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Validation of Game Advantage Disadvantage Control Considering Color Vision Characteristics: A Basic Study on "Among Us" with Different Color Settings

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Abstract

In online games, some people are disadvantaged due to hearing or vision handicaps that have nothing to do with their abilities. People with color vision diversity, who have difficulty seeing certain colors, are at a disadvantage in games that require color judgments because of the time it takes to read color information. To assist people with color vision diversity, some games support them by using color schemes that match their color vision type, but not all color vision types are supported, and there are limitations to the support provided. In our previous studies, we have conducted experiments in which we implemented a D-type simulating filter to clarify easy colors to recognize both for those with normal color vision and those with D-type color vision, and colors that are close in time to recognize for both users. However, we have not clarified whether these experiments are effective in actual games. In this study, we experimented using the game "Among Us" and examined whether it was possible to control the color handicap. Our results showed that it is possible to control the player's advantages and disadvantages in the game, both for those with normal color vision and those with color vision diversity, depending on the color scheme.

Keywords: Color vision diverse; Simulated filter; Game

1. Introduction

The popularity of computer and Internet-based competitive gaming has increased, and such gaming is now recognized as a type of sport known as esports [1]. In addition, the demand for entertainment that could be played at home during the COVID-19 era has further increased the demand for online games [2].

Normal color vision(95%) P-type color vision(1.5%) D-type color vision(3.5%) T-type color vision(0.001%)

Fig. 1. Vision and percentage of people with normal color vision and people with color vision diversity
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Among the wide variety of users who play these online games, there are sometimes handicaps. The term "handicap" refers to the difference between a stronger player and a weaker player and is not limited to differences in knowledge and skill between adults and children, professionals and amateurs, and so on. Physical handicaps such as hearing and vision issues can also put a player at a disadvantage when playing online games competitively. It is difficult for players themselves to improve the physical aspects of the game, such as hearing and vision factors, so it is desirable for those involved in the development of games to make as much effort as possible to solve these problems. We focus on the problem of handicaps in games for players who have color vision that differs from that of players with normal color vision.

People with color vision diversity perceive specific colors, such as red and green, differently than users with normal color vision [3]. Fig. 1 shows an original screenshot of the "Puyo Puyo" [4] game and three simulated screenshots with three types of color vision (P-type, D-type, and T-type). It is easy to understand the difficulty in playing this game experienced by P-type, D-type, and T-type color vision players. When playing a game, players must make decisions as quickly as possible, such as judging friends or foes or the effects of skills, and the color is one of the factors that allows them to acquire information. However, it is not easy for people with color vision diversity to obtain information from colors. As a result, it is not uncommon to see a difference in performance between the gameplay of those with normal color vision and those with color vision diversity. This difference can have a detrimental effect on scores.

In order to minimize this color handicap, an increasing number of game developers have implemented color vision support functions. For example, "Splatoon," [5] a game in which players compete to see which team can paint a level with more ink in three minutes, uses colors to distinguish the ink of the enemy or the ally. In order to improve the discrimination between the colors of enemies and allies, the system provides a function that fixes the colors used in online battles to yellow and blue. This enables people with color vision diversity to play games without encountering color combinations that are difficult for them to see. However, since there are multiple types of color vision, the color vision support in the above example does not provide support for all those with color vision diversity. In addition, the color combinations used in color vision support are often not easy for people with color vision diversity to distinguish.

Based on these problems, we have been investigating whether there are colors that are easier to distinguish for people with D-type color vision than for people with normal color vision in order to eliminate the color handicap experienced by people with color vision diversity who have various characteristics when playing games [6]. As a result, it was found that if the brightness of the color of the object of interest has a higher value than the brightness of the surrounding colors, this makes the color easier to discriminate both for people with normal vision and for those with D-type color vision. However, it has not been verified whether the factors obtained in previous studies can be controlled for advantages or disadvantages in actual games.

In this study, we focused on users with D-type (Deuteranope) color vision and clarify through experiments whether it was possible to control player advantages and disadvantages in games based on color vision characteristics. Specifically, we implemented a system that can simulate color vision types in real-time and conducted repeated experiments using "Among Us" [7], in which participants were divided into two groups: the normal color vision group and the color vision diversity group. In doing so, our aim was to formulate and test three hypotheses (described later in section 4) based on information obtained in previous studies.

