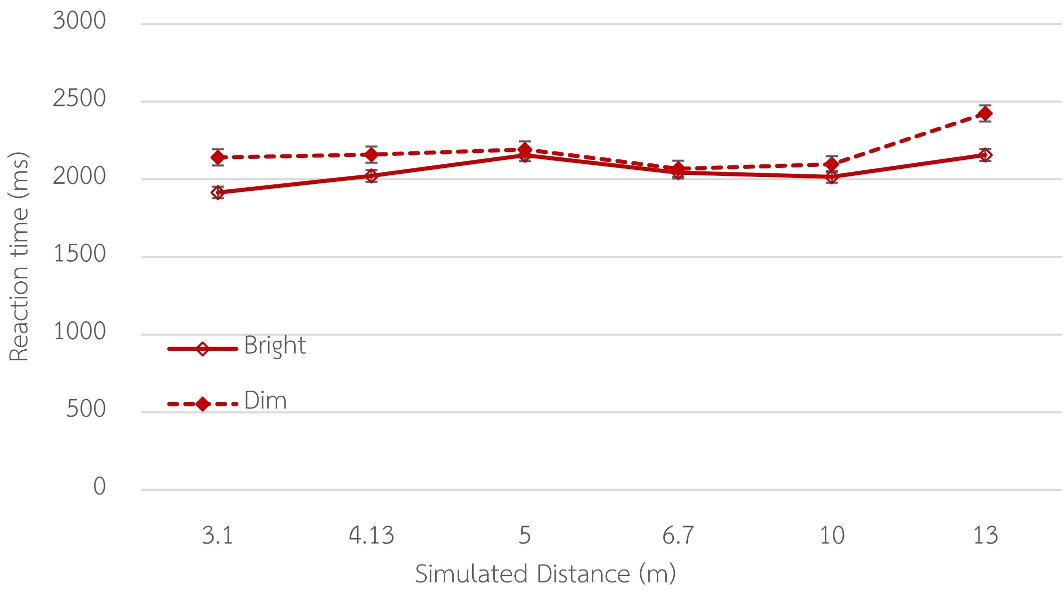

Figure 4-39 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for diamond shape/ red color.

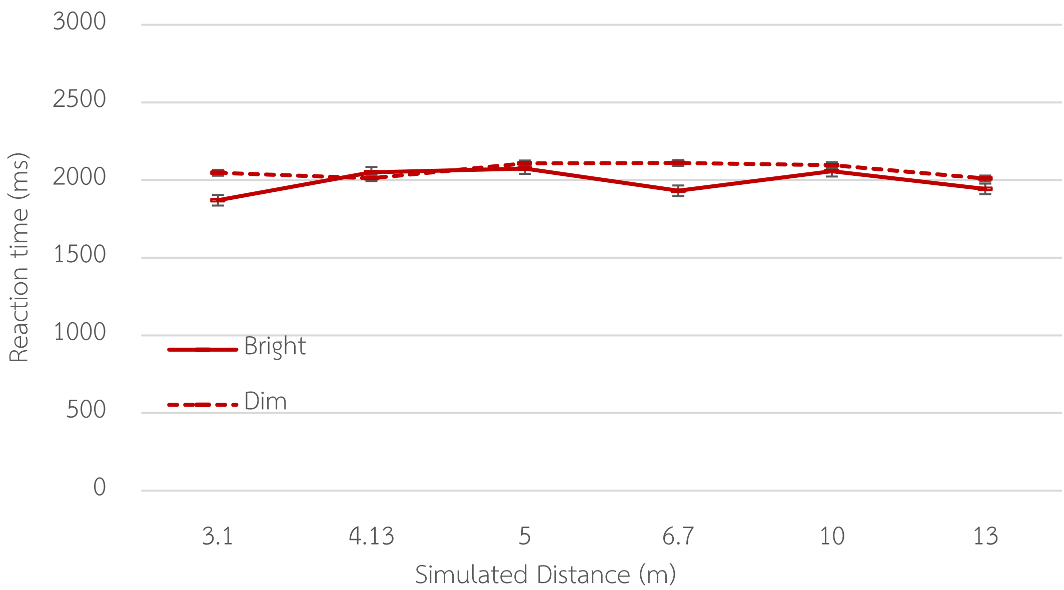

Figure 4-40 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for invert triangular shape/red color.

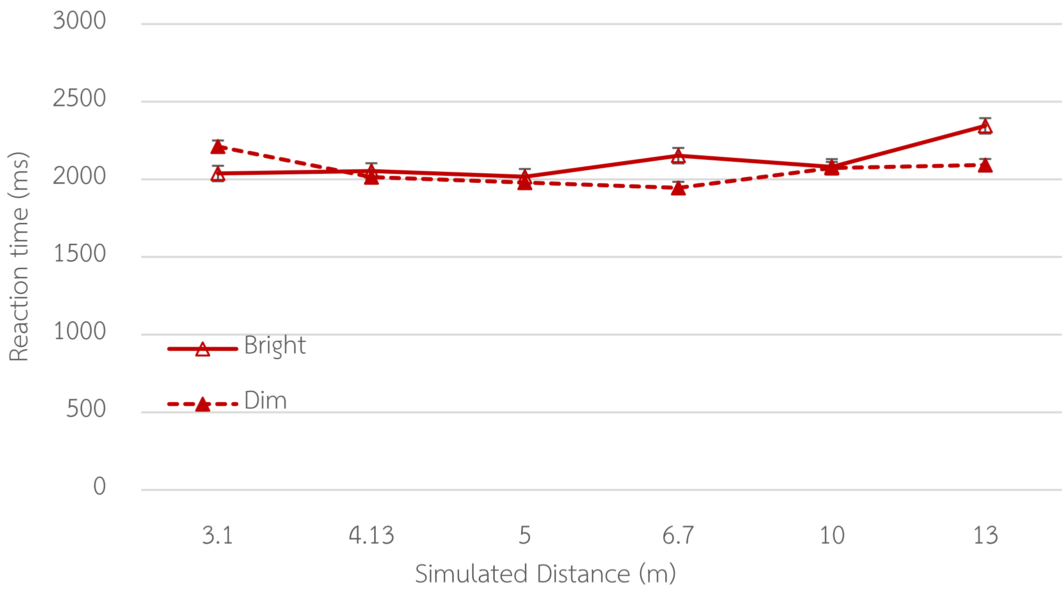

Figure 4-41 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for triangular shape/red color

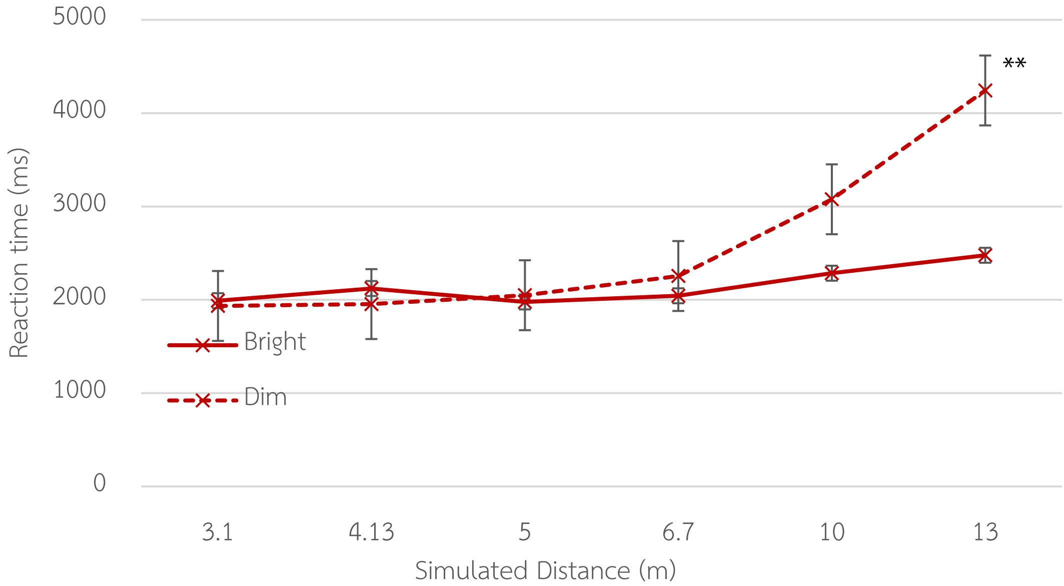

Figure 4-42 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for octagon shape/red color.

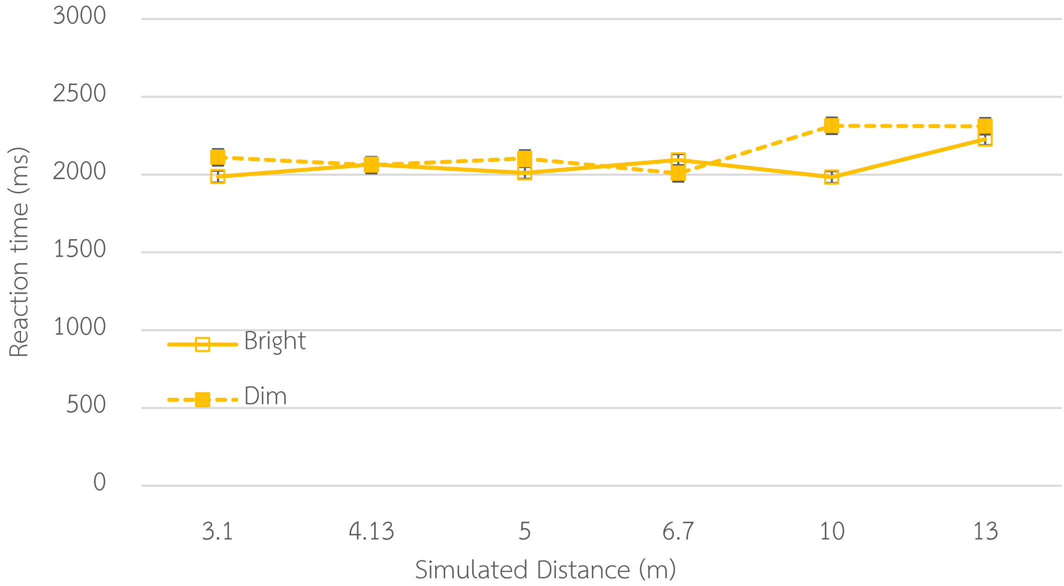

Figure 4-43 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for square shape/ yellow color.

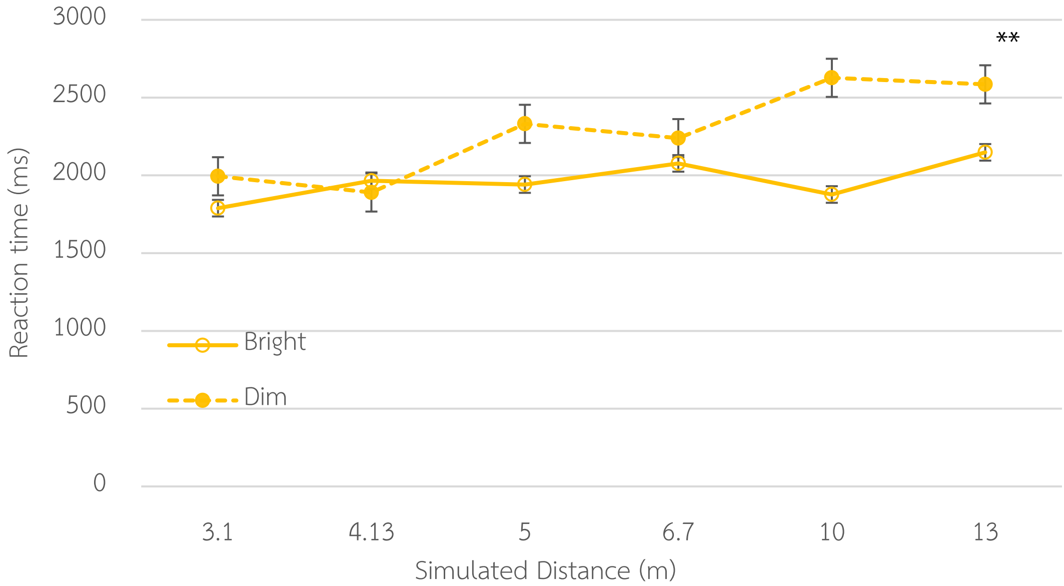

Figure 4-44 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for circle shape/yellow color.

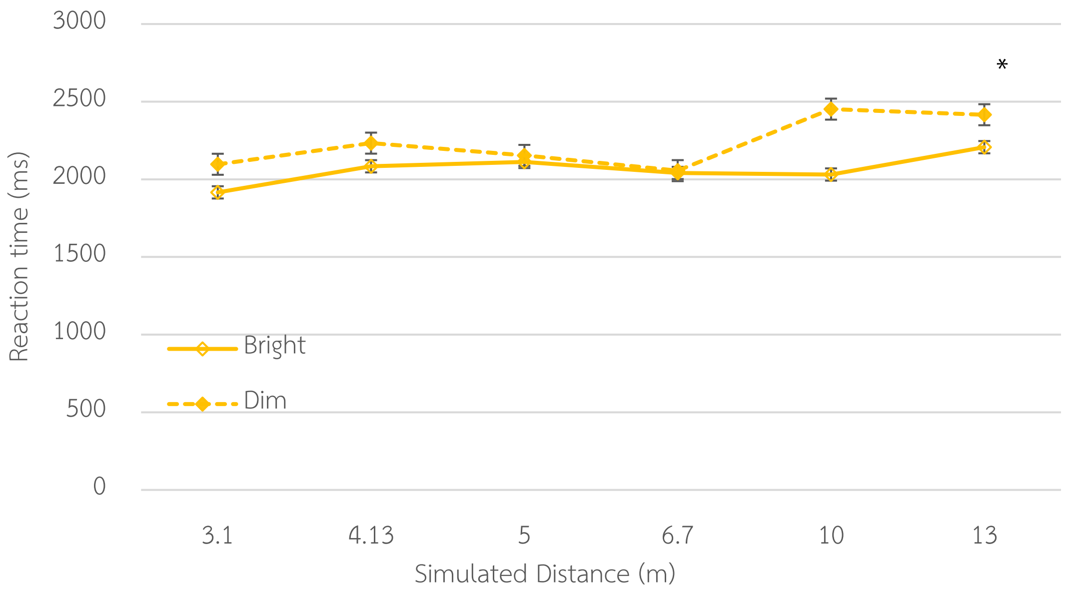

Figure 4-45 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for diamond shape/yellow color.

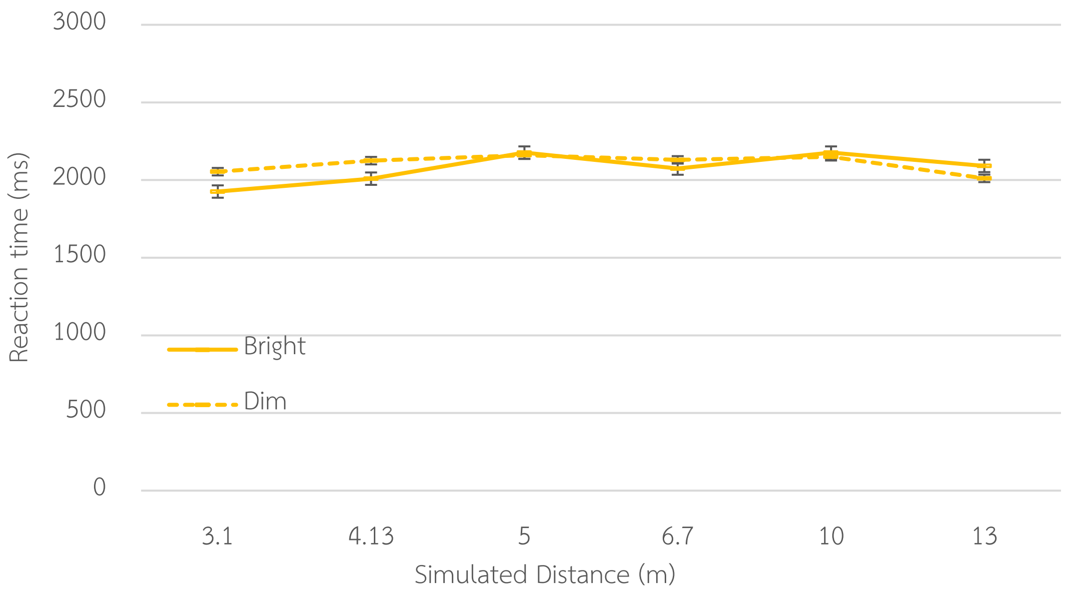

Figure 4-46 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for invert triangular shape/ yellow color.

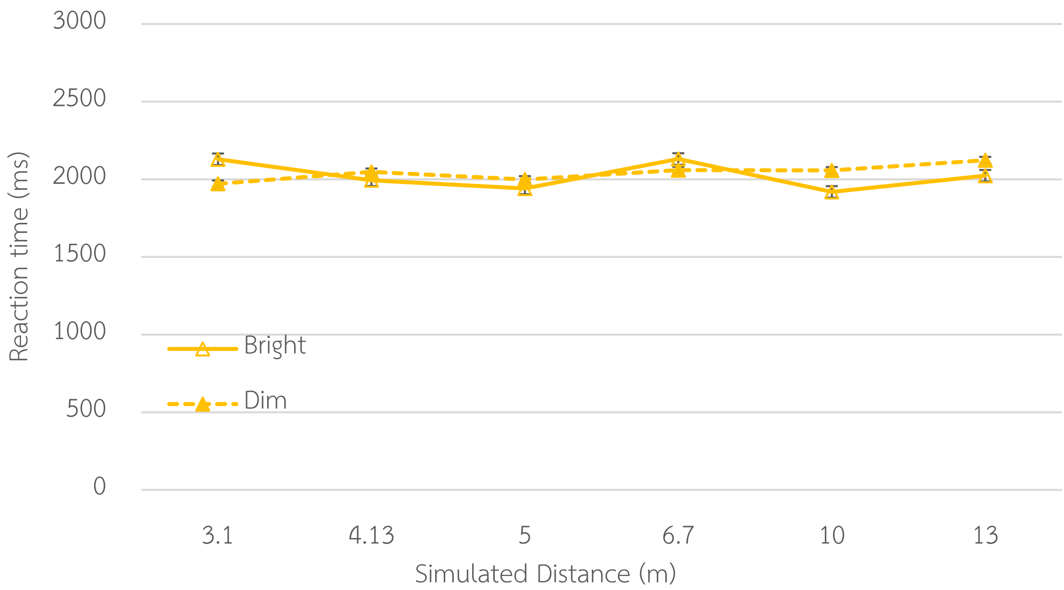

Figure 4-47 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for triangular shape/yellow color.

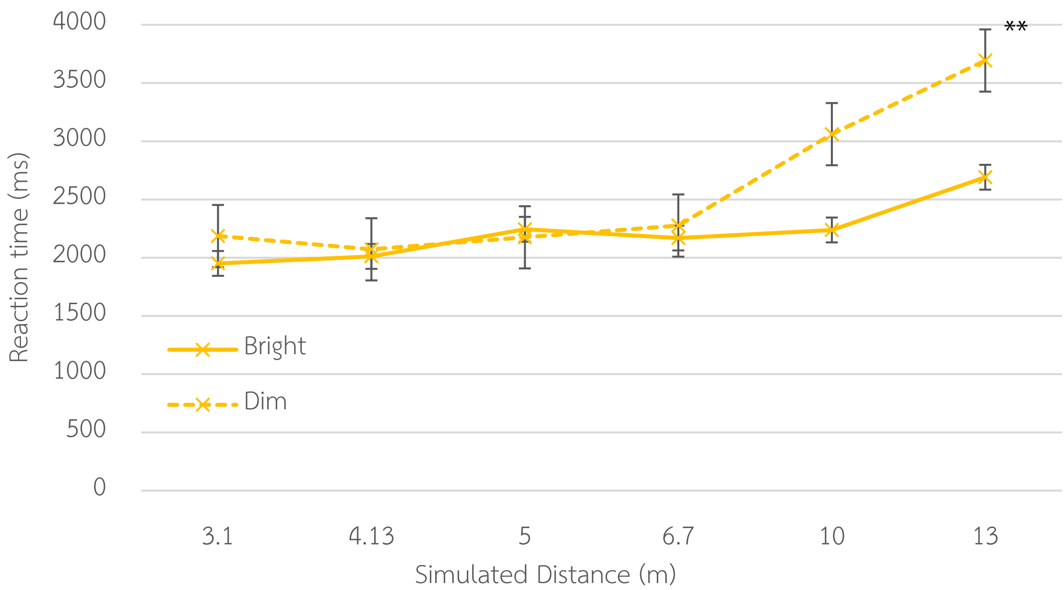

Figure 4-48 Reaction time under “Dim” and “Bright” conditions with simulated blurred vision for octagon shape/yellow color

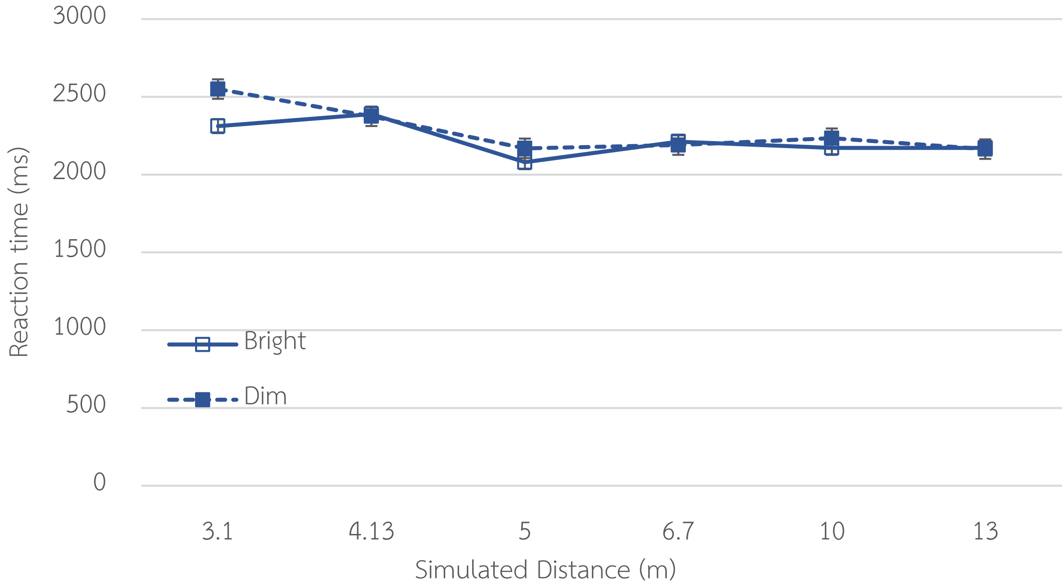

Figure 4-49 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for square shape/blue color

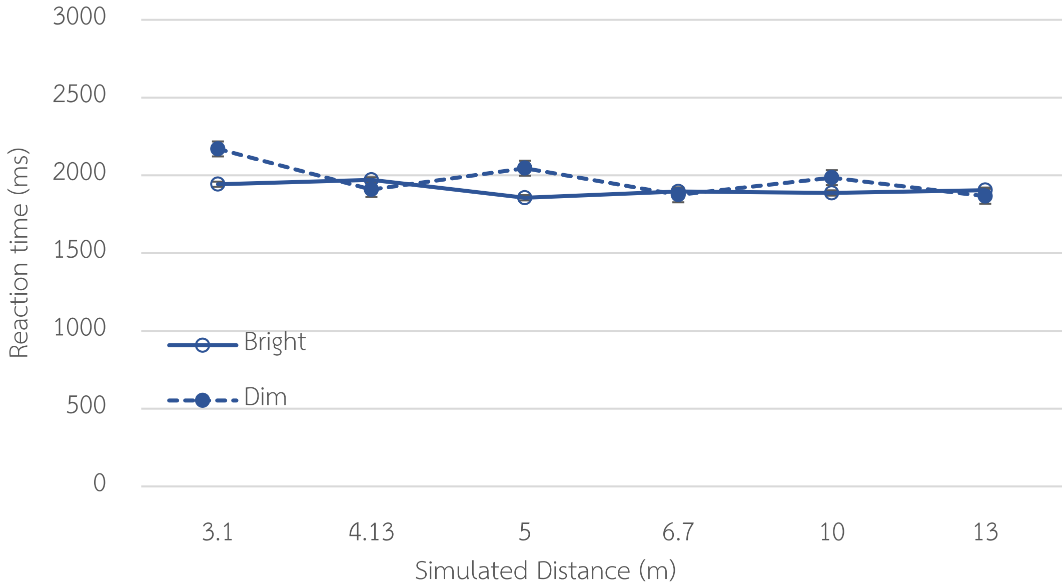

Figure 4-50 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for circle shape/blue color.