2. Related Work

2.1. Research into color vision diversity

The symptoms experienced by people with color vision diversity were first reported by Dalton in 1798 [8], and in 2002, about 5% of males and 0.2% of females in Japan were said to have color vision diversity [9].

The mechanism of the occurrence of the diversity of color vision involves LMS, the three types of cone cells of the human eye, which are photosensitive to the light of a specific range of wavelengths [10]. There are various methods for detecting visual diversity using this characteristic, such as the Standard Pseudoisochromatic Plates (SPP) [11], [12]. With the increasing use of smartphones, the development of color vision tests that can be performed with applications [13] is also underway. However, the colors of the products and displays are also significantly affected by lighting [14], and further validation of the effectiveness of the applications is needed [15].

As described above, the characteristics of the various types of visual diversity are varied and complex. Therefore, in order to eliminate the color handicap in games, it is necessary to fully understand the characteristics of the various patterns of visual diversity and the media that capture the colors and to implement appropriate visual support for each of them.

2.2. Research into color vision simulation

The concept of Color Universal Design (CUD) [16] has been proposed as a barrier-free solution for people with diverse visions. Color Universal Design is a way of thinking that takes into account the diversity in human color vision and uses color schemes that convey correct information to as many people as possible, but it is not popular.

To solve the problem of not knowing how people with diverse vision see colors, there have been many studies of methods for detecting combinations of colors that are difficult to distinguish and of methods for simulating color vision. Nakauchi et al. [17] conducted research using Color Universal Design to detect colors that are difficult to distinguish by people with type P (Protanope) and type D (Deuteranope), which are among the types of color vision diversity, and to automatically correct the colors to those that are easy to distinguish. Brettel et al. [18] proposed a method for simulating the appearance of colors on display for each type of vision. This method is based on the fact that colors appear differently depending on the medium via which they are projected, and since the medium the author wishes to simulate is a display, it is used as a reference.

In this research, the simulation of colors on the display was performed in real-time to improve the color handicap.

2.3. Research into supporting people with diverse vision

Currently, no effective treatment for color vision diversity has been found. However, various studies have been conducted to support people with color vision diversity in their daily lives.

Tanuwidjaja et al. [19] developed a system called Chroma based on the head-mounted display of Google Glass. Chroma is a wearable augmented reality system that can automatically convert colors according to color vision type, thereby promoting understanding of color perception among people with color vision diversity.

Ichikawa et al. [20] proposed a method of changing the color of a webpage for people with diverse visions. This method is based on an algorithm that decomposes the colors on the webpage into hierarchies and changes them based on their positional relationship in the color space. These authors have also proposed a method of color correction using still images [21], which quantifies the degree to which colors are difficult to distinguish for people with diverse vision and can change the color of all pixels.

In this study, we not only support people with color vision diversity themselves but also provide support for them through a system that makes it possible for people with diverse vision and normal vision to understand each other, which may be difficult for people with normal vision.

3. Prototype System

By adapting colors in various games that are more difficult to distinguish for people with normal color vision than for users with color vision diversity, and colors that are easier to distinguish both for those with normal color vision and those with color vision diversity, we believe that it may be possible to eliminate color handicaps (see Fig. 2). For this purpose, it is necessary to investigate which colors are easy to distinguish for each color vision type and whether these color combinations are easy to distinguish in the game both for people with normal color vision and those with color vision diversity. However, the percentage of color vision types such as T-type and P-type is very low, so it is difficult to conduct surveys or experiments on colors with a group of people with each color vision variation. In addition, color discrimination is affected by various conditions and environments, such as whether the colors are adjacent to each other or far apart, how large the areas of color are, whether the background color is white, black, or any other color, the brightness and color of the illumination when viewing colors, and the angle from which the illumination comes.

In this study, we implement a system that can simulate color vision types in real time using an actual game, based on the factors that can be colors that are easily discriminable obtained in our previous study [6], and investigate whether it is possible to control advantage and disadvantage in the game by observing the difference between the conditions with and without a filter using this system.

In order for the system to be complete on a single PC, a sub-display is provided in addition to the main display, and the game is launched on the sub-display. The system constantly captures the sub-display and converts the RGB values of any color on the screen into the RGB values of the color seen by a user with D-type color vision. To implement this D-type simulated filter, the system uses calculations used in previous studies [6], which first convert the RGB values into LMS values, then converts that value into the LMS values of the D-type color vision, and finally convert those values into RGB values (see Fig. 3). Based on the RGB values that have undergone this conversion, the image is displayed on the main display. The user’s mouse and keyboard operations are sent directly to the sub-display to enable game operation.

We implemented the prototype system using Processing. Fig. 4 shows an original screenshot of the game playing and its filtered screenshot after the calculation. The delay time was around 20ms on a Dell PC with Intel Core i7 CPU, 16GB memory, 4GB GPU, and 1920*1080 resolution.

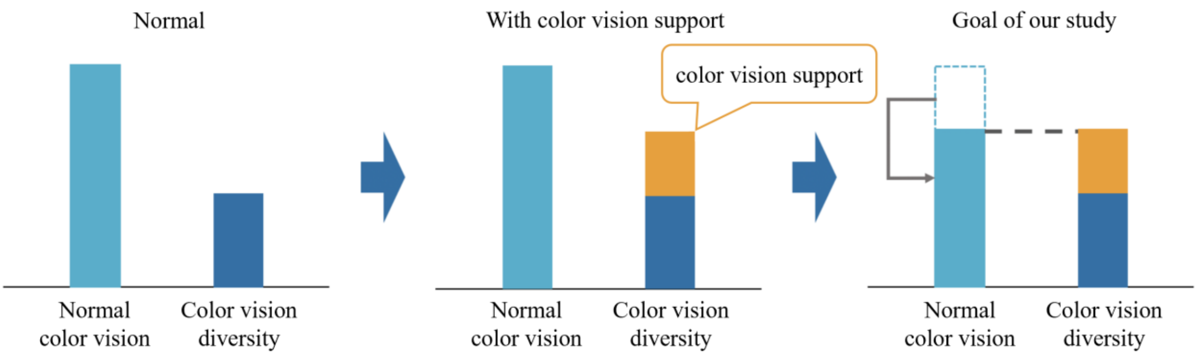

Fig. 2. Goal of our study: Vertical axis represents how smooth they can play the game

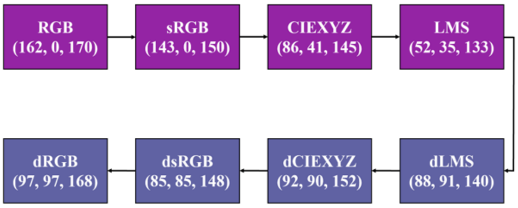

Fig. 3. Color conversion procedure for filters used in experiments

Fig. 4. Normal color vision (above) and D-type color vision (below): The color of the pink player can’t be identified ©2018 Among Us

4. Experiment

4.1. Experiment summary

In the experiment, a game was used to test the color discrimination of users with normal color vision and those with color vision diversity by creating conditions in which they were at an advantage or disadvantage in terms of color. To test various colors, it was necessary to use a certain number of colors, and color discrimination had to be important for the game to progress. In addition, since the delay of our prototype system was 20ms, some delays had to be acceptable.

"Among Us,” [8] a space werewolf game, is a multiplayer game that requires players to identify colors and play mini-games focusing on colors. It is also a game in which color is essential, as it is necessary to know how the players identify the colors in the “discussion” phase. In addition, the game is characterized by the fact that some delay is acceptable. Therefore, we used “Among Us” in this experiment to verify the hypotheses described below while changing the colors and using a real-time color conversion system.

4.2. Among Us

The essential rules of “Among Us” are the same as those of a werewolf game, with the game divided into Crewmates (the villagers’ team) and Imposters (the werewolves’ team). The victory condition for the Crewmates’ team is either “to complete all tasks in the spaceship” or “to discover the Imposters and expel them all.” The Imposters’ victory condition is either to “kill the Crewmates until the number of them becomes equal to the number of Imposters” or to “prevent the Crewmates from escaping.”

Tasks refer to “resolving problems that have occurred in the spaceship.” Many of the tasks are mini-games that can be completed by intuitive operations. Each player is assigned a specific task, and the task assigned to him or her is not revealed to other players. We will focus on the wiring connection task in this experiment; this involves connecting wires from the left side of the screen to the right side so that both ends of the wires are the same color (see Fig. 5 and Fig. 6).