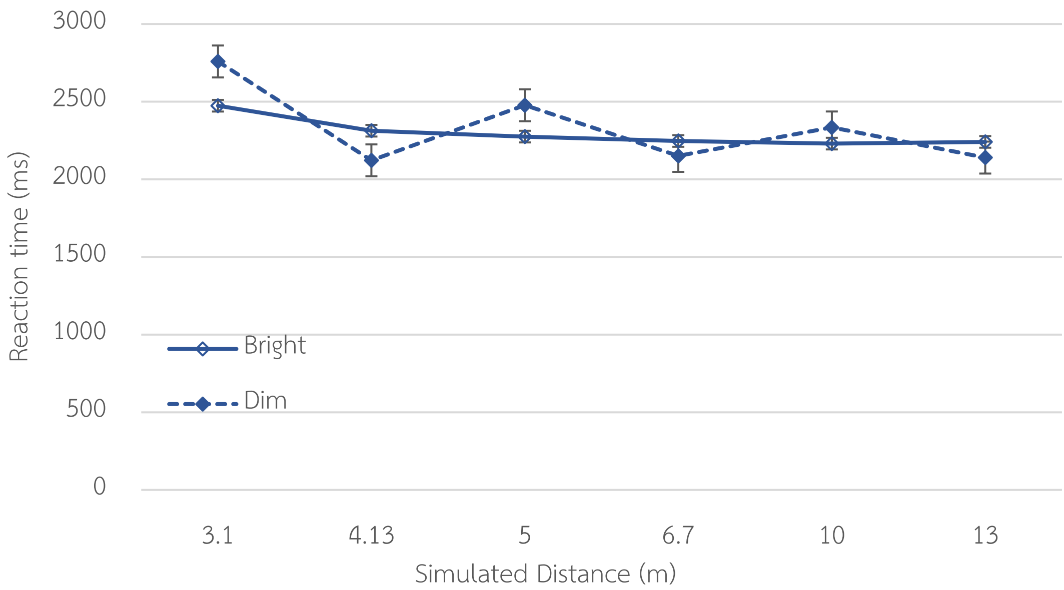

Figure 4-51 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for diamond shape/blue color

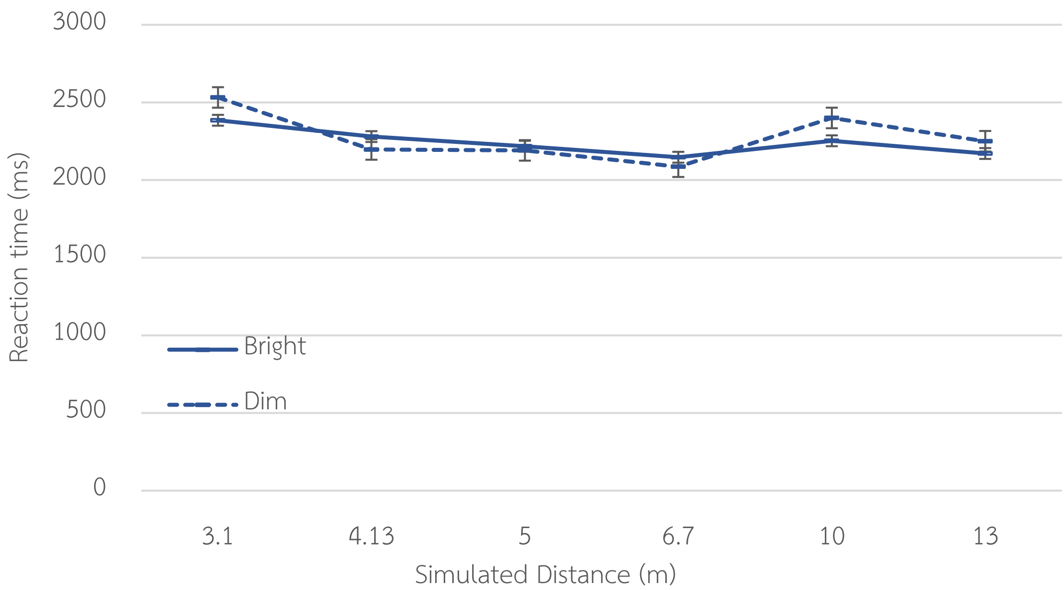

Figure 4-52 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for invert triangular shape/blue color.

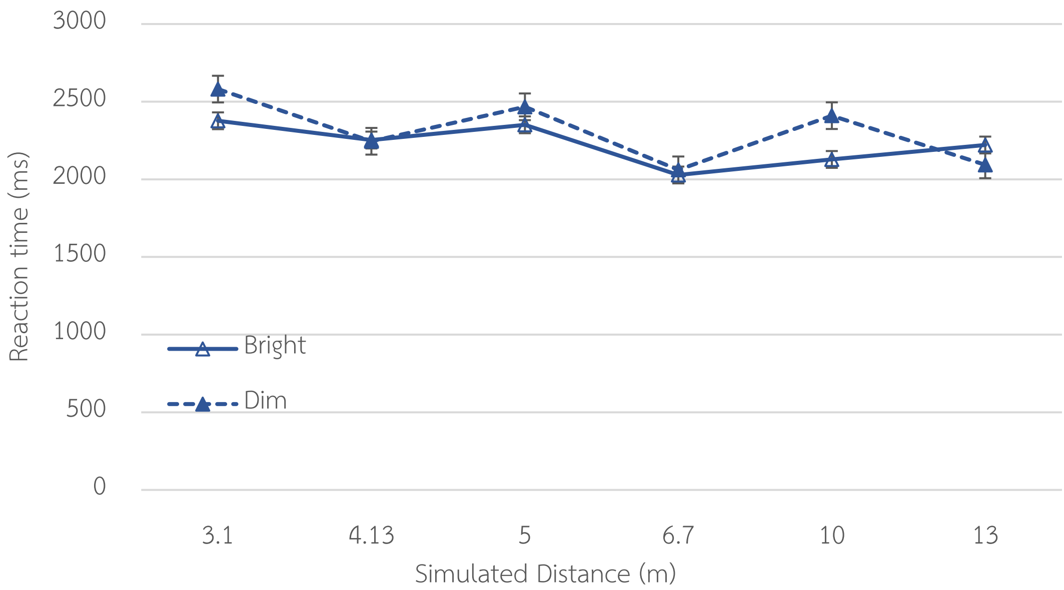

Figure 4-53 Reaction time under "Dim" and "Bright" conditions with simulated narrow vision for triangular shape/blue color.

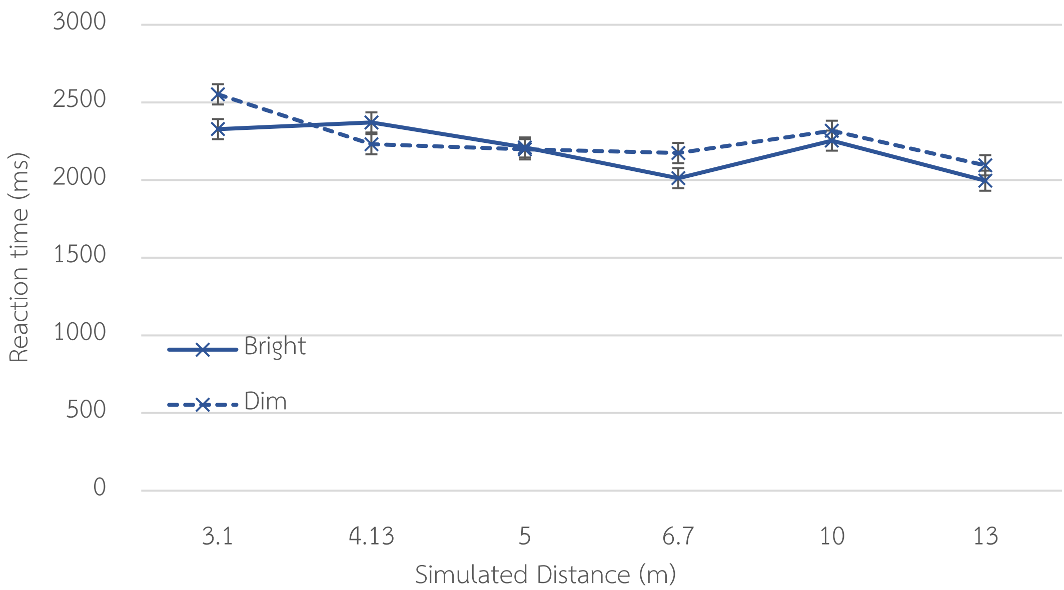

Figure 4-54 Reaction time under "Dim" and "Bright" conditions with simulated narrow vision for octagon shape/blue color.

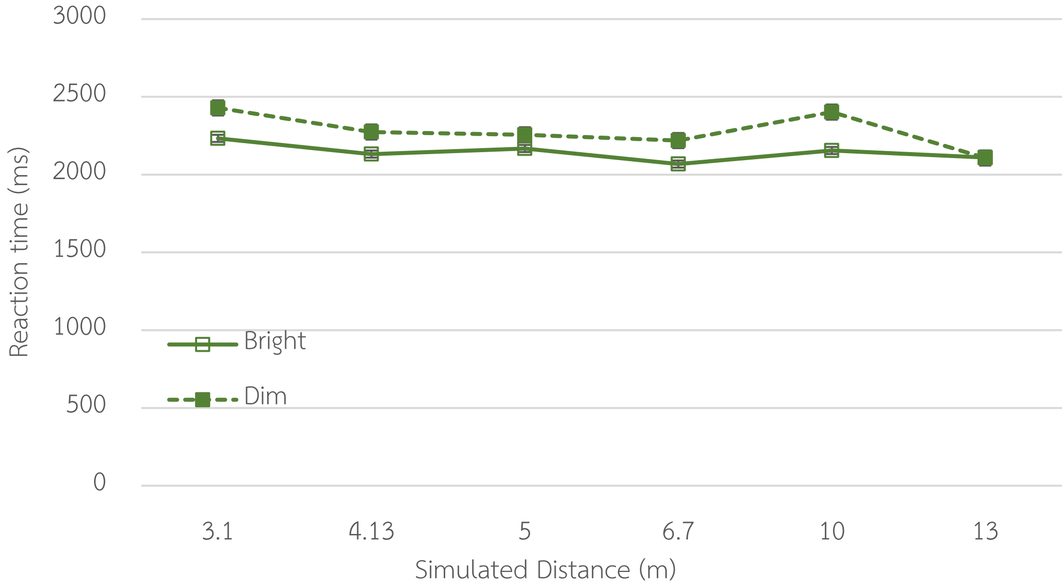

Figure 4-55 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for square shape/green color

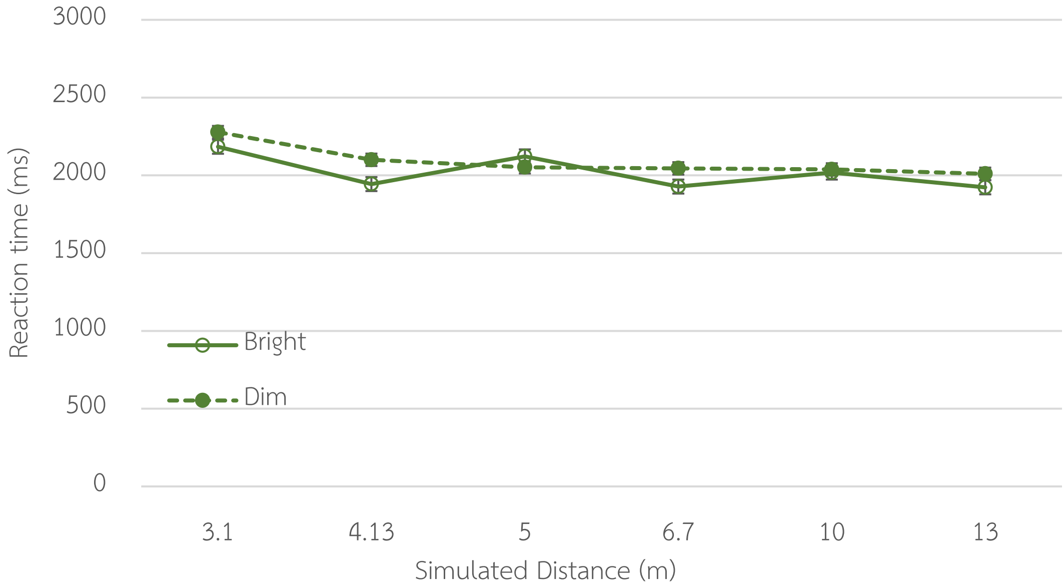

Figure 4-56 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for circle shape/green color

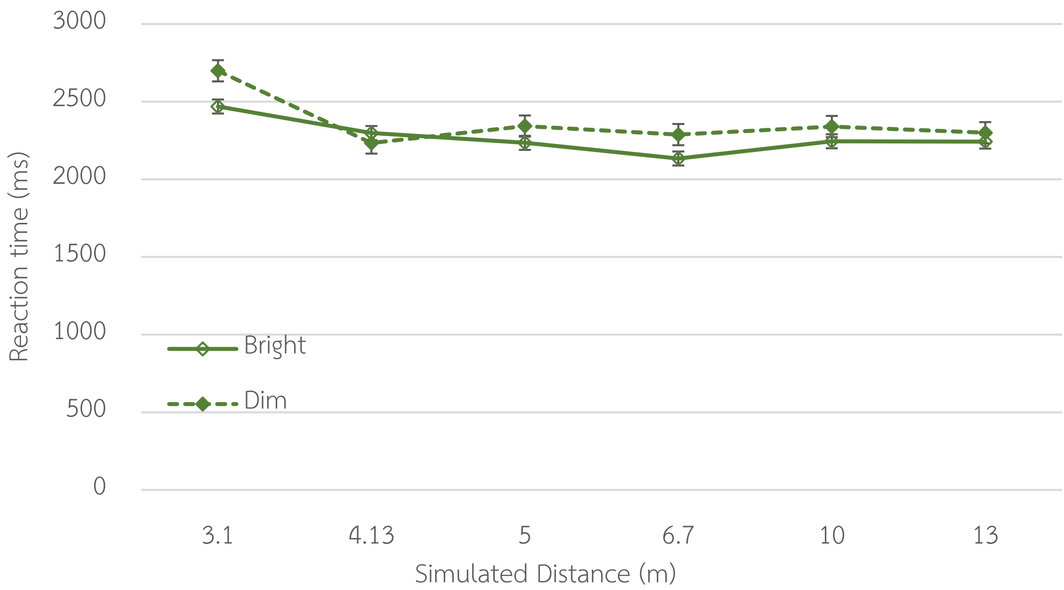

Figure 4-57 Reaction time under "Dim" and "Bright" conditions with simulated narrow vision for diamond shape/green color

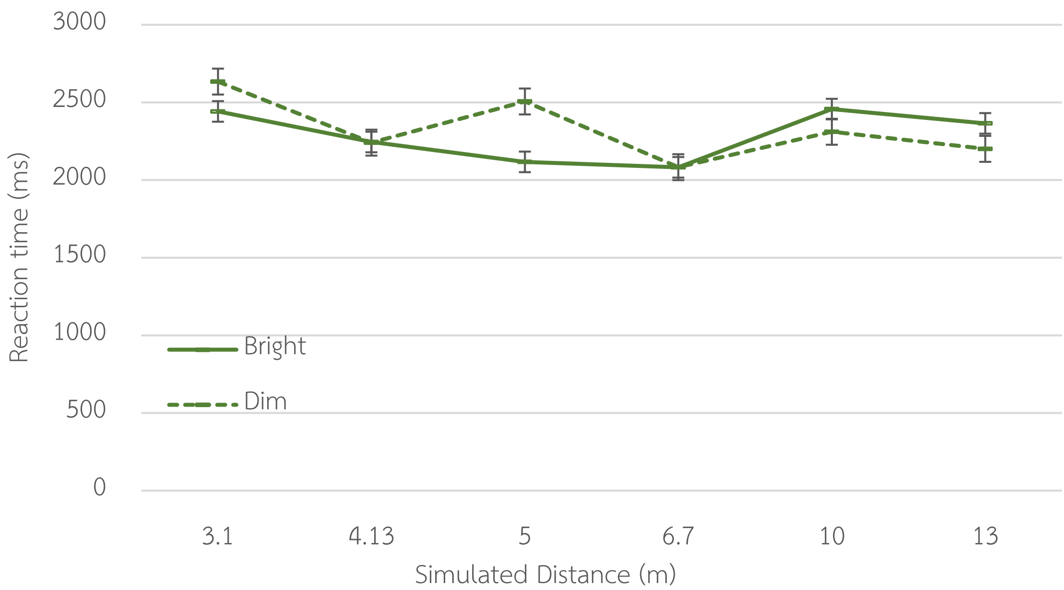

Figure 4-58 Reaction time under "Dim" and "Bright" conditions with simulated narrow vision for invert triangular shape/green color

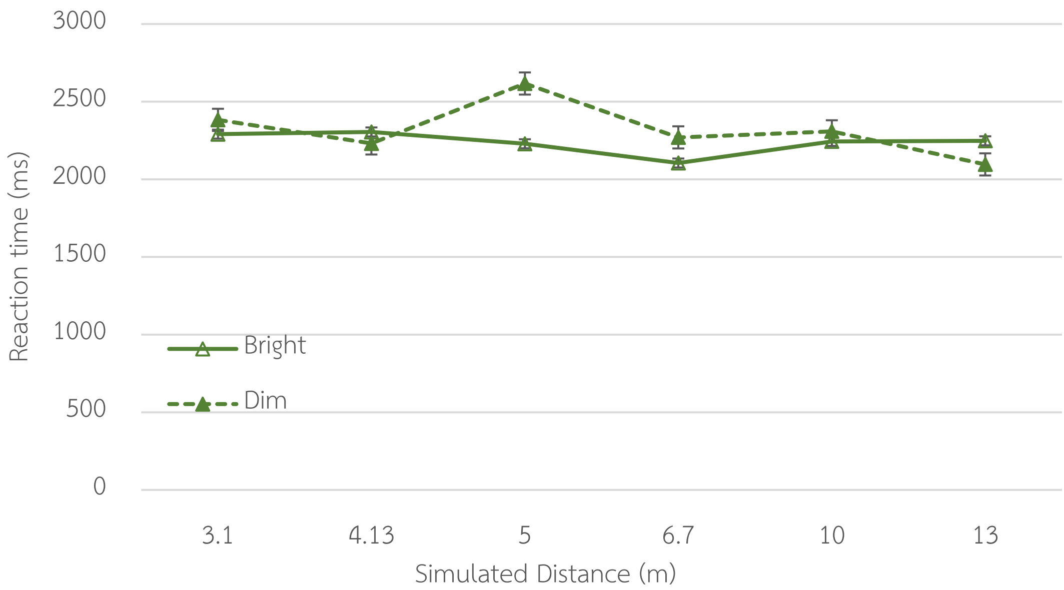

Figure 4-59 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for triangular shape/green color

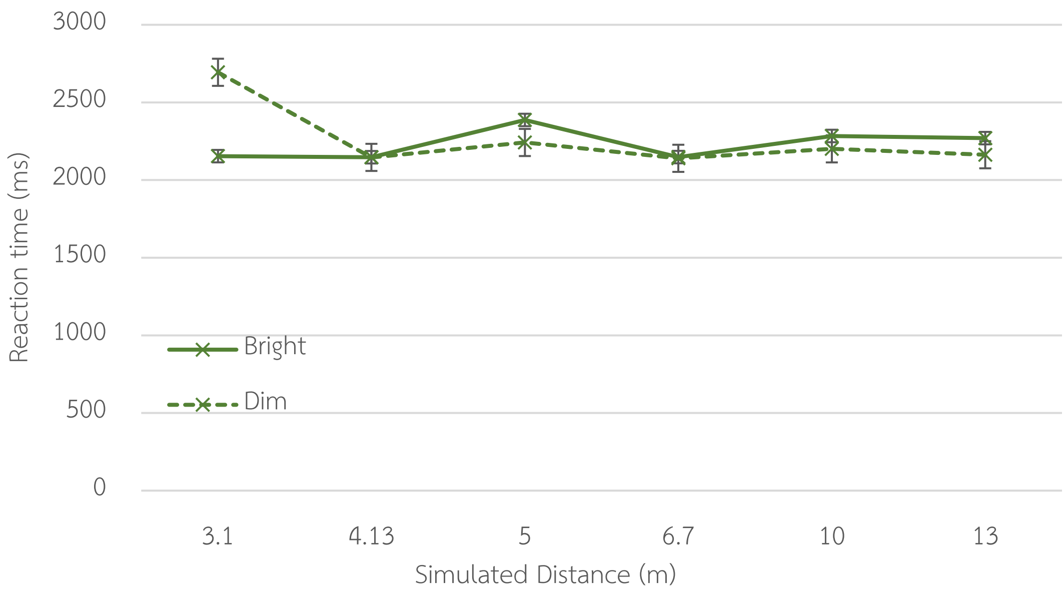

Figure 4-60 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for octagon shape/green color