The game has two phases, the “work phase” and the “discussion phase.” The work phase is the turn in which players can move freely around the map, and the discussion phase is the turn in which players gather and discuss via text chat and voice chat and decide by majority vote who to expel. The game always starts in the work phase, in which players walk around the spaceship to perform tasks, kill people, etc., according to their roles.

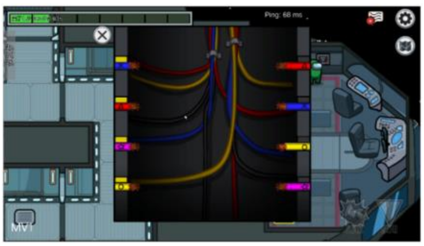

Fig. 5. Wire connection task when started ©2018 Among Us

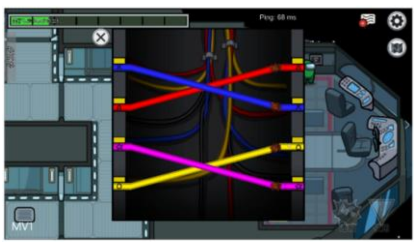

Fig. 6. Wire connection task when finished ©2018 Among Us

4.3. Experimental hypothesis and color selection

It was essential to identify and discuss the color of the characters in “Among Us,” so we formed the following hypotheses and tested them in an experiment.

- Hypothesis 1: Overall, characters of easily identifiable colors will be more conversational in the discussion phase than characters of less identifiable colors.
- Hypothesis 2: Overall, characters of easily identifiable colors, for example white, will have less variation in color representation in the discussion phase than the characters of less identifiable colors.
- Hypothesis 3: In the task focusing on the colors, tasks with less discriminative colors will take longer to complete than tasks with more discriminative colors.

Table 1 shows a correspondence between colors that are considered by the authors easy or difficult to identify for the combinations of character colors (12 colors) used in “Among Us,” based on the results obtained in previous studies [6]. C indicates a color that can be distinguished quickly by users with normal color vision, D indicates a color that can be distinguished quickly by users with D-type color vision, F indicates a color that is easy to distinguish for both, and × indicates a color that is difficult to distinguish for both.

In selecting the colors of the players used in “Among Us,” Table 1 was used as a reference for colors that are easy to identify and difficult to identify corresponding to the hypotheses, with particular attention paid to conditions where the background color was yellow. Table 2 shows the names and HSV of the player colors used in this experiment.

4.4. Experimental procedure

In this method, we used “Among Us,” [8] a space werewolf game, to simulate a game in which users with normal color vision and users with D-type color vision are mixed. In addition, the color of the game was converted to the color vision of users with D-type color vision in real-time and was presented in the experiment. We asked the users with normal color vision to experiment with and without the filter and judged their advantage or disadvantage based on the length of time they spent talking in the discussion or performing the task in the game.

In the experiment, we asked 10 male participants with normal color vision to cooperate. Of the 10, four were assigned to the filtered group using a D-type filter, and the remaining six were assigned to the unfiltered group with normal color vision. The black circles (●) in Table 2 indicate the group with a filter using a D-type filter, and the

Table 1. Color combinations with no difference in time to identify

	Orange	Green	Cyan	Purple	Pink	Red	Maroon	Blue	White	Black	Yellow	Lime
Orange		F	F	F	F	F	F	F	F	F	×	C
Green	F		F	F	F	C	C	F	F	F	F	F
Cyan	F	F		F	F	F	F	F	C	F	F	F
Purple	F	F	F		D	F	F	×	F	F	F	F
Pink	F	F	F	D		F	F	F	C	F	F	F
Red	F	C	F	F	F		C	F	F	F	F	F
Maroon	F	C	F	F	F	C		F	F	C	F	F
Blue	F	F	F	×	F	F	F		F	F	F	F
White	F	F	C	F	C	F	F	F		F	F	F
Black	F	F	F	F	F	F	C	F	F		F	F
Yellow	×	F	F	F	F	F	F	F	F	F		C
Lime	C	F	F	F	F	F	F	F	F	F	C	

C: Normal can identify quickly D: D-type can identify quickly F: both can identify ×: both can’t identify white circles (○) indicate the group using the normal color vision filter. Player colors were randomly assigned without overlap. The game map was the Skeld, with two normal tasks, three long tasks, and four short tasks.