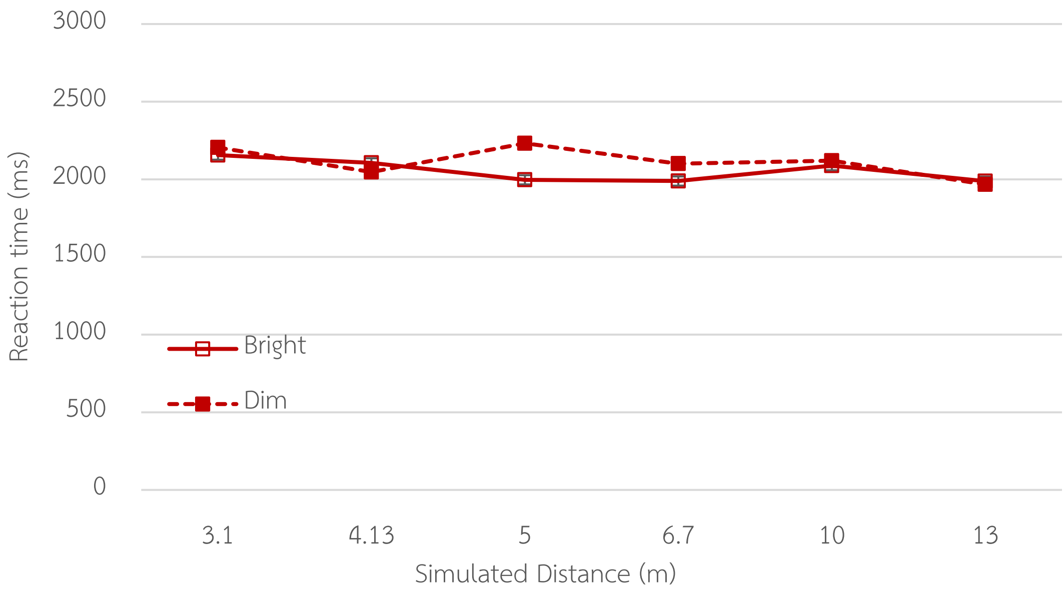

Figure 4-61 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for square shape/red color

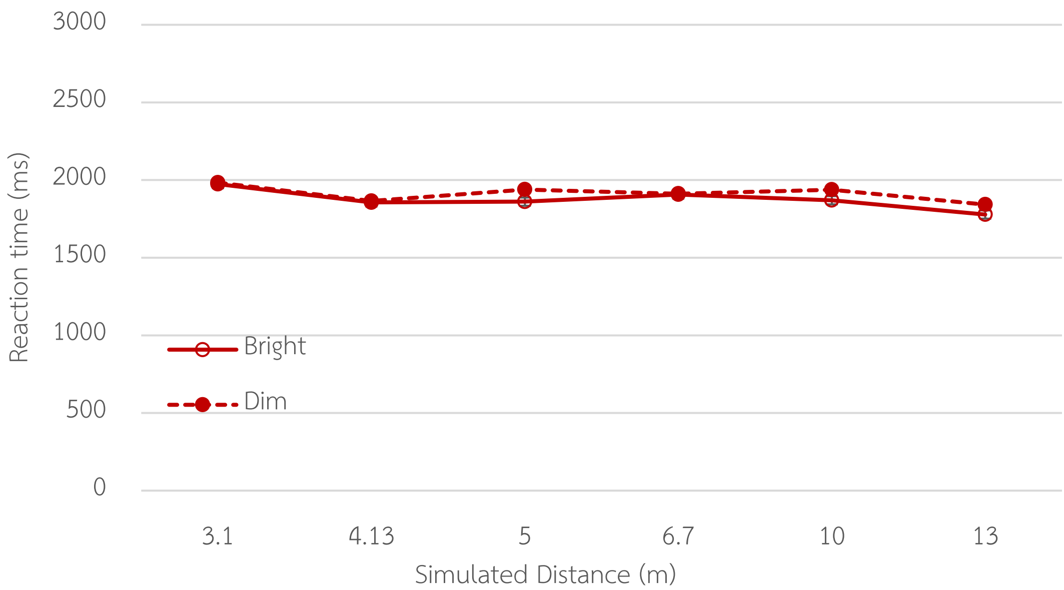

Figure 4-62 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for circle shape/red color

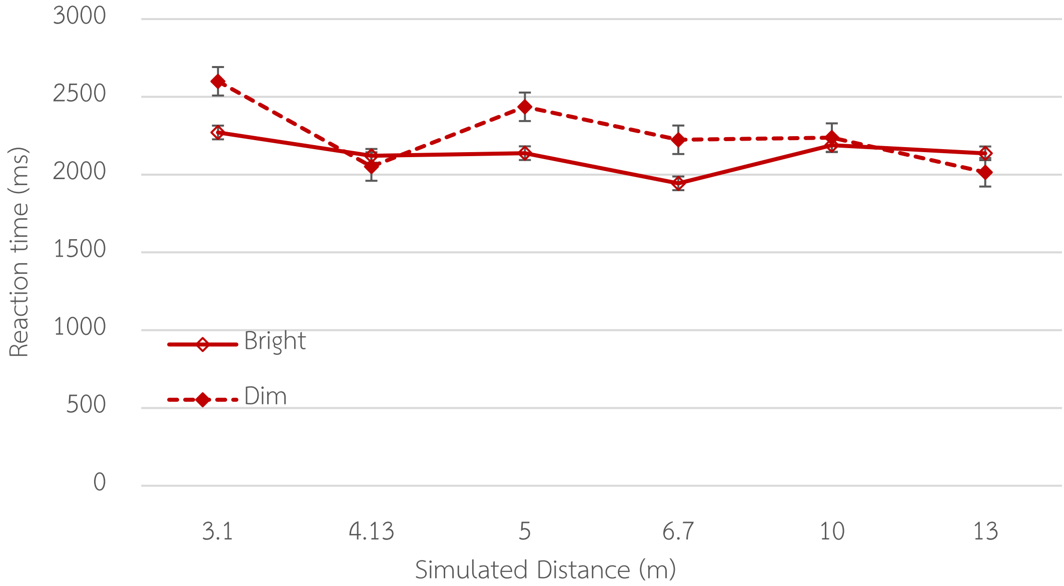

Figure 4-63 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for diamond shape/red color

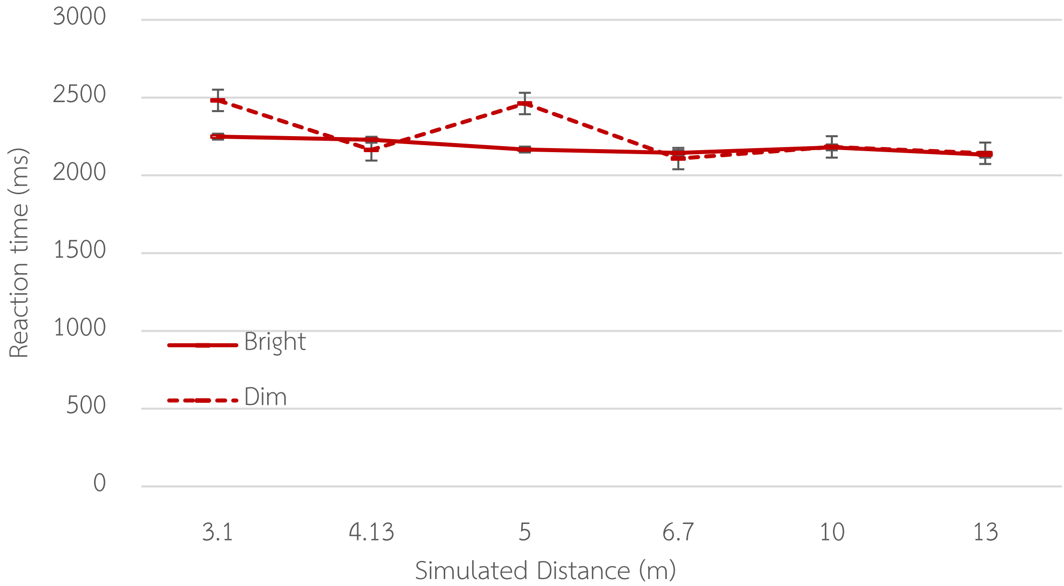

Figure 4-64 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for invert triangular shape/red color

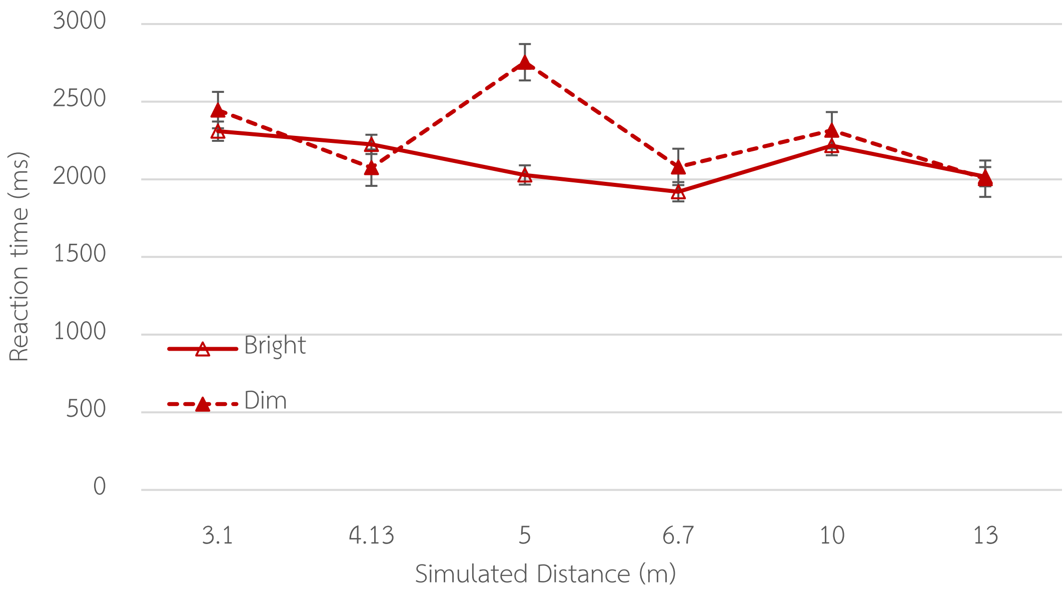

Figure 4-65 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for triangular shape/red color

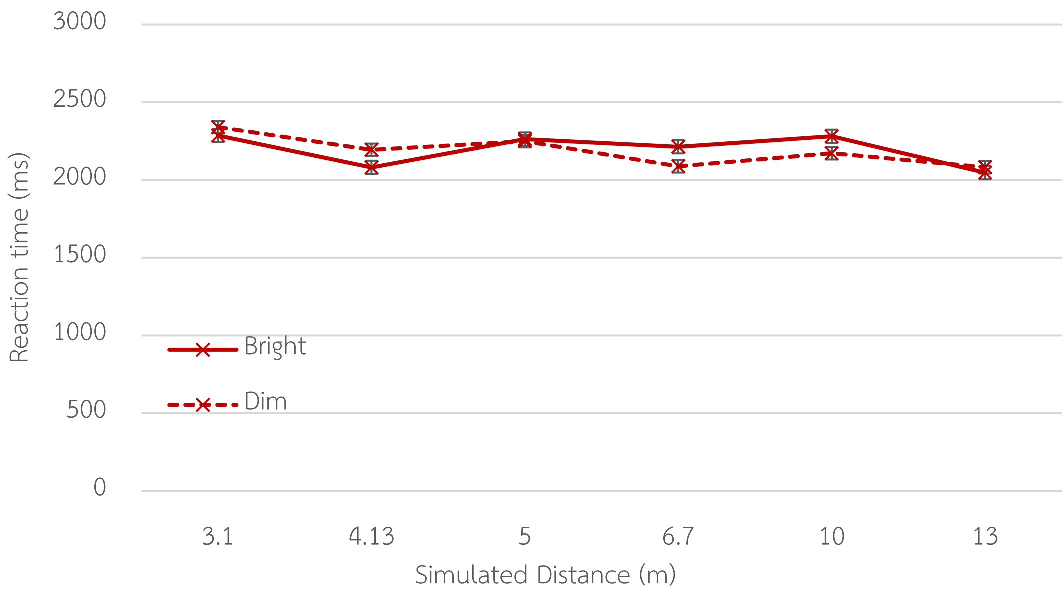

Figure 4-66 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for octagon shape/red color

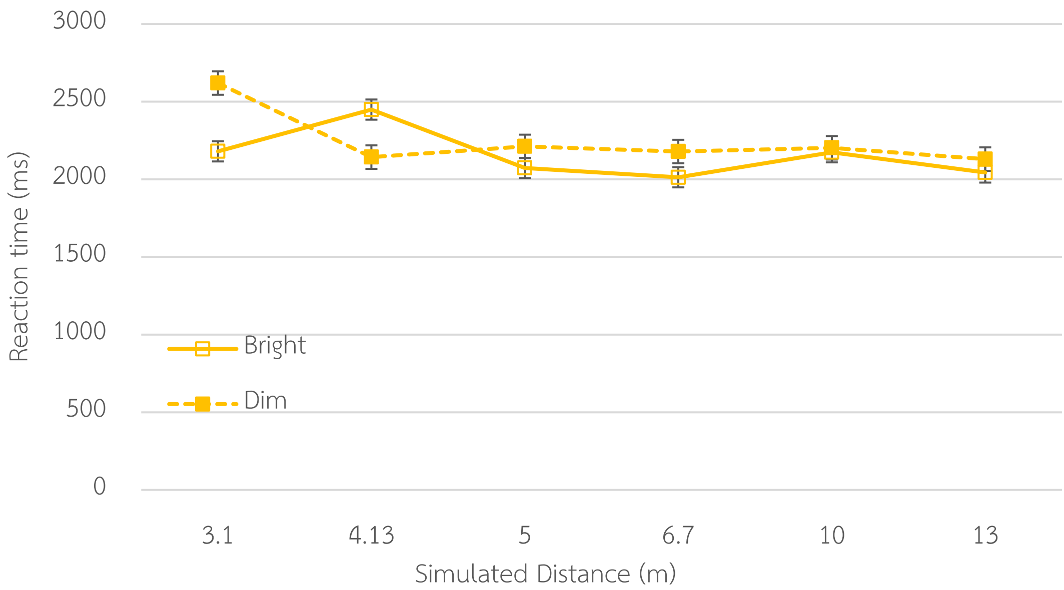

Figure 4-67 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for square shape/yellow color

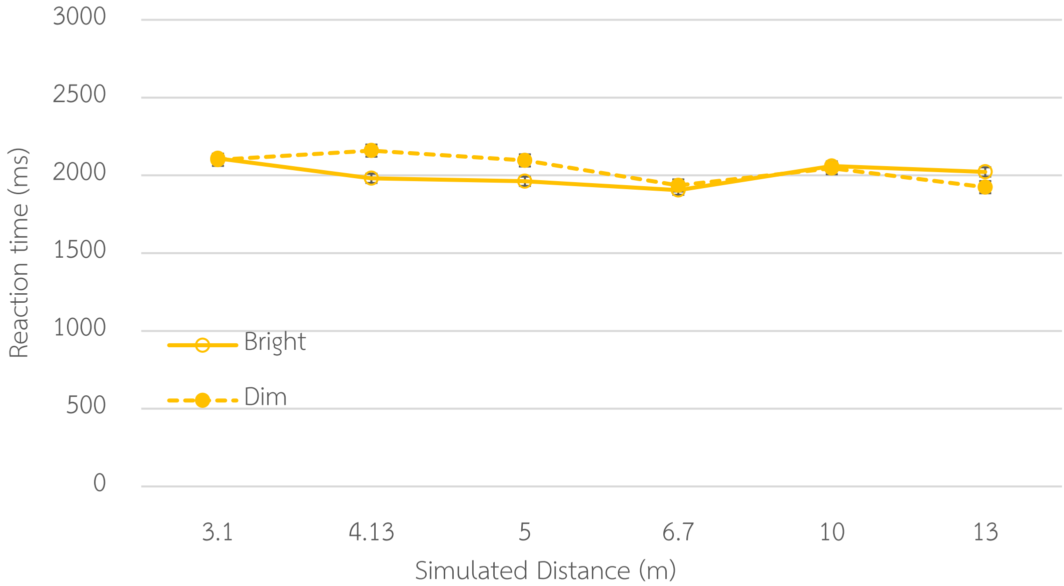

Figure 4-68 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for circle shape/ yellow color

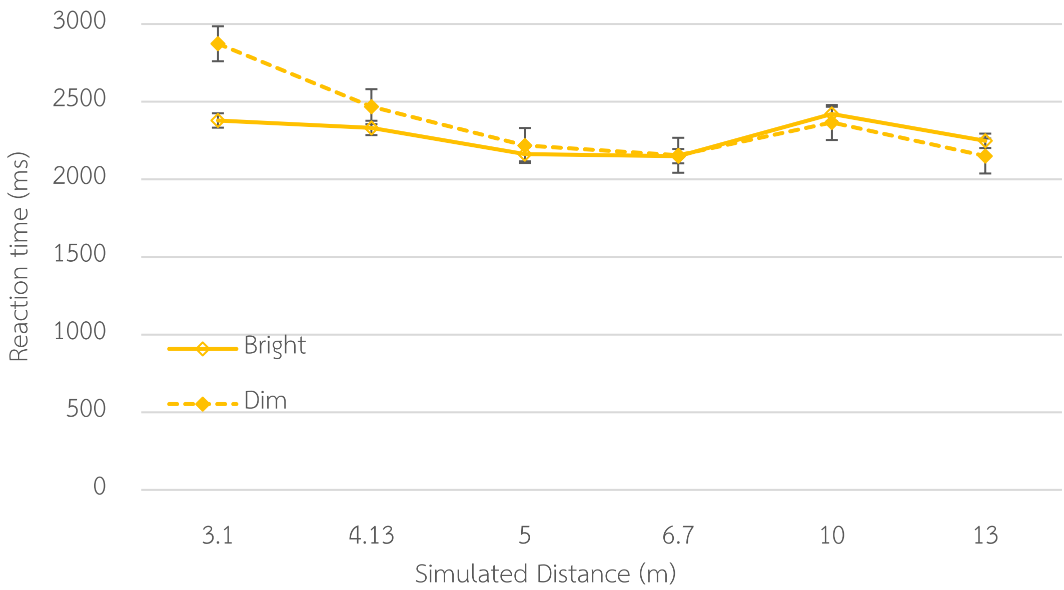

Figure 4-69 Reaction time under "Dim" and "Bright" conditions with simulated narrow vision for diamond shape/ yellow color

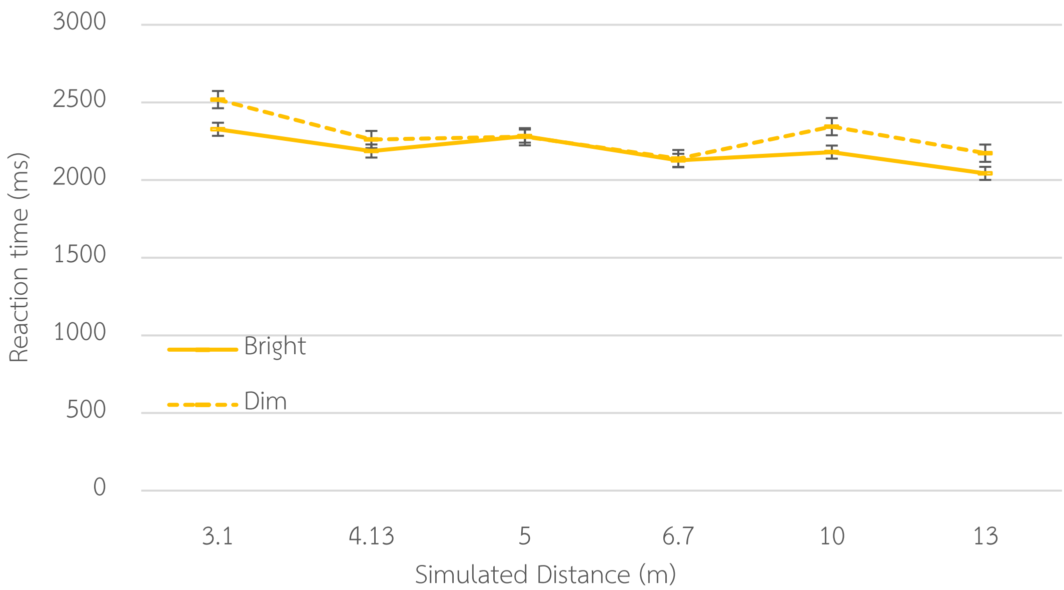

Figure 4-70 Reaction time under "Dim" and "Bright" conditions with simulated narrow vision for invert triangular shape/yellow color

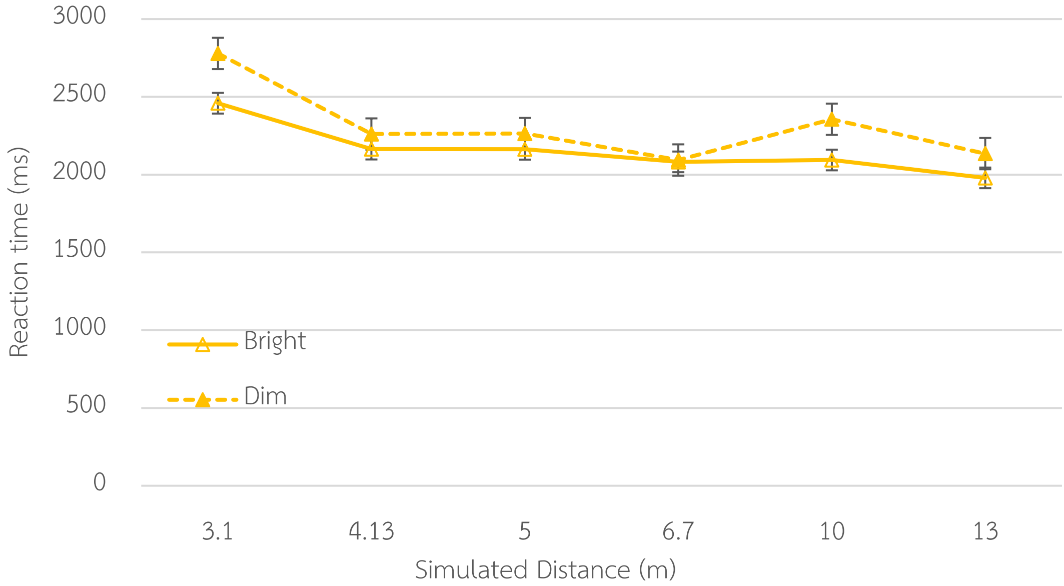

Figure 4-71 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for triangular shape/yellow color