As a precaution in the experiment, we told the participants in advance that the game screen should be set to full screen, that anything running in the background should be stopped as far as possible, and that the player names displayed during play should be set to four hiragana characters. The reason for fixing the players' names to four hiragana characters was to prevent others from recognizing the player by his/her name through the wall, which occurs when the length of the player's name is too long.

The filtered group was asked to run the system before the start of the game and to play the game as usual, using a keyboard and a mouse.

4.5. Experiment result

The experiment was conducted for a total of four games. Afterward, the recorded videos were collected from the participants and analyzed. The plan was to randomly select the participant who would use the D-type filter each time, but due to system specifications and other reasons, it did not work well on some participants' computers, so the experimental participants set up as the filtering group was fixed to some extent.

Table 3 shows the average time taken by the 10 collaborators to complete the wiring connection task as a whole, in the filtered and unfiltered conditions, as well as the number of tasks completed and the number of errors. The average time to complete the task was shorter, at 7.33 seconds, in the filtered condition than the 4.78 seconds taken in the unfiltered condition.

Table 4 shows the colors assigned to the Imposters and whether or not they were filtered. Two Imposters were assigned per game, and the white player was the Imposter in three out of four games. This bias in the Imposters can be attributed to the fact that the same color becomes the Imposter in consecutive games on the same game server. Of all three games in which the white player, which was assigned to different experimental collaborators, was the Imposter, the white player was eliminated in the discussion phase.

Table 5 shows the ratio of the "number of color names spoken" divided by the "total number of conversations" per game. In all games, the number of color-related comments was lower in the games with the filter than in the games without. Overall, 50% of the conversations were related to color. The reason for the lower percentage in the third game may have been that the player who was used to playing "Among Us" and was facilitating the game died, and there was no one left to facilitate the conversation.

Table 2. Colors used in the experiment and their HSV:
○: group with the normal color vision filter
●: group with the D-type color vision filter

	HSV	Round 1	Round 2	Round 3	Round 4
Orange	30, 89, 100	●		○	
Green	135, 87, 50	○		●	
Cyan	177, 73, 100	●	●	○	○
Purple	264, 71, 82	●	○	○	●
Pink	320, 65, 93	○	○	●	
Red	0, 91, 77	○	○	●	●
Maroon	343, 60, 42	○	○	○	●
Blue	231, 91, 82	●	●	○	○
White	202, 9, 100	○	●	○	○
Black	204, 21, 37	○	○	●	○
Yellow	60, 64, 96		●		○
Lime	112, 76, 94		○		●

Table 3. Average time and mistakes of the wire connection task

	Total	With filter	Without filter
average time(s)	5.73	7.33	4.78
mistakes/task	2/64	2/24	0/40

Table 4. Imposter color and filter conditions

	Color of the imposter	With filter
Match 1	Purple	○
	Maroon	
Match 2	Blue	○
	White	○
Match 3	Red	○
	White	
Match 4	Yellow	
	White	

Table 5. Percentage of the number of color names spoken to the total number of conversations

	With filter	Without filter
Match 1	0.519	0.534
Match 2	0.681	0.684
Match 3	0.323	0.433
Match 4	0.617	0.631

5. Discussion

In this study, we aimed to minimize the color handicap in gameplay, and based on the hypothesis described in section 4.1, we conducted an experiment to see if player advantages and disadvantages relating to color could be controlled.

First, we discuss Hypothesis 3: "In the task which focuses on the colors, tasks with less discriminative colors will take longer to complete than tasks with more discriminative colors." The colors used in the wiring connection task in "Among Us" are blue, red, pink, and yellow. These colors are distinguishable to a person with normal color vision, but red, yellow, blue, and pink look the same to a person with D-type color vision (see Fig. 7). In fact, two mistakes were observed out of 24 wiring connection tasks in the filtered condition (see Table 3). Both of these errors were caused by a player mistakenly connecting the red wire to the yellow wire, and the participants did not seem to notice the error. Table 3 also shows that the group with the filter took longer to recognize the colors than the group without the filter. During the discussion, there were comments such as, "The colors in the wiring connection task are too similar, and it takes too much time." Therefore, it was confirmed that the time required to complete the task was longer when colors that were difficult for people with color vision diversity to distinguish were used.

Next, Hypothesis 1: "Overall, characters of easily identifiable colors will be more conversational in the discussion phase than the characters of less identifiable colors," and Hypothesis 2: "Overall, characters of easily identifiable colors will have less variation in color representation in the discussion phase than the characters of less identifiable colors," are discussed with regard to each relevant situation.