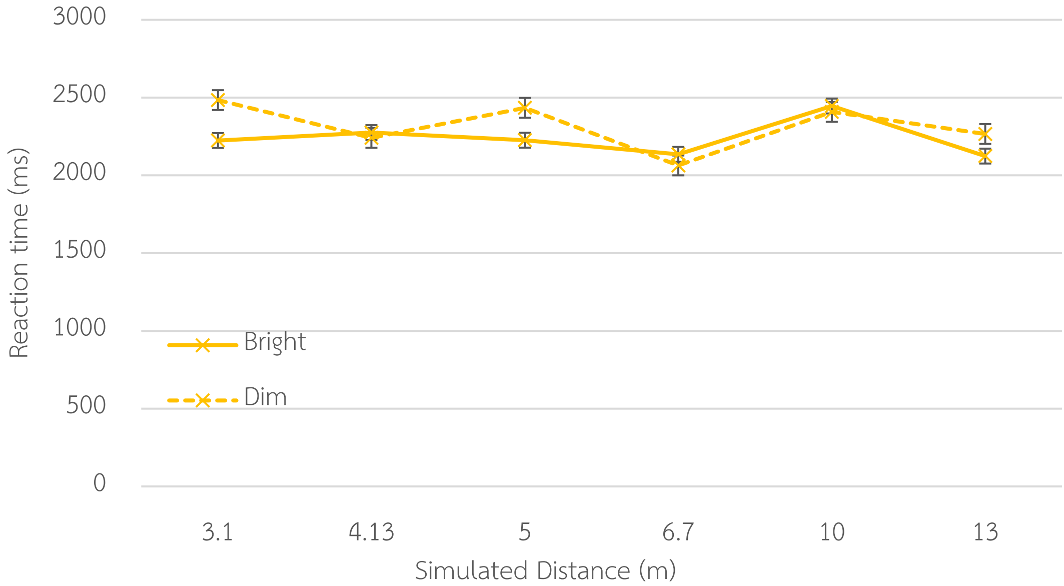

Figure 4-72 Reaction time under “Dim” and “Bright” conditions with simulated narrow vision for octagon shape/yellow color

4.2 Investigation of the effect of color portion of traffic signs on response time.

According to the results of 1st investigation, we selected 2 shapes for the next investigation; the triangle which was easily detected by blurred and occlusion vision, and the circle which gave the shortest reaction time for the narrow vison. In terms of color, there was smaller effect than the shapes, we, therefore, re-examined 4 colors as in the 1st investigation again but in the traffic sign pattern in Dim condition. We assume that if color affects the response time in Dim condition, it will affect in bright condition. To confirm the effect of color, color portion, shape, kinds of traffic and background, we examined with 864 stimuli. For total results, accuracy rate was 73.8%, 9,566 correct answer against 12,960 total observations. At first, accuracy rates are shown in Table A-5, A-6 and A-7, for blurred vision, occlusion vision, and narrow vision, respectively. For the blurred vision, 5 subjects answered correctly 2,590 times against 4,320 total observations, 59.95%, and for the occlusion vision, 5 subjects answered correctly 2,763 times against 4,320 total observations, 63.95%. Narrow vision, 5 subjects answered correctly 4,213 times against 4,320 total observations, 97.52%. Narrow vision showed higher accuracy rate than blurred vision and occlusion vision. Blurred vision and occlusion vision showed the better accuracy rate for closer simulated distance of 6.7 m (5.1 degrees visual angle) but narrow vision showed the same level of accuracy independent from distance in test (6.7 m to 26.6 m or 5.1 degrees to 1.3 degrees of visual angle), same as the 1st investigation. It is interesting to point out here that although the luminance contrast calculated from the maximum and minimum luminance measured through blurred and occlusion lenses of 4 colors of blurred vision is twice as much as of the occlusion vision, the occlusion vision (VA = 0.08) performs better than the blurred vision (VA = 0.06). We observed that the response time of the pictogram-based traffic sign during the experiment was longer as the observers showed hesitation before answering compared to the text-based traffic sign. We then examined the accuracy rate of these 2 types of traffic sign. The accuracy rate of pictogram traffic sign is lower than text traffic sign for blurred vision and occlusion vision for all 3 distances as shown in Figure 4-73. The longer the distance, the lower the accuracy rate is. This is not the case of narrow vision. Moreover, it was found that the accuracy rate for the circle shape is lower than triangular shape irrespective of other parameters in test at 2.6 degrees and 1.3 degrees of visual angle for blurred and occlusion visions as shown in Figure 4-74.

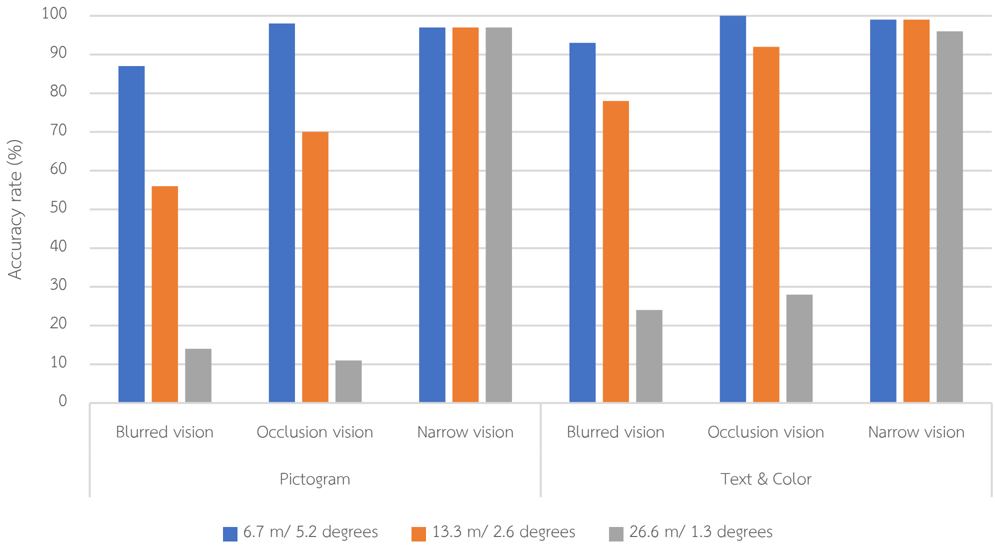

Figure 4-73 Accuracy rate of pictogram and text traffic signs.

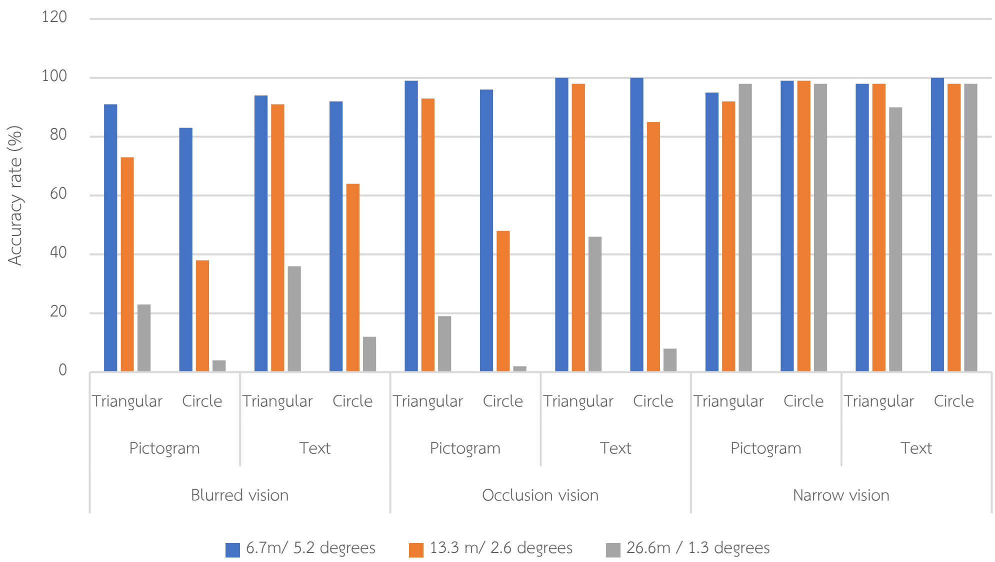

Figure 4-74 Accuracy rate of individual shape of traffic signs.

After confirming the accuracy rate for individual kinds of sign, 10,000 ms were added to individual reaction time data for each incorrect answer and analyzed which candidates design set is the best and if the reaction times are significantly different.

The accuracy rate percentage for all conditions are shown in Tables A-5, A-6 and A-7 for blurred, occlusion and narrow visions. After considering the accuracy of the answer, corrected answering times are shown in Tables A-8, A-9, and A-10, individually for simulated blurred vision, occlusion vision, and narrow vision respectively. For blurred vision and occlusion vision, the size of the sample to the eyes gets smaller, corrected answering time gets longer. It means the distance between person wearing simulated blurred vision glasses or occlusion vision glasses and traffic sign gets farther, recognizing the traffic sign gets more difficult. On the other hand, for narrow vision same as the 1st investigation, the size of the sample to the eyes does not greatly affect the answering time.

The full results of 2-way ANOVA applied to the corrected answering time data are shown in Tables A-11, A-12, and A-13, individually for simulated blurred vision, occlusion vision, and narrow vision. Tables 4-6, 4-7, and 4-8 show only the main parameters and parameter affecting the response time significantly for simulated blurred, occlusion and narrow visions respectively.

Table 4-6 Results of 2-way ANOVA of corrected answering time on simulated blurred vision.

Parameters	F value	P (>F)
Color	0.883	0.4489
Shape	209.046	<2.000E-16***
Color Portion (Negative/ Positive)	3.217	0.0402*
Type of traffic sign	23.698	<2.000E-16***
Background	24.958	1.69E-11***

Signif. Codes: 0.001< "***", 0.01< "**", 0.05< "*"

Note: The interaction between parameters did not show the significant difference on the reaction time. The full results of 2-way ANOVA are shown in the Appendix.

For blurred vision there are significant differences among corrected answering time resulted from shape, color portion (negative/ positive), and type of traffic sign, and background. Though background is a changeable factor, actual background including many trees provides the shortest corrected answering time. We found that the background with trees shows the lowest response time for the simulated blurred and occlusion vision (p<.001) and for the simulated narrow vision (p<.01). For shape, triangular showed shorter answering time than circle, same as the 1st investigation. For kind of sign, the signs that have only characters and color, such as "STOP" and "SOS" showed shorter answering time than other 4 signs that have more complicated pictogram design, such as "Pedestrians and bicycle only", "School zone", "Under construction", and "Caution for slip". This factor affected strongly in occlusion vision and we will discuss in detail later. For color portion, there is significant difference; negative presentation gives shorter response time.

Table 4-7 Results of 2-way ANOVA of corrected answering time on simulated occlusion vision.

Parameters	F Value	P (>F)
Type of traffic sign	23.552	<2.000E-16***
Background	18.691	8.32E-9***
Color	6.723	0.00016***
Shape	184.38	<2.000E-16***
Color Portion (Negative/ Positive)	1.479	0.22791
Type of traffic sign * Shape	3.053	0.00556**
Background * Shape	4.191	0.0152*
Color * Color Portion (Negative/ Positive)	7.784	3.52E-5***

Signif. Codes: 0.001< "***", 0.01< "**", 0.05< "*"

Note: The full results of 2-way ANOVA are shown in the Appendix.

Table 4-8 Results of 2-way ANOVA of corrected answering time on simulated Narrow vision.

Parameters	F Value	P (>F)
Type of traffic Sign	10.706	1.99E-13***
Background	7.2	0.000756***
Color	2.856	0.035773*
Shape	1.73	0.188505
Color Portion (Negative/ Positive)	0.192	0.825016
Type of traffic Sign * Color	4.997	2.22E-10***
Color * Shape	8.016	2.52E-5***
Shape * Color Portion (Negative/ Positive)	16.29	5.54E-5***
Type of traffic sign * Background * Color	2.731	1.24E-6***
Type of traffic sign * Background * Shape	3.484	0.000139***
Type of traffic sign * Color * Shape	3.053	6.12E-5***
Type of traffic sign * Color * Color Portion (Negative/ Positive)	4.055	2.1E-7***
Type of traffic sign * Background * Color * Color Portion (Negative/ Positive)	3.867	7.61E-12***
Type of traffic sign * Background * Shape * Color Portion (Negative/ Positive)	2.81	0.001789**
Type of traffic sign * Color * Shape * Color Portion (Negative/ Positive)	4.366	3.32E-8***
Type of traffic sign * Background * Color * Shape * Color Portion (Negative/ Positive)	2.823	4.99E-7***

Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”

Note: The full results of 2-way ANOVA are shown in the Appendix.

For occlusion vision there are significant differences among corrected answering time resulted from shape, color, color portion, type of traffic sign, and background. For shape, triangular showed shorter answering time than circle, same as the 1st investigation. For type of traffic sign, the signs that have only characters and color, such as "STOP" and "SOS" showed shorter answering time than other 4 signs that have more complicated pictogram design, such as "Pedestrians and bicycle only", "School zone", "Under construction", and "Caution for slip" as shown in Figure 4-75. In our study, the pictogram signs or symbol-based traffic signs gave lower accuracy response and longer response time to recognize compare to the text-based traffic signs. The results is contrary to the previous research (Dewar & Ells, 1974; Kline, Ghali, Kline, & Brown, 1990). However, latest study showed similar results to our study, in that, text-based sign is easily to recognize based on reaction time (Shinar & Vogelzang, 2013). It was recommended that the symbol traffic signs that are new and unfamiliar should have symbol with text (US Department of Transformation, 2009). Shinar and Vogelzang also emphasized that the problem of comprehension of the common or familiar symbol traffic signs maintained. In the case of uncommon and symbol-concept incompatible signs, the comprehension of the traffic signs is worse (Ben-Bassat & Shinar, 2006). We believe that for the low vision, this problem of traffic sign comprehension is more aggravated than the normal vision as confirmed by the previous research.

In our study, the light transmission through the simulated low vision lenses is about 30% in occlusion vision lenses which is cloudy compared to blurred vision having the transmission about 90% (Figure 4-77). In simulated blurred vision glasses, the blurry image is perceived, the light transmission is not a main problem but the sharpness. Under the same lighting condition and the same traffic sign stimulus, the detection time seems to be rather longer in case of occlusion vision but not significantly difference. However, the accuracy rate of occlusion vision is higher than blurred vision. The higher illuminance on the sign for blurred vision seems to support for defection but does not support for comprehension. The image perceived through the occlusion glasses is cloudy but sharper than the blurred glasses. The comparison of images through blurred and occlusion lenses are shown in Figure 4-78. The Weber luminance contrast obtained through the occlusion glasses, consequently, is lower than through the blurred glasses for all 4 colors in test. This can be pointed out that for the response of the blurred and occlusion types of low vision, the detection ability requires high luminance and the comprehension ability requires sharpness of sign.

The results so far show that the text-based traffic signs are recommended for the low vision. For color, yellow showed the longest answering time and it is significantly different from blue, green and red colors which the response times among them are not significantly different. For color portion, negative design showed shorter answering time than positive design.

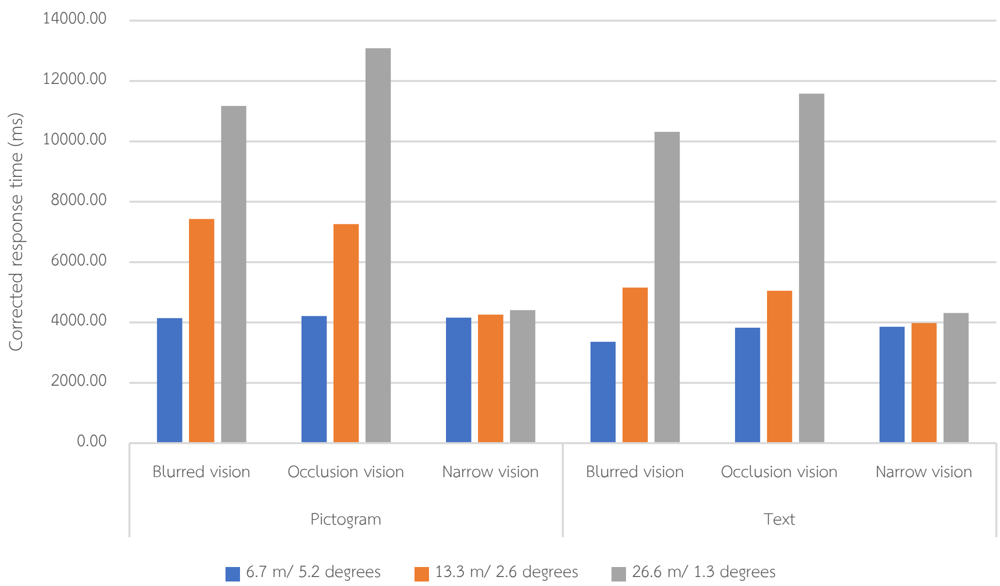

Figure 4-75 Corrected response time of pictogram and text traffic signs.

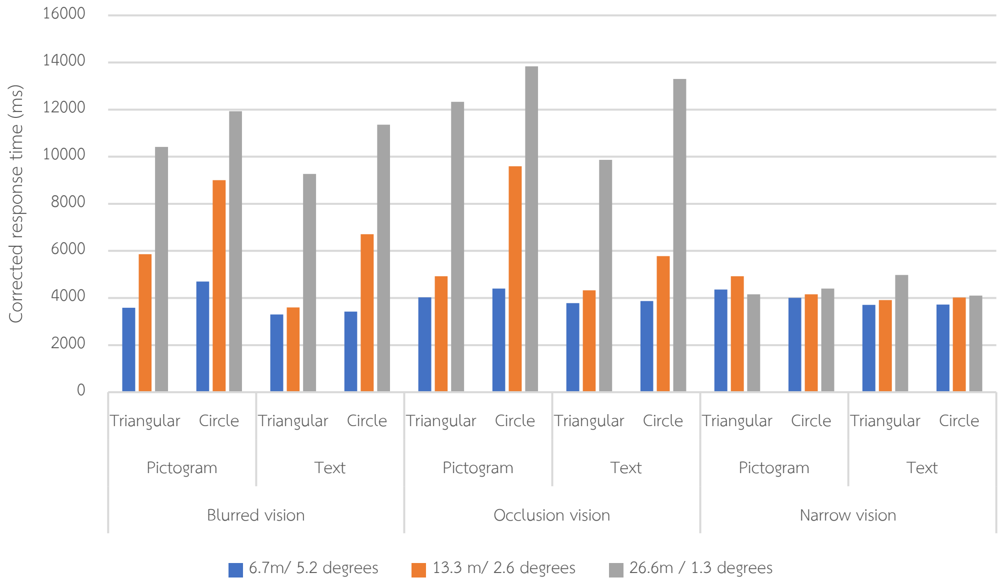

Figure 4-76 Corrected response time of individual shape of traffic signs.

For narrow vision there are significant differences among corrected answering times resulted from color, type of traffic sign, and background. For color, there are no significant differences among 4 colors at the nearest simulated distance of 6.7 m. When the distance gets longer at 13.3 m and 26.6 m, the response time of blue increases continuously and get significantly different from red, green and yellow at 26.6 m, red and green stay steady at 13.3 m and increase at 26.6 m as well as yellow increase at 13.3 m and maintains the same response time at 26.6 m which is not significantly different from read and green. For kind of sign, same as occlusion vision and blurred vision, the signs which has only texts and color, such as “STOP” and “SOS” show shorter answering time than other 4 signs which has more complicated pictogram design, such as “Pedestrians and bicycle only”, “School zone”, “Under construction”, and “Caution for slip”.

In our study, it seems that the less transmission in 400–440 nm of blurred vision lens (Figure 4.77) does not affect color perception ($p>.05$, Figure 4-79) over the shape that the triangular shape ($p<.05$) is recognized quicker than circle one (Figure 4-85).

The transmittance percentage of occlusion vision lens is rather constant across the wavelength of 400 nm to 700 nm, however the cloudy feature of the glasses (VA = 0.08) reduces approximately 50% of transmittance across 400–700 nm. The effect resulted in color perception showed through the response time, in that, response time of yellow is significantly different from red, green, and blue. Red, green, and blue response times are not different from each other (p >.05). We then deleted the choice of yellow as a candidate design for the simulated occlusion vision. For the combination effect, color and color portion we found that blue-negative pattern shows significantly different in shorter response time from others (Figure 4-88).

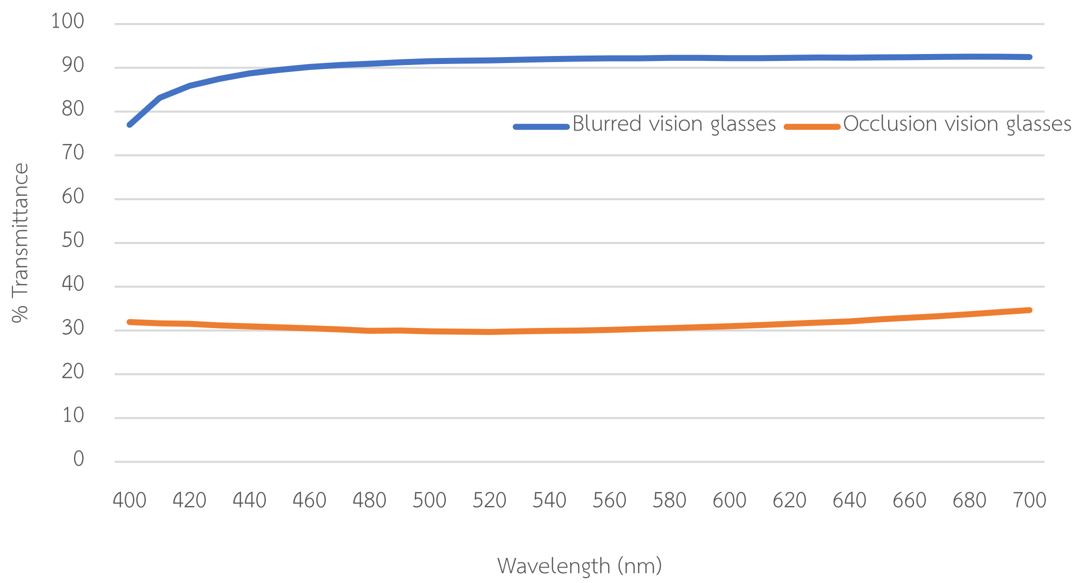

Figure 4-77 Transmissions of simulated blurred vision lenses and occlusion vision lenses.

Figure 4-78 Appearance of images through blurred and occlusion lenses compared to without lenses.

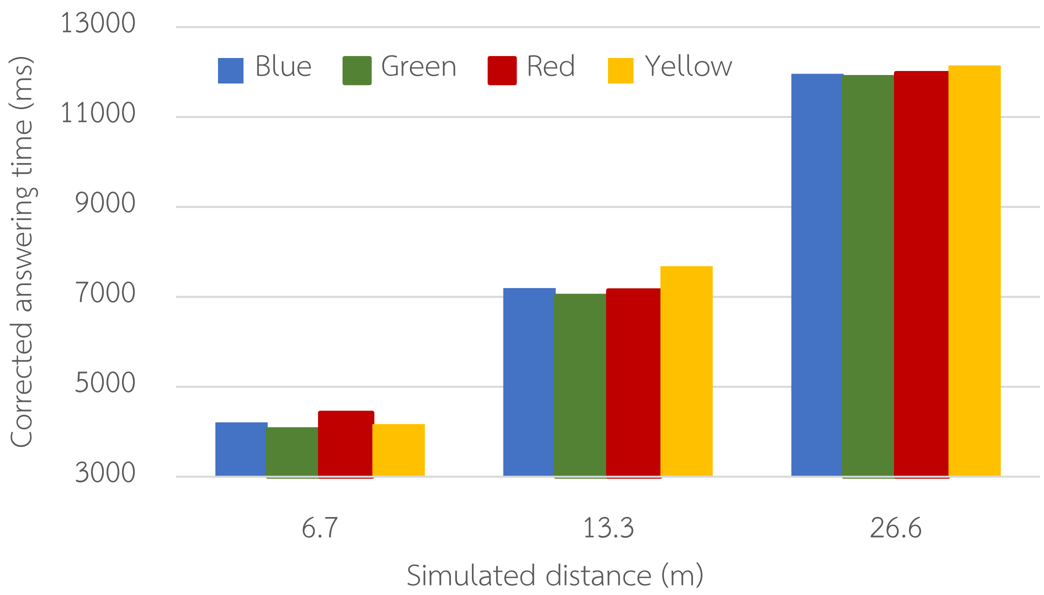

Figure 4-79 Corrected answering time (reaction time) under "Dim" condition with simulated blurred vision for stimulus with four colors

Signif. Codes: 0.001< "***", 0.01< "**", 0.05< "*"

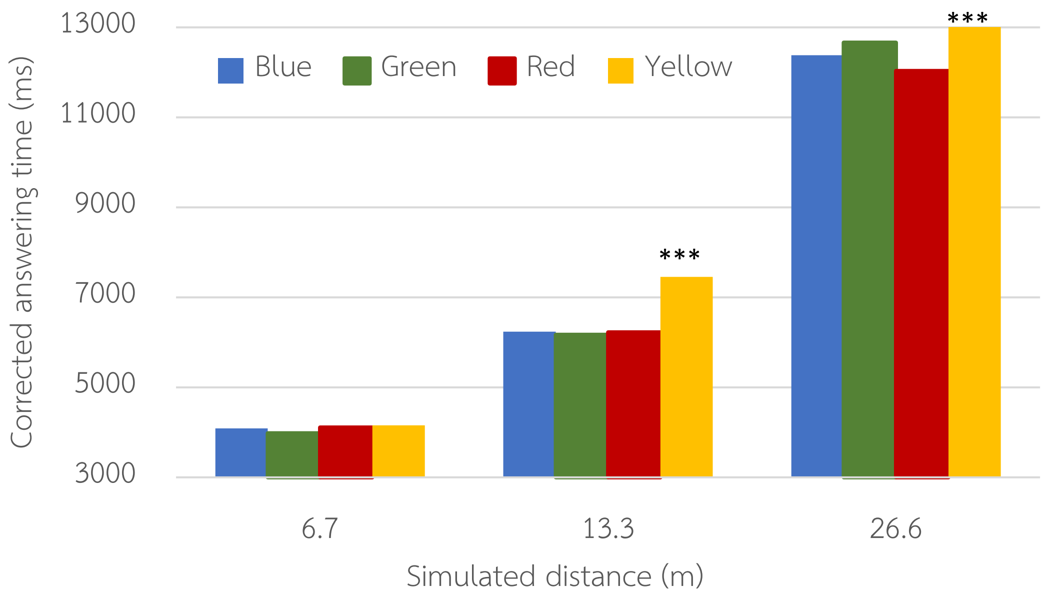

Figure 4-80 Corrected answering time (reaction time) under "Dim" condition with simulated occlusion vision for stimulus with four colors

Signif. Codes: 0.001< "***", 0.01< "**", 0.05< "*"

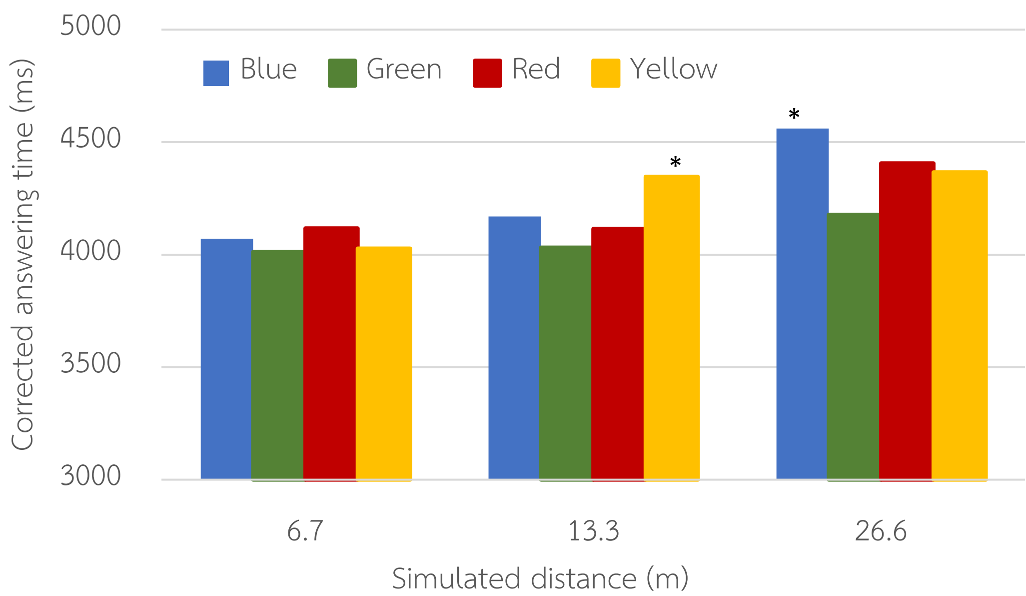

Figure 4-81 Corrected answering time (reaction time) under "Dim" condition with simulated narrow vision for stimulus with four colors

Signif. Codes: 0.001< "***", 0.01< "**", 0.05< "*"

Figure 4-82 Corrected answering time (reaction time) under “Dim” condition with simulated blurred vision for stimulus with two color portions.

Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”

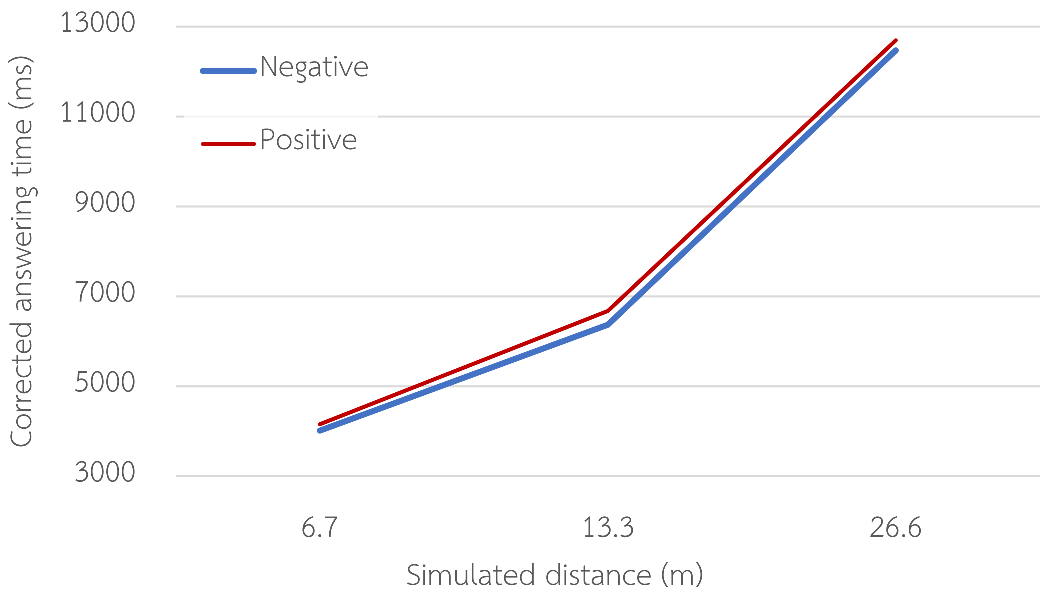

Figure 4-83 Corrected answering time (reaction time) under “Dim” condition with simulated occlusion vision for stimulus with two color portions.

Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”

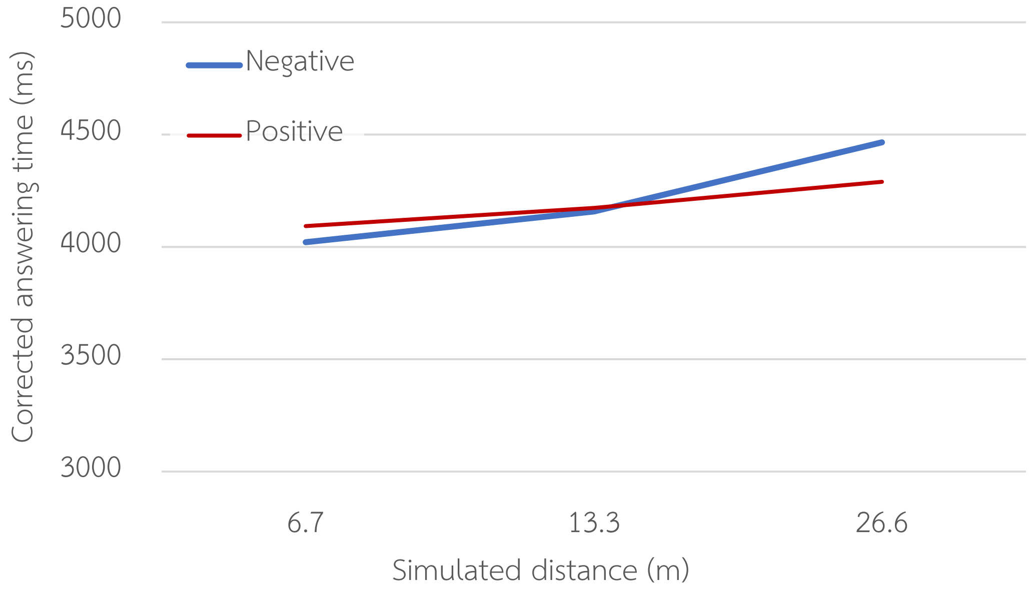

Figure 4-84 Corrected answering time (reaction time) under “Dim” condition with simulated narrow vision for stimulus with two color portions.
Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”

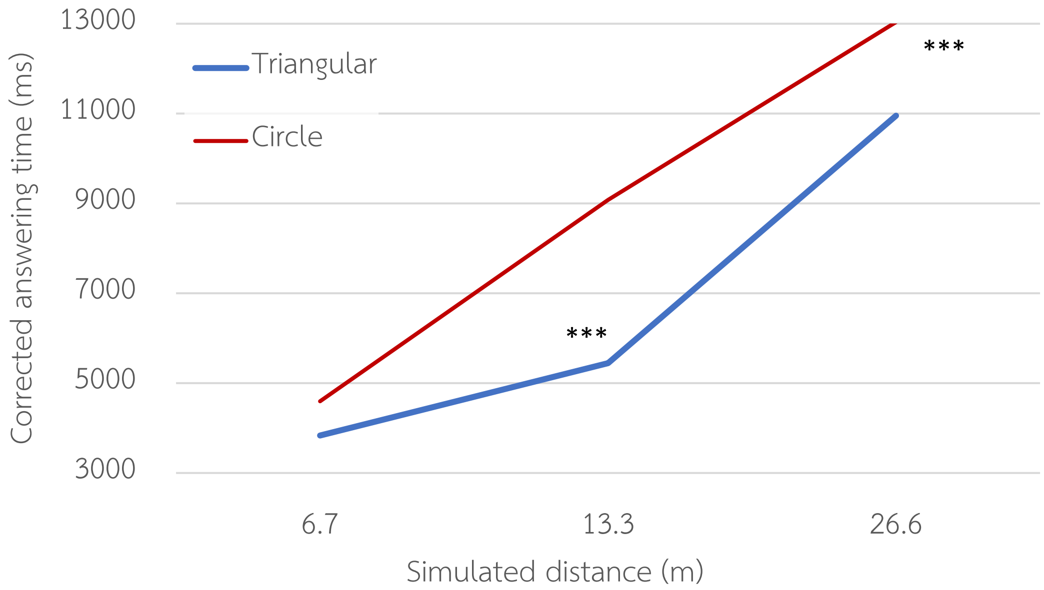

Figure 4-85 Corrected answering time (reaction time) under “Dim” condition with simulated blurred vision for stimulus with two shapes.
Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”

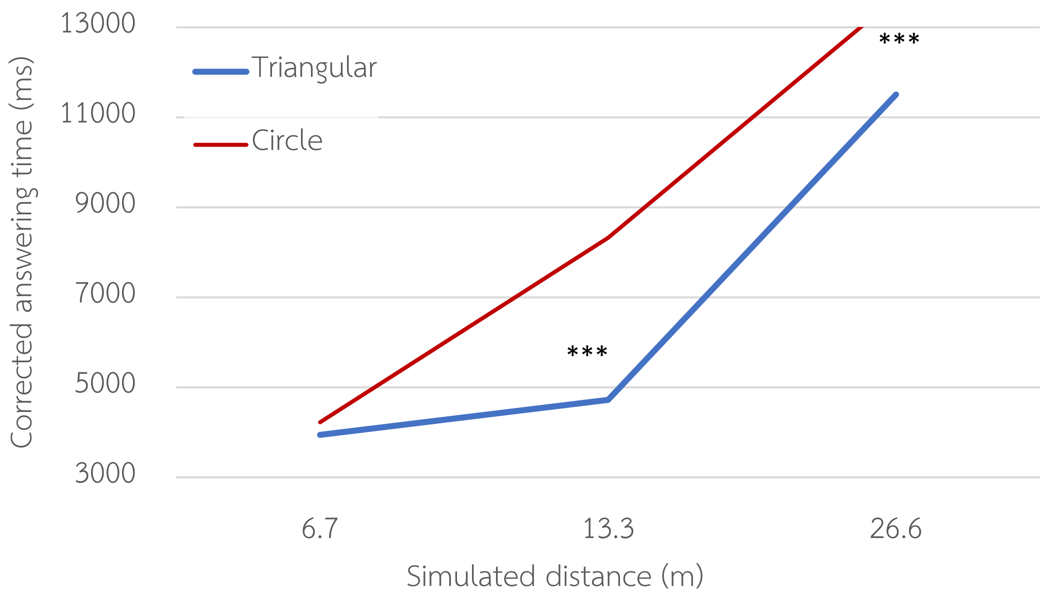

Figure 4-86 Corrected answering time (reaction time) under “Dim” condition with simulated occlusion vision for stimulus with two shapes.

Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”

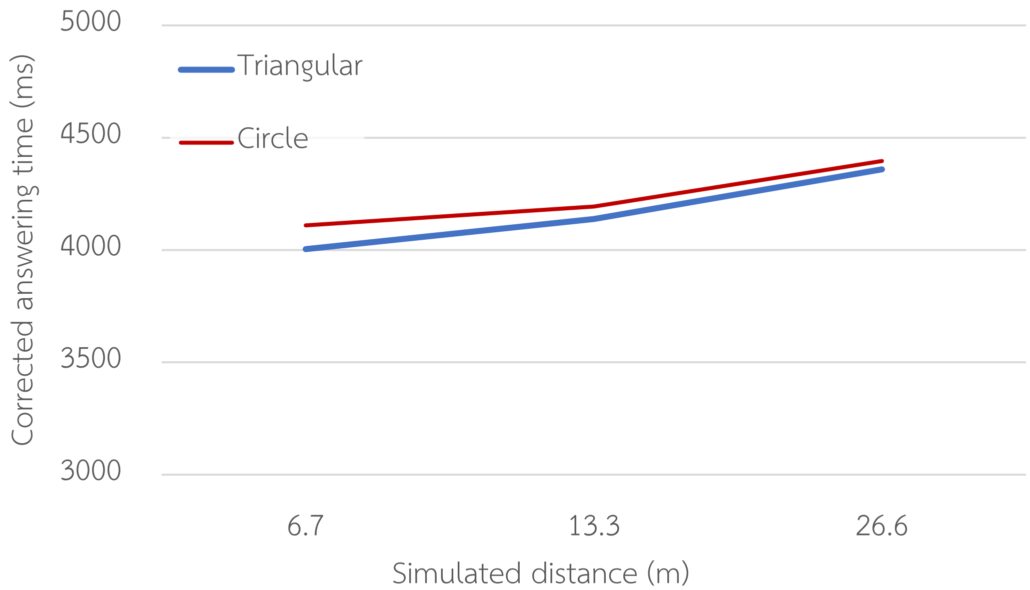

Figure 4-87 Corrected answering time (reaction time) under “Dim” condition with simulated narrow vision for stimulus with two shapes.

Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”

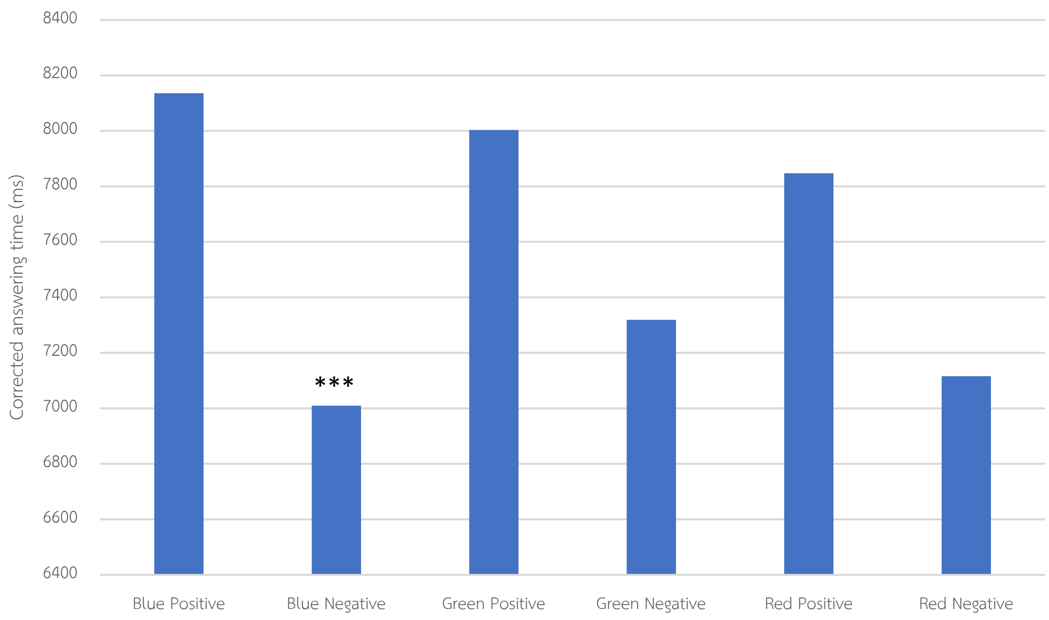

Figure 4-88 Corrected answering time (reaction time) under "Dim" condition with simulated occlusion vision for stimulus with combination of color & color portion. Signif. Codes: 0.001< "***", 0.01< "**", 0.05< "*"

From these results, we selected the combination of shape, color, and color portion for individual type of low vision. First of all, for occlusion vision and blurred vision, the combination of triangular-blue-negative was selected. The following reasons are confirmed again: 1) the triangular shape shows significant shorter response time for the blurred and occlusion glasses.; 2) color does not affect the response time for blurred vision glasses and 3) the response time of red, green and blue are not significantly different for blurred vision but the combination of blue and negative shows the shortest response time and yellow shows longest response time.

For narrow vision, circle-yellow-positive design was selected with the following reasons: 1) In the 1st investigation, circle significantly shows shorter response time over than other 5 shapes in test, and in the 2nd investigation there is no significant difference between triangular and circle shapes but the accuracy rate of pictogram-based/shape and text-based/shape (Figure 4-74) of circle shape is higher that triangular.; 2) In the 1st investigation, blue, green, red and yellow in circle shape do not affect the response time of the narrow vision and the response time is approximately 2,000 ms from the simulated distance of 4.13 m to 13 m, however, in the 2nd investigation when the simulated distance is extended to 26.6 m, blue shows longest response time while there is no significant difference among other red, green and yellow. Red will be used in the new design at the edge when the current design is red, to keep attention. In the 1st investigation, red shows less response time than other colors. Although the response time of green is not different from yellow, green has tendency to blend with green leaves background and difficult to recognize.

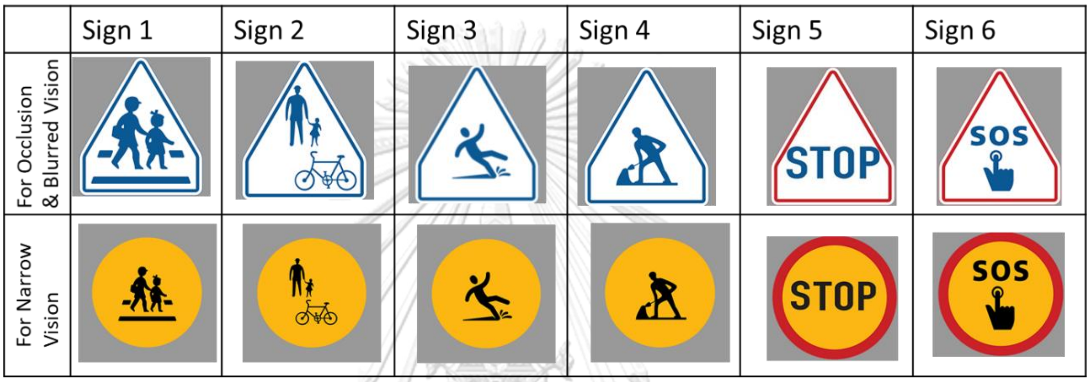

Figure 4-89 Candidate set of designs

4.3 Investigation of the farthest distance required to response on the improved traffic signs compared with the current traffic signs by normal vision subjects wearing 3 types of simulated low vision glasses (blurred vision, occlusion vision and narrow vision).

For this investigation, a Google form was used to set a series of questionnaire to perform remote test. The answer “I cannot see” was added to each question. The total accuracy rate of this investigation was 79.1% against 7290 answers, the results of accuracy rate of blurred, occlusion and narrow visions each simulated low vision are shown in Figure 4-90, Figure 4-91 and Figure 4-92 respectively. Three sets of the optimized designs of signs, blue, negative designs with triangular shape, were prepared for blurred and occlusion visions, and yellow, positive designs with circle shape, were prepared for narrow vision. Furthermore, a set of current designs were added on these two sets. First of all, it is outstanding that the text-based traffic sign maintains the high accuracy rate percentage compared to pictogram-based sign for blurred and occlusion visions. In terms of pictogram-based traffic sign, the 'School zone' and 'Caution for slip' traffic signs designed for the blurred and occlusion visions show higher accuracy than the current designs when viewed with simulated occlusion vision glasses except for the 'Caution for slip' that the accuracy rate percentages are the same for improved and current designs when viewed through the simulated blurred vision. The rest of 3 pictogram designs show approximately 10% lower accuracy rate than the current design. For these pictogram-based traffic signs designed for blurred, occlusion and narrow visions, when were viewed with simulated narrow vision glasses, the accuracy rate percentage is 100 except for the 'Pedestrian and bicycle only' designed for blurred and occlusion visions that show accuracy rate percentage about 90.

In terms of text-based traffic sign designed for blurred and occlusion visions, the 'STOP' one of the improved design shows higher and equal accuracy compared to the current design when viewed through the simulated blurred and occlusion visions respectively. The current "SOS' sign shows the best accuracy. The improved designs of text-based traffic sign for narrow vision show the best accuracy that is the same as current design.

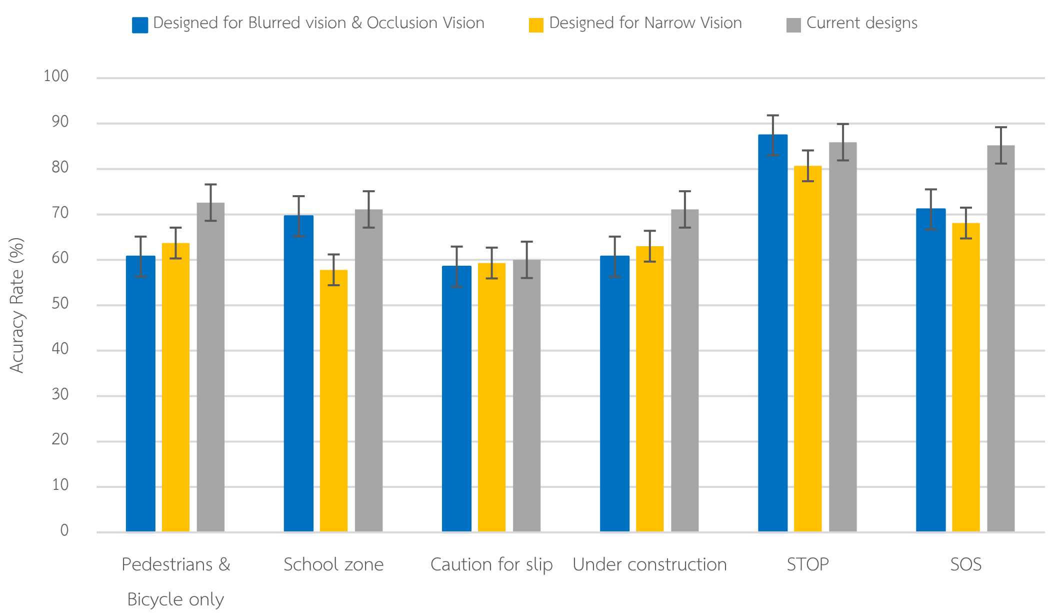

Figure 4-90 Accuracy rate of simulated blurred vision on 2 set of candidate designs and current design.

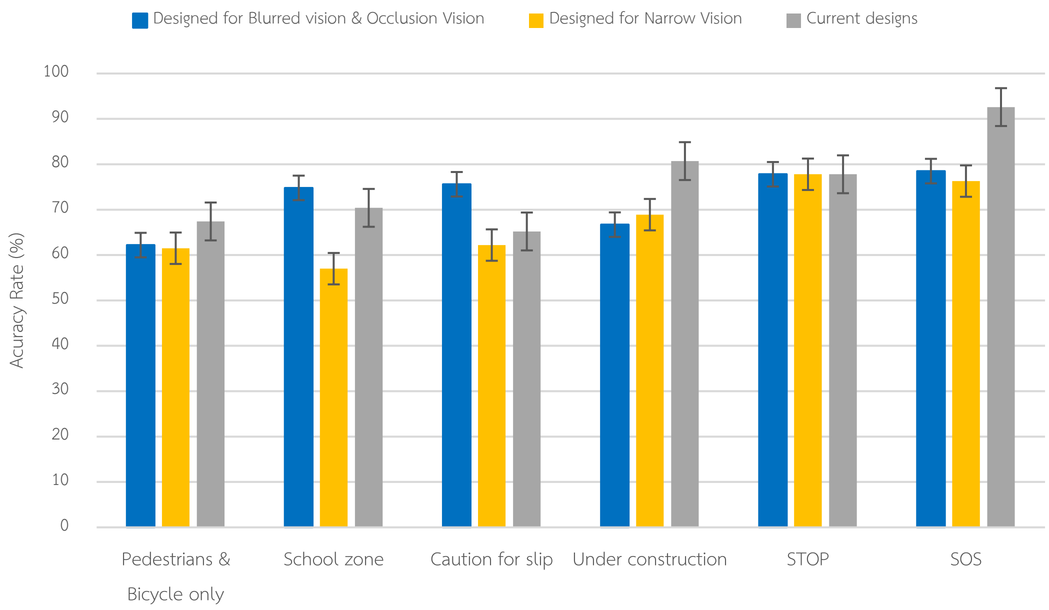

Figure 4-91 Accuracy rate of simulated occlusion vision on 2 set of candidate designs and current design.

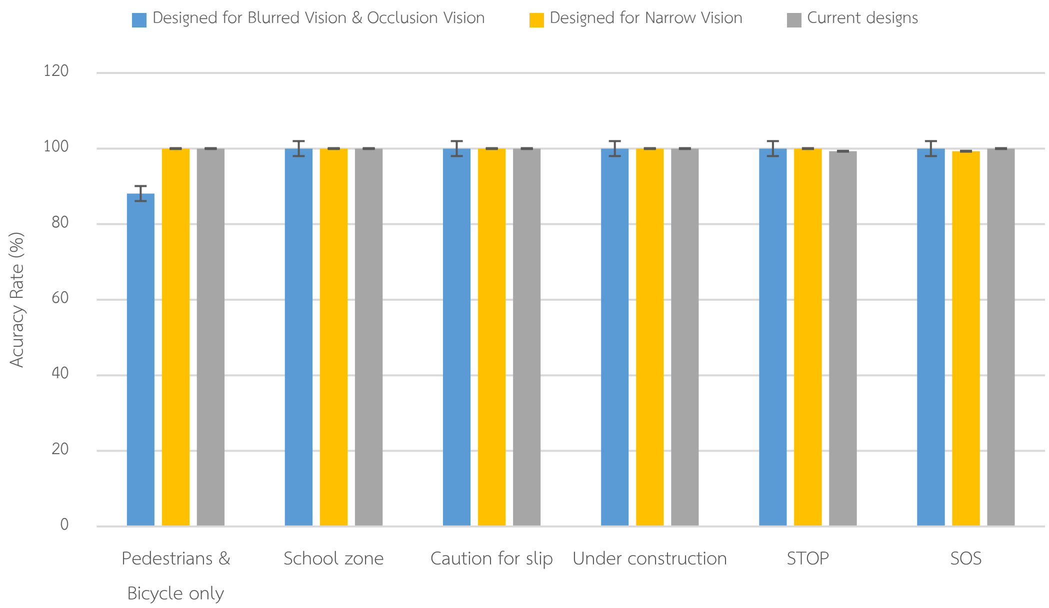

Figure 4-92 Accuracy rate of simulated narrow vision on 2 set of candidate designs and current design.

The results of response time of blurred, occlusion and narrow vision are shown in Figure 4-93, Figure 4.94 and Figure 4-95 respectively. Again, the text-based traffic sign shows less response time than the pictogram-based one. In terms of pictogram traffic sign designed for blurred and occlusion visions, the response times of the ‘School zone’ and the ‘Caution for slip’ are shorter than that of current design when viewed through blurred and occlusion vision. The rest of 2 pictogram designs: the ‘Pedestrian and bicycle only’ and the ‘Under construction’ show higher response time than the current design. In terms of text-based traffic sign, the ‘STOP’ design shows similar response time to the current design. The current ‘SOS’ design gives the shortest response time. In terms of the pictogram-based traffic signs for narrow vision, the candidate designs: the ‘School zone’, the ‘Caution for slip’ and the ‘Under construction’ show similar response time of about 3.0–3.5 seconds to the current signs. Two of the text-based candidate and current traffic signs for narrow vision have similar response time of about 3.0 seconds.

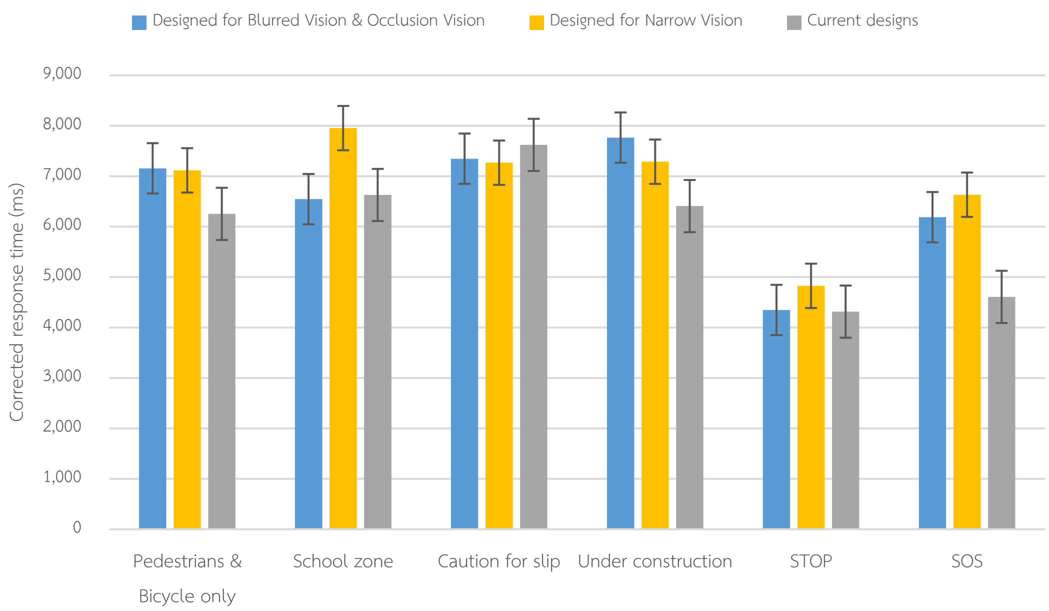

Figure 4-93 Corrected response time of simulated blurred vision on 2 set of candidates and current.

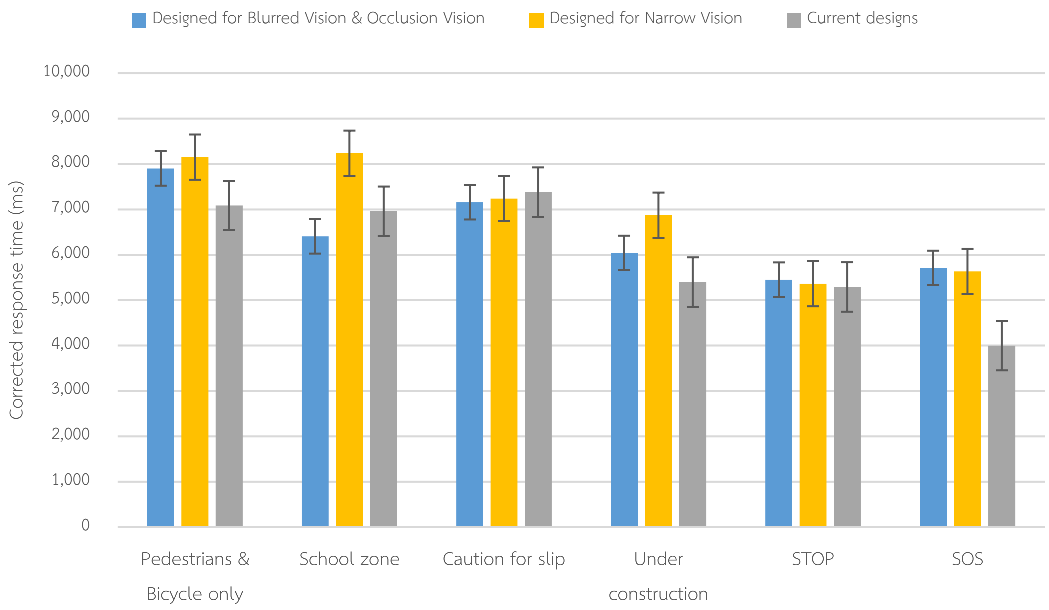

Figure 4-94 Corrected response time of simulated occlusion vision on 2 set of candidates and current.

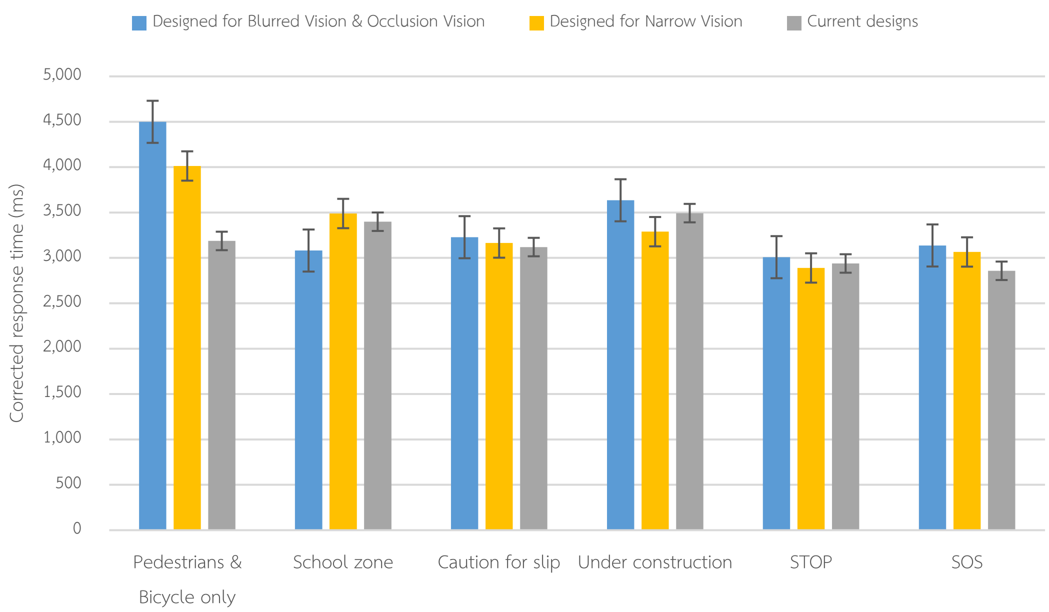

Figure 4-95 Corrected response time of simulated narrow vision on 2 set of candidates and current.

The results of the size of visual angle and the accuracy rate (Figure 4-96) and that of visual angle and the response time (Figure 4-96) and that of visual angle and the response time (Figure 4-97) are demonstrated to analyze the farthest distance when the comprehension of the traffic sign is perfectly correct.

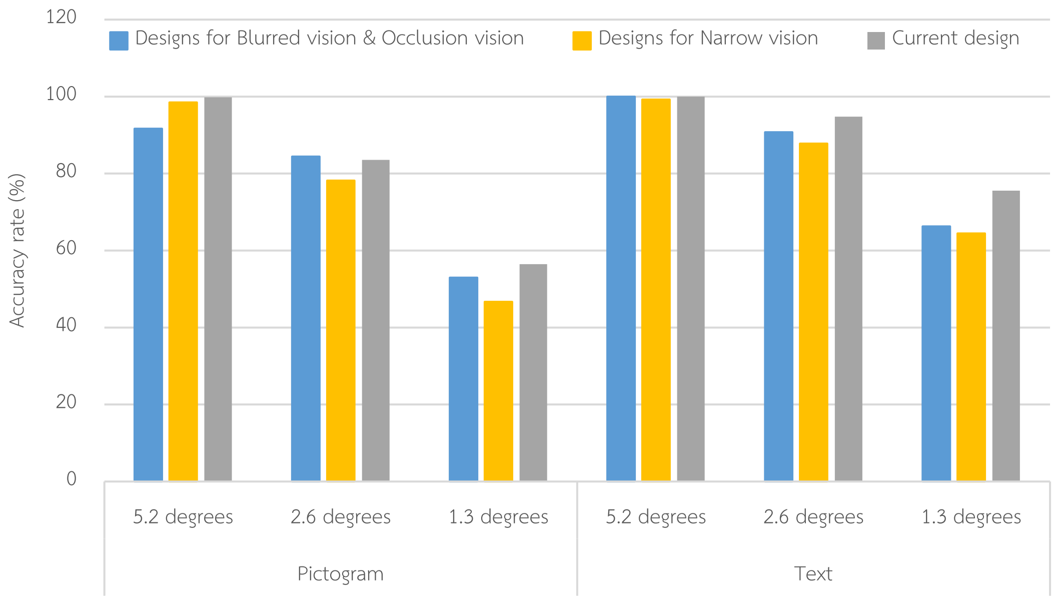

Figure 4-96 Visual angles and accuracy rate of candidate and current traffic sign.

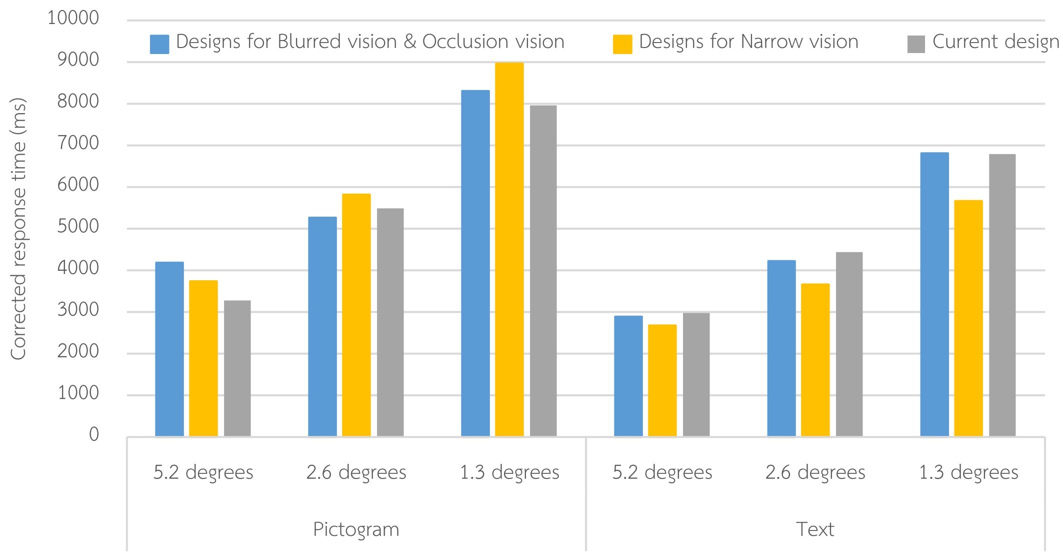

Figure 4-97 Visual angles and response time of candidate and current traffic signs.

The results show that the farthest distance where the simulated low vision in test gives the accuracy rate of 100% and response time of about 3–4 seconds is 6.7 m of simulated distance when viewed the pictogram traffic sign size of 60 cm or the arch of visual angle of 5.2 degrees. For the text-based traffic sign the response time is 3 seconds. We could say that in application to the low vision, the traffic sign presented to the low vision: blurred, occlusion and narrow vision should be size greater than 5.2 degrees of visual angle. This results of visual angle is similar to the previous research (Ikeda et al., 2009). They demonstrated that the color patch size presented to the cataract visually impaired people should be greater than 6 ° of visual angle to attain color perception close to the original color.

The improved pictogram traffic signs that give higher accuracy rate than the current design at the visual angle of 5.2 degrees are the 'School zone' and the 'Caution for slip' for blurred and occlusion visions. For narrow vision, at the same visual angle, all improved designs, both pictogram-based and text-based give similar accuracy rate and response time to the current design.

One reason that the current traffic sign gives higher accuracy rate or equally accuracy rate compared to the improved traffic sign is probably the familiarity of the current traffic signs. This reason supported by the previous research (Shinar & Vogelzang, 2013) that the familiarity is one of the ergonomic principles that affects the traffic sign comprehension. Therefore, the new design of pictogram should have text along with it.

Then, we added 10 seconds to individual reaction time data for each incorrect answer and analyzed which candidates design set is the best and if the reaction times are significantly different.

Comparison of the average reaction time on individual kind of sign with 3 types of simulated low vision are shown in Figure 4-93, 4-94, and 4-95. As they showed clearly, for simulated narrow vision, there is very little difference between sets of candidate designs and current design. While simulated blurred vision and simulated occlusion vision are showed that for the simple design sign, the reaction time is shorter than complicated design signs which are the same as the results of 2nd investigation.

CHAPTER 5
CONCLUSIONS AND SUGGESTIONS

5.1 Conclusion

This research mainly aimed to identify the most effective traffic sign for the simulated blurred, occlusion and narrow vision. Based on the successive empirical study of illumination condition, shape, color, color portion (negative and positive), background, type of traffic sign and the distance in response to the reaction time, it can be concluded as follows:

Fastest response time for shapes with color of the traffic sign by blurred, occlusion and narrow visions.

The dim condition, having luminance of 18.9 cd/m^2 on white point, has a strong negative impact for blurred and occlusion visions, on identifying the circle and the octagon when the subtended visual angle of the shape is less than 3.4 degrees, in another word, the simulated distance is greater than 10 m observing the 0.6 m stimulus. The triangular shape presented with the subtended visual angle greater than 3.4 degrees can be fast and correctly identified. The dim condition demonstrates a slight negative impact for the narrow vision on identifying the shape with sides: square, diamond and octagon when the size of visual angle is large (11 degrees). The circle is accurately identified by the simulated narrow vision from the subtended visual angle of 2.6 degrees to 8.2 degrees in both Dim and Bright conditions. The colors do not have an impact on response time as much as the shape in Dim and Bright conditions for all 3 simulated low vision types. Red shows lower response time than yellow, green and blue in both Dim and Bright conditions, whereas blue and green are hard to identify under Dim condition. The Bight condition does not give any confusion of shape with color.

Impact of color portion in traffic signs in Dim condition.

When the information of traffic sign is added to shape and color in pictogram and text forms, the comprehension of traffic sign involves, consequently, the size of visual angle required to recognize the traffic sign (reflected in accuracy rate) is greater than 5.2 degrees for blurred and occlusion visions, which is larger than the size of visual angle required to identify the shape with color (greater than 3.4 degrees). In contrast, the information of traffic sign added to shape with color, does not affect the simulated narrow vision. The size of visual angle required to recognize the traffic sign can be from 1.3 degrees. With the results of shape with color, it can be concluded that the size of visual angle of the simulated narrow vision required to comprehend the traffic signs is between 1.3 degrees to 8.2 degrees

In terms of shape, the triangle and the circle traffic signs affect the accuracy rate and response time of the simulated blurred and occlusion vision similarly, in that, the accuracy rate is found higher and response time is found lower in the triangle traffic sign than in the circle traffic sign. On the other hand, the simulated narrow vision comprehends the circle traffic signs better than the triangle for both pictogram-based and text-based traffic signs, irrespective of the subtended visual angle in test, 5.2 degrees to 1.3 degrees. The simulated narrow vision increasingly comprehends the triangular traffic sign when the subtended visual angle decreases from 5.2 degrees to 1.3 degrees.

The average time of comprehension both types of traffic signs is approximately 4 seconds for 3 sizes of subtended visual angle, for simulated narrow vision. For blurred and occlusion visions, the average time to comprehend the pictogram-based traffic sign increases from about 4 seconds to 7 seconds when the size of subtended visual angle decreases from 5.2 degrees to 2.6 degrees, whereas the average time to comprehend the text-based traffic sign is faster, it increases from 3.5 seconds to 5 seconds for 5.2 degrees and 2.6 degrees respectively.

The colors: red, green, yellow and blue in traffic sign do not have impact to the blurred, occlusion and narrow vision at the sizes of visual angle 5.2 degrees. When the sizes of visual angle decrease, all colors in test does not affect the blurred vision, yellow slightly increases the response time of occlusion vision and narrow vision of about 500 ms. At the smallest size of visual angle, blue increases the response time of narrow vision and it is greater than other colors about 200 ms. We could conclude that colors have very slightly impact on the response of these 3 types of low vision to the traffic sign.

The color portion (negative/positive) has very slightly impact to only the blurred vision at the size of visual angle 5.2 degrees, the difference of the response time between positive and negative is about 300 ms. It does not have the impact to the simulated occlusion vision; however, the combined effect of color portion and color shows greater response time in blue positive than blue negative.

Comparison of the improved traffic signs for people with low vision to the current traffic signs.

In comparison to the current traffic sign, the candidate triangular-blue-negative traffic signs designed for the simulated blurred and occlusion visions shows better accuracy only for 2 signs of pictogram-based 'School zone' and 'Caution for slip' when viewed by the simulated occlusion vision, as well as only 1 sign of text-based 'STOP' when viewed by the simulated blurred vision.

The comparable ones to the current traffic signs are 'School zone' and 'Caution for slip' viewed by the blurred vision as well as the 'STOP' viewed by the occlusion vision. The rest of the candidates is inferior to the signs designed for the narrow vision has the same performance on accuracy of 100% as the current traffic signs at the subtended visual angle of 5.2 degrees to 1.3 degrees.

The farthest distance given the subtended visual angle of 5.2 degrees shows 100% accuracy only for the pictogram-based of current traffic signs when viewed by all 3 types of the simulated low vision. At longer distance the accuracy rate decreases for all traffic signs.

For the text-based traffic signs, the candidate for blurred and occlusion visions and the current ones show 100% accuracy when views by 3 types of the simulated low vision at 5.2 degrees of visual angle. At the longer distance, the accuracy rate decreases.

5.2 Suggestions

To better understand the implication of these results, future studies could address on the following issues:

The comparison of the potential candidate designs with text and the current design should be test ed. There are many variations in the individuals visual functioning of the low vision; therefore, the participants with low vision should be recruited for the test.

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APPENDIX

Table A-1 Summary of 2 way-ANOVA for reaction time

	Df	Sum Sq	Mean Sq	F value	Pr (>F)
Luminance of Monitor	1	35206428	35206428	138.95	<2.2e-16 ***
Simulated Distance	1	42065891	42065891	166.0224	<2.2e-16 ***
Kind of simulated-glasses	2	6957158	3478579	13.729	1.11e-06***
Color	3	17820904	5940301	23.4447	4.12e-15***
Shape	5	110346325	22069265	87.1013	<2.2e-16 ***
1*2	1	4279648	4279648	16.8906	3.99e-05***
1*3	2	2024943	1012472	3.9959	0.0184219**
1*5	5	11386077	2277215	8.9875	1.57e-08***
2*3	2	76368059	38184029	150.7107	<2.2e-16 ***
2*4	3	2448686	816229	3.2214	0.0216913**
2*5	5	102673259	20534652	81.0446	<2.2e-16 ***
3*5	10	47160023	4716002	18.6128	<2.2e-16 ***
4*5	15	5744062	382937	1.5113	0.0916682
1*2*3	2	9921502	4960751	19.5787	3.27e-09***
1*2*5	5	12640702	2528140	9.9779	1.55e-09***
1*3*5	10	751643	757164	2.9883	0.0009072***
2*3*5	10	47619764	4761976	18.7942	<2.2e-16 ***
1*2*3*5	10	14230996	1423100	5.6166	2.04e-08***
Residuals	9216	2335102405	253375		

Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”,

Table A-2 Averages of reaction time with simulated blurred vision under dim and bright conditions.

Shape	Color	Average		Maximum		Minimum	
		300cd/m^2	8.9cd/m^2	300cd/m^2	8.9cd/m^2	300cd/m^2	8.9cd/m^2
Square	Blue	2090	2098	2312	2218	1959	2006
	Green	2124	2167	2238	2344	1990	2104
	Red	2045	2116	2177	2255	1918	1959
	Yellow	2062	2151	2228	2314	1984	2008
Circle	Blue	1855	2203	1962	2797	1803	1982
	Green	2037	2174	2171	2524	1906	1993
	Red	1879	1991	2076	2160	1797	1801
	Yellow	1966	2278	2148	2627	1789	1890
Diamond	Blue	2174	2124	2345	2302	1996	1981
	Green	2169	2165	2225	2294	2057	2027
	Red	2051	2180	2157	2424	1915	2068
	Yellow	2065	2235	2207	2452	1916	2056
Invert Triangular	Blue	2131	2130	2231	2234	2035	2050
	Green	2126	2225	2189	2369	2077	2153
	Red	1987	2064	2074	2110	1870	2010
	Yellow	2076	2105	2177	2160	1926	2011
Triangular	Blue	2074	2100	2189	2198	1902	1967
	Green	2082	2170	2252	2396	1934	2080
	Red	2114	2052	2344	2211	2017	1945
	Yellow	2023	2043	2131	2123	1919	1971
Octagon	Blue	2177	2614	2803	3959	2009	2087
	Green	2340	2665	3059	3883	2107	2004
	Red	2149	2585	2477	4243	1977	1934
	Yellow	2217	2577	2691	3693	1951	2072

Table A-3 Averages of reaction time with simulated occlusion vision under dim and bright conditions.

Shape	Color	Average		Maximum		Minimum	
		300cd/m^2	8.9cd/m^2	300cd/m^2	8.9cd/m^2	300cd/m^2	8.9cd/m^2
Square	Blue	2035	2190	2146	2269	1938	2140
	Green	2137	2262	2251	2552	1986	2046
	Red	2032	2162	2167	2410	1873	1955
	Yellow	1995	2114	2071	2315	1918	1972
Circle	Blue	1979	2212	2404	2613	1824	1989
	Green	2150	2390	2659	2807	1914	2042
	Red	1873	2147	1948	2947	1800	1861
	Yellow	2132	2289	2577	2641	1891	1957
Diamond	Blue	2108	2199	2201	2310	1999	2121
	Green	2202	2319	2333	2543	2152	2106
	Red	2074	2127	2186	2217	1999	2036
	Yellow	2096	2211	2241	2329	1967	2086
Invert Triangular	Blue	2117	2208	2354	2394	2022	2110
	Green	2156	2264	2334	2465	2017	2113
	Red	2042	2044	2177	2152	1948	1928
	Yellow	2057	2090	2173	2205	1976	2012
Triangular	Blue	2045	2118	2261	2160	1933	2082
	Green	2125	2206	2197	2331	2052	2131
	Red	2008	2074	2137	2191	1949	1972
	Yellow	2036	2082	2117	2179	1978	1947
Octagon	Blue	2379	2560	3369	3589	2016	2120
	Green	2551	2725	3954	3765	2030	2156
	Red	2247	2442	2883	3300	1907	1984
	Yellow	2378	2762	3322	3793	2086	2074

Table A-4 Averages of reaction time with simulated narrow vision under dim and bright conditions.

Shape	Color	Average		Maximum		Minimum	
		300cd/m^2	8.9cd/m^2	300cd/m^2	8.9cd/m^2	300cd/m^2	8.9cd/m^2
Square	Blue	2223	2280	3404	4661	2080	2164
	Green	2144	2281	3434	4904	2068	2107
	Red	2054	2112	2845	5696	1988	1967
	Yellow	2155	2248	3152	4414	2013	2130
Circle	Blue	1909	1975	4103	5072	1856	1866
	Green	2020	2087	4670	5067	1923	2010
	Red	1875	1913	2870	4723	1778	1842
	Yellow	2006	2043	4710	5288	1905	1924
Diamond	Blue	2297	2331	3357	4021	2230	2122
	Green	2271	2367	3284	4028	2134	2234
	Red	2133	2261	3206	3783	1944	2015
	Yellow	2282	2372	3345	4736	2149	2150
Invert Triangular	Blue	2242	2276	3248	3931	2147	2086
	Green	2285	2329	3229	4430	2082	2083
	Red	2183	2257	3673	4041	2133	2108
	Yellow	2191	2285	3368	4281	2043	2138
Triangular	Blue	2226	2309	3660	3388	2028	2061
	Green	2237	2318	3096	3788	2105	2096
	Red	2119	2279	3402	7978	1920	2004
	Yellow	2157	2315	3236	4348	1979	2094
Octagon	Blue	2195	2261	4927	7604	1996	2095
	Green	2232	2264	6782	6505	2147	2140
	Red	2196	2188	3836	6649	2047	2082
	Yellow	2238	2316	4684	6777	2124	2064

Table A-5 Accuracy rate of answer on simulated blurred vision.

Kind of sign	Color	Color Portion	Shape	The size of the sample to the eyes. (degrees)		
				5.2	2.6	1.3
Pedestrians & Bicycle only	Blue	Negative	Triangular	100%	87%	67%
			Circle	93%	33%	7%
		Positive	Triangular	93%	80%	20%
			Circle	100%	33%	0%
	Green	Negative	Triangular	100%	93%	33%
			Circle	100%	47%	13%
		Positive	Triangular	100%	100%	33%
			Circle	100%	67%	27%
	Red	Negative	Triangular	100%	100%	20%
			Circle	100%	47%	13%
		Positive	Triangular	100%	87%	13%
			Circle	100%	40%	7%
	Yellow	Negative	Triangular	100%	100%	27%
			Circle	100%	47%	7%
		Positive	Triangular	100%	100%	27%
			Circle	100%	33%	7%
School zone	Blue	Negative	Triangular	100%	87%	13%
			Circle	80%	33%	0%
		Positive	Triangular	93%	73%	33%
			Circle	60%	27%	0%
	Green	Negative	Triangular	100%	67%	33%
			Circle	80%	40%	0%
		Positive	Triangular	100%	73%	33%
			Circle	93%	33%	0%
	Red	Negative	Triangular	100%	80%	27%
			Circle	73%	33%	0%
		Positive	Triangular	100%	73%	20%
			Circle	93%	40%	0%
	Yellow	Negative	Triangular	100%	73%	27%
			Circle	93%	40%	13%
		Positive	Triangular	100%	80%	33%
			Circle	80%	27%	0%

Under Construction	Blue	Negative	Triangular	100%	87%	7%
			Circle	93%	40%	0%
		Positive	Triangular	100%	87%	7%
			Circle	93%	47%	0%
	Green	Negative	Triangular	100%	80%	13%
			Circle	93%	53%	0%
		Positive	Triangular	100%	67%	13%
			Circle	100%	47%	0%
	Red	Negative	Triangular	100%	80%	20%
			Circle	67%	33%	0%
		Positive	Triangular	100%	80%	13%
			Circle	67%	47%	0%
	Yellow	Negative	Triangular	100%	67%	13%
			Circle	87%	40%	7%
		Positive	Triangular	100%	93%	13%
			Circle	100%	33%	0%
Caution for Slip	Blue	Negative	Triangular	100%	60%	33%
			Circle	87%	33%	0%
		Positive	Triangular	100%	80%	20%
			Circle	100%	40%	0%
	Green	Negative	Triangular	93%	67%	27%
			Circle	87%	47%	7%
		Positive	Triangular	100%	67%	20%
			Circle	87%	40%	7%
	Red	Negative	Triangular	100%	80%	13%
			Circle	80%	33%	7%
		Positive	Triangular	100%	60%	27%
			Circle	87%	40%	0%
	Yellow	Negative	Triangular	67%	33%	20%
			Circle	93%	33%	0%
		Positive	Triangular	93%	73%	27%
			Circle	87%	27%	13%

STOP	Blue	Negative	Triangular	100%	100%	53%
			Circle	100%	80%	20%
		Positive	Triangular	100%	100%	53%
			Circle	100%	93%	13%
	Green	Negative	Triangular	100%	100%	47%
			Circle	100%	67%	27%
		Positive	Triangular	100%	100%	47%
			Circle	100%	87%	7%
	Red	Negative	Triangular	93%	93%	53%
			Circle	100%	87%	40%
		Positive	Triangular	100%	100%	47%
			Circle	100%	73%	13%
	Yellow	Negative	Triangular	100%	87%	27%
			Circle	100%	60%	13%
		Positive	Triangular	100%	100%	20%
			Circle	100%	60%	13%
SOS	Blue	Negative	Triangular	100%	100%	47%
			Circle	100%	67%	7%
		Positive	Triangular	100%	100%	27%
			Circle	100%	53%	7%
	Green	Negative	Triangular	100%	93%	33%
			Circle	100%	60%	0%
		Positive	Triangular	100%	100%	27%
			Circle	100%	67%	0%
	Red	Negative	Triangular	100%	93%	40%
			Circle	93%	60%	0%
		Positive	Triangular	100%	93%	40%
			Circle	100%	60%	7%
	Yellow	Negative	Triangular	100%	100%	20%
			Circle	100%	47%	27%
		Positive	Triangular	100%	93%	27%
			Circle	100%	60%	7%

Table A-6 Accuracy rate of answer on simulated occlusion vision.

Kind of sign	Color	Color Portion	Shape	The size of the sample to the eyes. (degrees)		
				5.2	2.6	1.3
Pedestrians & Bicycle only	Blue	Negative	Triangular	100%	100%	60%
			Circle	100%	93%	0%
		Positive	Triangular	100%	100%	20%
			Circle	100%	40%	0%
	Green	Negative	Triangular	100%	100%	27%
			Circle	100%	60%	7%
		Positive	Triangular	100%	93%	20%
			Circle	100%	60%	33%
	Red	Negative	Triangular	100%	93%	40%
			Circle	100%	93%	7%
		Positive	Triangular	100%	100%	33%
			Circle	100%	40%	0%
	Yellow	Negative	Triangular	100%	100%	0%
			Circle	93%	33%	0%
		Positive	Triangular	100%	100%	47%
			Circle	100%	53%	0%
School zone	Blue	Negative	Triangular	100%	100%	20%
			Circle	100%	27%	0%
		Positive	Triangular	100%	100%	20%
			Circle	67%	7%	0%
	Green	Negative	Triangular	100%	93%	13%
			Circle	100%	33%	0%
		Positive	Triangular	100%	100%	13%
			Circle	100%	27%	0%
	Red	Negative	Triangular	100%	100%	27%
			Circle	100%	47%	0%
		Positive	Triangular	100%	93%	20%
			Circle	100%	20%	0%
	Yellow	Negative	Triangular	100%	87%	0%
			Circle	100%	13%	0%
		Positive	Triangular	100%	100%	13%
			Circle	87%	13%	0%

Under Construction	Blue	Negative	Triangular	100%	100%	33%
			Circle	100%	73%	0%
		Positive	Triangular	100%	100%	13%
			Circle	93%	53%	0%
	Green	Negative	Triangular	100%	100%	7%
			Circle	100%	87%	0%
		Positive	Triangular	100%	87%	20%
			Circle	100%	67%	0%
	Red	Negative	Triangular	100%	100%	20%
			Circle	100%	67%	7%
		Positive	Triangular	100%	100%	33%
			Circle	100%	60%	0%
	Yellow	Negative	Triangular	93%	87%	0%
			Circle	100%	27%	0%
		Positive	Triangular	100%	100%	27%
			Circle	100%	53%	0%
Caution for Slip	Blue	Negative	Triangular	100%	93%	20%
			Circle	100%	80%	7%
		Positive	Triangular	100%	67%	20%
			Circle	93%	40%	0%
	Green	Negative	Triangular	100%	87%	20%
			Circle	100%	47%	0%
		Positive	Triangular	100%	93%	7%
			Circle	93%	47%	0%
	Red	Negative	Triangular	100%	93%	7%
			Circle	100%	53%	7%
		Positive	Triangular	100%	80%	13%
			Circle	100%	40%	0%
	Yellow	Negative	Triangular	67%	33%	0%
			Circle	93%	33%	0%
		Positive	Triangular	100%	93%	7%
			Circle	100%	47%	0%

STOP	Blue	Negative	Triangular	100%	100%	40%
			Circle	100%	100%	20%
		Positive	Triangular	100%	100%	33%
			Circle	100%	87%	0%
	Green	Negative	Triangular	100%	100%	33%
			Circle	100%	93%	27%
		Positive	Triangular	100%	100%	27%
			Circle	100%	67%	0%
	Red	Negative	Triangular	100%	100%	60%
			Circle	100%	93%	20%
		Positive	Triangular	100%	100%	73%
			Circle	100%	87%	7%
	Yellow	Negative	Triangular	100%	93%	40%
			Circle	100%	60%	0%
		Positive	Triangular	100%	100%	20%
			Circle	100%	67%	0%
SOS	Blue	Negative	Triangular	100%	93%	67%
			Circle	100%	87%	7%
		Positive	Triangular	93%	100%	53%
			Circle	100%	93%	7%
	Green	Negative	Triangular	100%	100%	87%
			Circle	100%	93%	13%
		Positive	Triangular	100%	87%	27%
			Circle	100%	100%	0%
	Red	Negative	Triangular	100%	100%	67%
			Circle	100%	93%	13%
		Positive	Triangular	100%	100%	60%
			Circle	100%	93%	0%
	Yellow	Negative	Triangular	100%	100%	27%
			Circle	100%	60%	7%
		Positive	Triangular	100%	100%	53%
			Circle	100%	87%	0%

Table A-7 Accuracy rate of answer on simulated narrow vision.

Kind of sign	Color	Color Portion	Shape	The size of the sample to the eyes. (degrees)		
				5.2	2.6	1.3
Pedestrians & Bicycle only	Blue	Negative	Triangular	100%	100%	100%
			Circle	100%	100%	100%
		Positive	Triangular	100%	93%	100%
			Circle	93%	67%	100%
	Green	Negative	Triangular	100%	100%	100%
			Circle	100%	100%	100%
		Positive	Triangular	100%	100%	100%
			Circle	100%	93%	100%
	Red	Negative	Triangular	100%	100%	100%
			Circle	100%	100%	100%
		Positive	Triangular	100%	100%	67%
			Circle	100%	100%	93%
	Yellow	Negative	Triangular	100%	100%	100%
			Circle	100%	100%	93%
		Positive	Triangular	100%	100%	100%
			Circle	100%	100%	100%
School zone	Blue	Negative	Triangular	100%	100%	67%
			Circle	100%	93%	67%
		Positive	Triangular	100%	100%	100%
			Circle	67%	93%	100%
	Green	Negative	Triangular	100%	93%	100%
			Circle	100%	100%	100%
		Positive	Triangular	100%	100%	100%
			Circle	93%	100%	93%
	Red	Negative	Triangular	100%	100%	100%
			Circle	100%	100%	100%
		Positive	Triangular	100%	100%	100%
			Circle	100%	100%	100%
	Yellow	Negative	Triangular	100%	100%	93%
			Circle	100%	100%	100%
		Positive	Triangular	100%	100%	93%
			Circle	100%	93%	100%

Under Construction	Blue	Negative	Triangular	100%	100%	100%
			Circle	100%	100%	100%
		Positive	Triangular	100%	100%	100%
			Circle	93%	100%	100%
	Green	Negative	Triangular	93%	100%	100%
			Circle	100%	100%	100%
		Positive	Triangular	93%	100%	100%
			Circle	100%	100%	100%
	Red	Negative	Triangular	93%	100%	93%
			Circle	93%	100%	100%
		Positive	Triangular	93%	100%	100%
			Circle	67%	93%	100%
	Yellow	Negative	Triangular	100%	100%	100%
			Circle	93%	100%	100%
		Positive	Triangular	100%	100%	100%
			Circle	100%	100%	93%
Caution for Slip	Blue	Negative	Triangular	93%	100%	100%
			Circle	100%	100%	100%
		Positive	Triangular	100%	100%	100%
			Circle	100%	93%	100%
	Green	Negative	Triangular	93%	100%	100%
			Circle	100%	100%	100%
		Positive	Triangular	100%	87%	100%
			Circle	100%	100%	100%
	Red	Negative	Triangular	93%	100%	100%
			Circle	93%	100%	100%
		Positive	Triangular	100%	100%	100%
			Circle	93%	100%	100%
	Yellow	Negative	Triangular	100%	33%	67%
			Circle	100%	100%	100%
		Positive	Triangular	100%	100%	93%
			Circle	100%	100%	100%

STOP	Blue	Negative	Triangular	93%	100%	93%
			Circle	100%	100%	100%
		Positive	Triangular	100%	100%	100%
			Circle	67%	100%	100%
	Green	Negative	Triangular	100%	100%	100%
			Circle	100%	93%	100%
		Positive	Triangular	93%	100%	93%
			Circle	100%	93%	100%
	Red	Negative	Triangular	93%	100%	100%
			Circle	100%	100%	100%
		Positive	Triangular	100%	100%	100%
			Circle	100%	100%	100%
	Yellow	Negative	Triangular	100%	100%	100%
			Circle	100%	93%	100%
		Positive	Triangular	67%	93%	100%
			Circle	100%	100%	100%
SOS	Blue	Negative	Triangular	93%	100%	93%
			Circle	100%	100%	100%
		Positive	Triangular	67%	100%	100%
			Circle	100%	100%	100%
	Green	Negative	Triangular	100%	100%	100%
			Circle	100%	93%	100%
		Positive	Triangular	93%	100%	93%
			Circle	100%	93%	100%
	Red	Negative	Triangular	93%	100%	100%
			Circle	100%	100%	100%
		Positive	Triangular	100%	100%	100%
			Circle	100%	100%	100%
	Yellow	Negative	Triangular	100%	100%	100%
			Circle	100%	93%	100%
		Positive	Triangular	67%	93%	100%
			Circle	100%	100%	100%

Table A-8 Corrected answering time (average, ms) on simulated blurred vision.

Kind of sign	Color	Color Portion	Shape	The size of the sample to the eyes. (degrees)		
				5.2	2.6	1.3
Pedestrians & Bicycle only	Blue	Negative	Triangular	3606	4937	7058
			Circle	4366	10849	12983
		Positive	Triangular	4177	6102	11933
			Circle	4547	10731	13489
	Green	Negative	Triangular	3669	4530	10754
			Circle	3975	9333	12373
		Positive	Triangular	3896	3571	10287
			Circle	3529	6966	11028
	Red	Negative	Triangular	3446	3940	11657
			Circle	3938	9132	12292
		Positive	Triangular	3992	5646	12374
			Circle	3871	9887	13285
	Yellow	Negative	Triangular	3527	3597	11029
			Circle	3847	9314	13069
		Positive	Triangular	3784	3754	11049
			Circle	3826	10177	12702
School zone	Blue	Negative	Triangular	4057	5694	12251
			Circle	6470	10555	14246
		Positive	Triangular	4296	6688	10491
			Circle	8031	11251	13615
	Green	Negative	Triangular	3687	8055	10420
			Circle	6273	10516	14293
		Positive	Triangular	3947	6598	10213
			Circle	4355	11111	13604
	Red	Negative	Triangular	3847	6090	11236
			Circle	7107	10485	13470
		Positive	Triangular	4008	6305	12143
			Circle	4486	10217	13681
	Yellow	Negative	Triangular	4106	6624	11160
			Circle	4388	10139	12253
		Positive	Triangular	3872	6306	10530
			Circle	6160	11086	13959

Under Construction	Blue	Negative	Triangular	3721	5621	12882
			Circle	4195	9939	14041
		Positive	Triangular	3634	5290	13000
			Circle	4320	9417	13756
	Green	Negative	Triangular	3700	6228	12641
			Circle	4907	8624	13926
		Positive	Triangular	4009	7687	12621
			Circle	3602	9246	13523
	Red	Negative	Triangular	3890	6678	11754
			Circle	7257	10376	13776
		Positive	Triangular	3384	6029	12184
			Circle	6868	9490	13404
	Yellow	Negative	Triangular	3983	7464	12581
			Circle	5236	9563	13457
		Positive	Triangular	3830	6423	12505
			Circle	3602	10951	14084
Caution for Slip	Blue	Negative	Triangular	3578	8024	10222
			Circle	5358	10437	13694
		Positive	Triangular	3420	5967	11547
			Circle	4060	10060	13640
	Green	Negative	Triangular	4197	7214	10833
			Circle	5366	9473	13184
		Positive	Triangular	3705	7152	11569
			Circle	5309	9775	13439
	Red	Negative	Triangular	4065	5758	12493
			Circle	6082	10499	13067
		Positive	Triangular	3577	7615	11171
			Circle	5376	9977	13681
	Yellow	Negative	Triangular	6797	10285	11937
			Circle	4415	10659	13284
		Positive	Triangular	4698	6506	10868
			Circle	5495	11126	12109

STOP	Blue	Negative	Triangular	3513	3517	8729
			Circle	3744	5833	11930
		Positive	Triangular	3404	3569	8304
			Circle	4130	4797	12371
	Green	Negative	Triangular	3800	3483	8837
			Circle	3390	6971	10799
		Positive	Triangular	3359	3180	9242
			Circle	3648	5039	13007
	Red	Negative	Triangular	4296	4253	9056
			Circle	3877	5413	10207
		Positive	Triangular	3616	3615	8350
			Circle	3523	6341	11954
	Yellow	Negative	Triangular	3242	4908	12127
			Circle	3754	8069	12586
		Positive	Triangular	3249	3395	11083
			Circle	3766	8084	12126
SOS	Blue	Negative	Triangular	3635	3875	9535
			Circle	3865	6969	12902
		Positive	Triangular	3385	4039	11600
			Circle	3484	8533	12885
	Green	Negative	Triangular	3306	4387	11023
			Circle	3697	8465	14128
		Positive	Triangular	4399	3540	10288
			Circle	3635	7435	13368
	Red	Negative	Triangular	3989	4112	9742
			Circle	4279	7603	13765
		Positive	Triangular	3593	4288	9677
			Circle	3806	7778	13055
	Yellow	Negative	Triangular	3467	4475	11670
			Circle	3705	9116	10804
		Positive	Triangular	3662	4395	11082
			Circle	3666	8004	13465

Table A-9 Corrected answering time (average, ms) on simulated occlusion vision.

Kind of sign	Color	Color Portion	Shape	The size of the sample to the eyes. (degrees)		
				5.2	2.6	1.3
Pedestrians & Bicycle only	Blue	Negative	Triangular	4283	4215	8207
			Circle	4151	5433	14134
		Positive	Triangular	3800	4534	11865
			Circle	4282	10208	13988
	Green	Negative	Triangular	4073	4046	12164
			Circle	4414	8525	13258
		Positive	Triangular	3846	4487	12102
			Circle	4192	7965	10843
	Red	Negative	Triangular	3947	5171	10043
			Circle	4351	5457	13192
		Positive	Triangular	4267	4320	10827
			Circle	4357	10534	14419
	Yellow	Negative	Triangular	4004	4405	13666
			Circle	4545	10605	13772
		Positive	Triangular	4020	3739	9662
			Circle	4265	8995	13915
School zone	Blue	Negative	Triangular	4192	4060	12616
			Circle	3899	12222	13919
		Positive	Triangular	3629	4420	12571
			Circle	6930	14095	14822
	Green	Negative	Triangular	3657	4792	13316
			Circle	4161	11246	14364
		Positive	Triangular	3969	4158	13222
			Circle	4139	11893	14100
	Red	Negative	Triangular	3843	4297	11270
			Circle	3581	9738	14322
		Positive	Triangular	4111	4690	12297
			Circle	4396	12339	13956
	Yellow	Negative	Triangular	3805	6034	14054
			Circle	3969	13429	14456
		Positive	Triangular	3891	4217	13075
			Circle	5218	13307	14334

Under Construction	Blue	Negative	Triangular	3723	4218	10849
			Circle	3722	7309	13761
		Positive	Triangular	3994	4510	13094
			Circle	4366	8797	14292
	Green	Negative	Triangular	4081	4374	13762
			Circle	3517	6028	14105
		Positive	Triangular	3803	5919	12170
			Circle	4406	7277	13641
	Red	Negative	Triangular	4191	4229	12453
			Circle	4307	7467	13121
		Positive	Triangular	3724	4204	11253
			Circle	7140	8466	13688
	Yellow	Negative	Triangular	4516	5371	14136
			Circle	4309	11144	14027
		Positive	Triangular	3714	5150	11730
			Circle	3739	8974	14030
Caution for Slip	Blue	Negative	Triangular	3696	4904	12766
			Circle	3933	6659	13511
		Positive	Triangular	3583	7313	12139
			Circle	4667	10091	13649
	Green	Negative	Triangular	3681	5284	12163
			Circle	4089	9237	14065
		Positive	Triangular	3876	4623	13702
			Circle	4405	9570	13939
	Red	Negative	Triangular	4059	4892	13260
			Circle	3740	8922	13279
		Positive	Triangular	4086	6000	12867
			Circle	4194	10313	14227
	Yellow	Negative	Triangular	6931	10408	14169
			Circle	4628	11078	13875
		Positive	Triangular	3841	4450	13086
			Circle	4770	9740	13806

STOP	Blue	Negative	Triangular	3449	3658	10186
			Circle	3783	3873	11927
		Positive	Triangular	3706	3879	11641
			Circle	4089	5542	13863
	Green	Negative	Triangular	3671	3813	11354
			Circle	3685	4697	11273
		Positive	Triangular	3892	3984	11746
			Circle	4185	7480	14148
	Red	Negative	Triangular	3542	4220	8343
			Circle	4018	5111	12301
		Positive	Triangular	3744	4165	6924
			Circle	4340	5540	13053
	Yellow	Negative	Triangular	4050	5035	13101
			Circle	3622	9008	14674
		Positive	Triangular	2978	3609	12664
			Circle	3794	7954	14288
SOS	Blue	Negative	Triangular	3967	4621	7775
			Circle	3848	5458	13363
		Positive	Triangular	4707	4569	8748
			Circle	3696	5117	13415
	Green	Negative	Triangular	4078	4181	5753
			Circle	3736	4527	12788
		Positive	Triangular	4130	5675	12000
			Circle	3872	4296	13905
	Red	Negative	Triangular	3625	4479	8291
			Circle	3797	4927	12786
		Positive	Triangular	3579	4574	8664
			Circle	3737	5334	13960
	Yellow	Negative	Triangular	3686	4655	11415
			Circle	4073	8215	13255
		Positive	Triangular	3688	4036	9200
			Circle	3703	5361	13799

Table A-10 Corrected answering time (average, ms) on simulated narrow vision.

Kind of sign	Color	Color Portion	Shape	The size of the sample to the eyes. (degrees)		
				5.2	2.6	1.3
Pedestrians & Bicycle only	Blue	Negative	Triangular	3682	3805	4092
			Circle	4175	3820	4285
		Positive	Triangular	3634	4584	4027
			Circle	5014	7580	4109
	Green	Negative	Triangular	3897	3951	4373
			Circle	4062	4579	4370
		Positive	Triangular	3996	3678	3988
			Circle	4145	3791	4084
	Red	Negative	Triangular	3914	4312	7392
			Circle	3983	4022	4788
		Positive	Triangular	3962	3813	3918
			Circle	4044	4235	4161
	Yellow	Negative	Triangular	3699	4150	4009
			Circle	3964	4085	4838
		Positive	Triangular	3814	4113	4004
			Circle	3897	3764	3900
School zone	Blue	Negative	Triangular	3863	3785	7688
			Circle	3915	4435	7737
		Positive	Triangular	3625	3954	4052
			Circle	7310	4787	4237
	Green	Negative	Triangular	3739	4892	4095
			Circle	4068	4016	3872
		Positive	Triangular	3862	3889	4065
			Circle	4357	4241	4879
	Red	Negative	Triangular	3894	4045	3922
			Circle	3989	4107	4388
		Positive	Triangular	3712	3830	4312
			Circle	4172	4035	4033
	Yellow	Negative	Triangular	3891	3894	4626
			Circle	3961	4278	4234
		Positive	Triangular	3976	4029	4595
			Circle	3776	4945	4606

Under Construction	Blue	Negative	Triangular	4164	4068	3912
			Circle	3552	4222	4354
		Positive	Triangular	3951	3818	4217
			Circle	4496	3844	4588
	Green	Negative	Triangular	4625	4150	4181
			Circle	3707	4019	4230
		Positive	Triangular	4331	4197	4237
			Circle	3973	3898	4181
	Red	Negative	Triangular	4668	4047	4895
			Circle	4537	3865	4163
		Positive	Triangular	4480	4339	4276
			Circle	7395	4880	4040
	Yellow	Negative	Triangular	3858	4095	4243
			Circle	4378	4054	4226
		Positive	Triangular	4085	4513	3874
			Circle	4426	4249	5211
Caution for Slip	Blue	Negative	Triangular	4218	4197	3902
			Circle	3764	3807	4423
		Positive	Triangular	4011	4108	3930
			Circle	3706	4681	3741
	Green	Negative	Triangular	3651	3757	4543
			Circle	4018	3749	4274
		Positive	Triangular	3690	4942	4071
			Circle	3764	3806	4210
	Red	Negative	Triangular	3724	3695	4797
			Circle	3673	4088	4930
		Positive	Triangular	3704	3642	3902
			Circle	4277	3996	4876
	Yellow	Negative	Triangular	7213	10596	4144
			Circle	3796	3865	4201
		Positive	Triangular	4365	3984	3770
			Circle	3840	3983	3996

STOP	Blue	Negative	Triangular	4435	3742	4470
			Circle	3464	3710	4118
		Positive	Triangular	3804	3681	3917
			Circle	3819	4119	7164
	Green	Negative	Triangular	4156	3418	4029
			Circle	4416	4732	3874
		Positive	Triangular	4754	3725	4298
			Circle	3828	4291	3798
	Red	Negative	Triangular	3704	3575	4554
			Circle	3487	3796	4194
		Positive	Triangular	3524	3767	3900
			Circle	3836	4037	4086
	Yellow	Negative	Triangular	3560	3670	4074
			Circle	3658	4546	3960
		Positive	Triangular	3451	4225	7057
			Circle	3641	3900	3982
SOS	Blue	Negative	Triangular	3569	3752	4034
			Circle	3795	3815	3899
		Positive	Triangular	3714	3829	3938
			Circle	4025	3932	4629
	Green	Negative	Triangular	3635	3671	3952
			Circle	3666	3755	4062
		Positive	Triangular	4168	3669	4357
			Circle	3786	3950	4247
	Red	Negative	Triangular	4483	4236	3975
			Circle	4345	5095	4391
		Positive	Triangular	3515	5059	3862
			Circle	3784	4252	3998
	Yellow	Negative	Triangular	4341	3971	4660
			Circle	4055	3661	3975
		Positive	Triangular	3487	3776	4118
			Circle	3533	3962	4479

Table A-11 Results of 2-way ANOVA of corrected answering time on simulated blurred vision.

	Df	Sum Sq	Mean Sq	F value	P (>F)
Color	3	61610000	20540000	0.883	0.4489
Shape	1	4860000000	4860000000	209.046	<2.000E-
Color Ratio	2	149600000	74780000	3.217	16***
Kind of Sign	7	3856000000	550900000	23.698	0.0402*
Background	2	1160000000	580200000	24.958	<2.000E-
Kind of Sign * Background	12	204200000	17020000	0.732	16***
Kind of Sign * Color	18	251900000	13990000	0.602	1.69E-11***
Background * Color	6	110600000	18430000	0.793	0.7211
Kind of Sign * Shape	6	168200000	28040000	1.206	0.901
Background * Shape	2	105000000	52500000	2.258	0.5756
Color * Shape	3	57980000	19330000	0.831	0.2997
Kind of Sign * Color Ratio	6	41830000	6971000	0.3	0.1047
Background * Color Ratio	2	9547000	4773000	0.205	0.4764
Color * Color Ratio	3	25630000	8545000	0.368	0.9372
Shape * Color Ratio	1	186200	186200	0.008	0.8144
Kind of Sign * Background * Color	34	305500000	8985000	0.387	0.7764
Kind of Sign * Background * Shape	11	148300000	13480000	0.58	0.9287
Kind of Sign * Color * Shape	16	163200000	10200000	0.439	0.9995
Background * Color * Shape	6	71300000	11880000	0.511	0.8467
Kind of Sign * Background * Color Ratio	12	175400000	14620000	0.629	0.9728
Kind of Sign * Color * Color Ratio	17	186600000	10980000	0.472	0.8003
Background * Color * Color Ratio	6	273900000	45660000	1.964	0.8194
Kind of Sign * Shape * Color Ratio	6	64950000	10820000	0.466	0.9658
Background * Shape * Color Ratio	2	2444000	1222000	0.053	0.0673
Color * Shape * Color Ratio	3	71940000	23980000	1.031	0.8342
Kind of Sign * Background * Color * Shape	30	252600000	8419000	0.362	0.9488
Kind of Sign * Background * Color * Color Ratio	30	150200000	5005000	0.215	0.3774
Kind of Sign * Background * Shape * Color	10	192400000	19240000	0.828	0.9995
Ratio	15	91100000	6073000	0.261	1
Kind of Sign * Color * Shape * Color Ratio	6	74820000	12470000	0.536	0.6019
Background * Color * Shape * Color Ratio	30	279000000	9302000	0.4	0.998
Kind of Sign * Background * Color * Shape *	4012	93270000000	23250000		0.7809
Color Ratio					0.9986
Residuals					

Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”

Table A-12 Results of 2-way ANOVA of corrected answering time on simulated occlusion vision.

	Df	Sum Sq	Mean Sq	F Value	P (>F)
Kind of Sign	7	3782000000	540200000	23.552	<2.000E-16***
Background	2	857500000	428700000	18.691	8.32E-9***
Color	3	462700000	154200000	6.723	0.00016***
Shape	1	4229000000	4229000000	184.38	<2.000E-16***
Color Ratio	2	67870000	33930000	1.479	0.22791
Kind of Sign * Background	12	364700000	30390000	1.325	0.19643
Kind of Sign * Color	18	167400000	9297000	0.405	0.98731
Background * Color	6	81800000	13630000	0.594	0.73516
Kind of Sign * Shape	6	420200000	70030000	3.053	0.00556**
Background * Shape	2	192300000	96130000	4.191	0.0152*
Color * Shape	3	67050000	22350000	0.974	0.40373
Kind of Sign * Color Ratio	6	20000000	3334000	0.145	0.98999
Background * Color Ratio	2	12300000	6150000	0.268	0.76483
Color * Color Ratio	3	535600000	178500000	7.784	3.52E-5***
Shape * Color Ratio	1	107200000	107200000	4.671	0.03073
Kind of Sign * Background * Color	36	405300000	11260000	0.491	0.99548
Kind of Sign * Background * Shape	12	112600000	9386000	0.409	0.96082
Kind of Sign * Color * Shape	18	174700000	9705000	0.423	0.98373
Background * Color * Shape	6	38080000	6347000	0.277	0.94813
Kind of Sign * Background * Color Ratio	12	90340000	7529000	0.328	0.98447
Kind of Sign * Color * Color Ratio	18	210500000	11690000	0.51	0.9553
Background * Color * Color Ratio	6	62240000	10370000	0.452	0.84383
Kind of Sign * Shape * Color Ratio	6	98810000	16470000	0.718	0.63515
Background * Shape * Color Ratio	2	104700000	52360000	2.283	0.10215
Color * Shape * Color Ratio	3	57150000	19050000	0.83	0.47692
Kind of Sign * Background * Color * Shape	32	475000000	14840000	0.647	0.93737
Kind of Sign * Background * Color * Color Ratio	32	327600000	10240000	0.446	0.99703
Kind of Sign * Background * Shape * Color Ratio	11	53220000	4838000	0.211	0.99701
Kind of Sign * Color * Shape * Color Ratio	15	154700000	10320000	0.45	0.9642
Background * Color * Shape * Color Ratio	6	64350000	10720000	0.468	0.83282
Kind of Sign * Background * Color * Shape * Color Ratio	30	370600000	12350000	0.539	0.98117
Residuals	4001	91780000000	22940000		

Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”

Table A-13 Results of 2-way ANOVA of corrected answering time on simulated Narrow vision.

	Df	Sum Sq	Mean Sq	F Value	P (>F)
Kind of Sign	7	203400000	29054869	10.706	1.99E-13***
Background	2	39080000	19540448	7.2	0.000756***
Color	3	23250000	7749691	2.856	0.035773*
Shape	1	4695000	4694651	1.73	0.188505
Color Ratio	2	1044000	522052	0.192	0.825016
Kind of Sign * Background	10	46590000	4659071	1.717	0.071154
Kind of Sign * Color	16	217000000	13561269	4.997	2.22E-10***
Background * Color	6	30400000	5065953	1.867	0.082678
Kind of Sign * Shape	5	53470000	10694659	3.941	0.001446**
Background * Shape	2	2691000	1345618	0.496	0.609106
Color * Shape	3	65260000	21754854	8.016	2.52E-5***
Kind of Sign * Color Ratio	5	50600000	10120909	3.729	0.002271**
Background * Color Ratio	2	7253000	3626477	1.336	0.262944
Color * Color Ratio	3	18550000	6184448	2.279	0.077468
Shape * Color Ratio	1	44210000	44208143	16.29	5.54E-5***
Kind of Sign * Background * Color	30	222400000	7412752	2.731	1.24E-6***
Kind of Sign * Background * Shape	10	94540000	9454020	3.484	0.000139***
Kind of Sign * Color * Shape	15	124300000	8286517	3.053	6.12E-5***
Background * Color * Shape	6	41150000	6858552	2.527	0.019179*
Kind of Sign * Background * Color Ratio	10	91320000	9132211	3.365	0.000221
Kind of Sign * Color * Color Ratio	15	165100000	11003662	4.055	2.1E-7***
Background * Color * Color Ratio	6	61720000	10287384	3.791	0.000907***
Kind of Sign * Shape * Color Ratio	5	24890000	4977859	1.834	0.102698
Background * Shape * Color Ratio	2	8975000	4487699	1.654	0.19149
Color *Shape * Color Ratio	3	27300000	9100204	3.353	0.01816*
Kind of Sign * Background * Color * Shape	30	168000000	5598530	2.063	0.000582
Kind of Sign * Background * Color * Color Ratio	30	314800000	10493673	3.867	7.61E-12***
Kind of Sign * Background * Shape * Color Ratio	10	76250000	7624713	2.81	0.001789**
Kind of Sign * Color * Shape * Color Ratio	15	177700000	11849593	4.366	3.32E-8***
Background * Color * Shape * Color Ratio	6	26650000	4441422	1.637	0.132787
Kind of Sign * Background * Color * Shape * Color	30	229800000	7661600	2.823	4.99E-7***
Ratio	4029	10930000000	2713904		
Residuals					

Signif. Codes: 0.001< “***”, 0.01< “**”, 0.05< “*”

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