The first situation involved a discussion of a situation in which the orange player was found dead, and there were five players, including the orange player, in the vicinity of the body. In this situation, the purple player in the with-filter group stated that the pink player was there, but the maroon player in the without-filter group did not notice the pink player. This suggests that the without-filter group may have a harder time identifying pink in the actual game.

The second situation was a conversation in the graveyard after the death of the orange player. Orange remarked from a ghost's perspective, "Pink looks white," which is influenced by the fact that the screen after death has a clearer field of vision than the screen when the player is alive (see Fig. 8 and Fig. 9). Thus, it can be seen that the difference in the brightness of the visual field is an important factor in recognizing colors.

The third situation was a comment made by the group with the filter in a situation where everyone was alive. From the first to the fourth match, each collaborator mentioned colors that were easy to identify or similar. The group with filter mentioned "pink, cyan and white," "maroon and black," "yellow and lime," "green, red and orange," and "purple and blue" as colors that were difficult to identify. The no-filter group also listed "purple and blue" as colors that were difficult to discriminate between. Based on these statements, we consider that "purple and blue" are colors that are difficult to discriminate between in both conditions, and that this color combination further expands

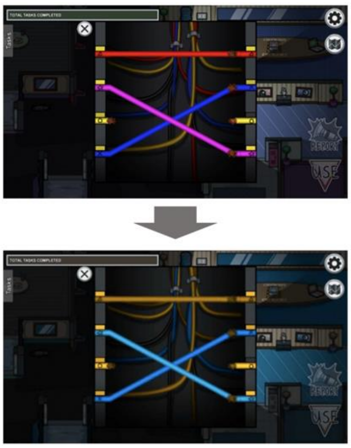

Fig. 7. Normal vision (above) and D-type vision (below) of the wire connection task: The red and yellow wires are hard to distinguish ©2018 Among Us

Fig. 8. Player's view when alive ©2018 Among Us

Fig. 9. Player's view when dead ©2018 Among Us

the color handicap mentioned in the hypotheses discussed in section 4.1. We also consider that the combination of "yellow and lime" is the most difficult combination of colors for players with D-type color vision to distinguish and that this color combination further increases their color handicap. However, in the fourth match, in both conditions, "red" was stated to be no more similar to any other color than any other color. From this, we believe that the color red is a color that can be distinguished both by users with normal color vision and users with color vision diversity, and this is a factor that enables us to achieve the objective of this study. However, in the first and third matches where green was used, there were many comments that "red and green are almost the same," which means that some colors may be difficult to distinguish, depending on the color used.

The fourth situation was a debate in which the blue Imposter (group with filter) was defending the white Imposter (group with filter). When white made a kill on the left side of the map when he/she was the only player on the left side, blue said in defense, "I think I saw white on the right side," during the discussion. However, cyan (group with filter) and red (group without filter) strongly disagreed with this statement, saying that white was definitely not there. In other words, white is a color that can be confidently identified in both conditions, with no color being difficult to distinguish. When cyan and red were asked to reflect again after the game in which this discussion took place, they responded, "I was not sure what color it was, but I could say with absolute confidence that I did not see white." Therefore, white is considered to be easy to distinguish both for users with normal color vision and users with color vision diversity. However, many respondents said that black was difficult to distinguish from maroon, which is a result that contradicts the hypothesis.

These results indicate that, depending on the color scheme, it is possible to control player advantages and disadvantages in the game both for players with normal color vision and those with color vision diversity.

6. Summary

In this study, we aimed to eliminate the color handicap that people with color vision diversity feel when playing games. Based on the hypothesis that "overall, characters of easily identifiable colors will be more conversational in the discussion phase than the characters of less identifiable colors," "overall, characters of easily identifiable colors will have less variation in color representation in the discussion phase than the characters of less identifiable colors" and "in the task which focuses on the colors, tasks with less discriminative colors will take longer to complete than tasks with more discriminative colors," we conducted an experiment using "Among Us" and examined whether control of color handicap was possible.

The results of the experiment showed that "in the color-focused task, the task with the hard-to-identify color took longer to complete than the task with the easy-to-identify color," indicating that both normal color vision and color-variant players were at an advantage or disadvantage in the game depending on the color scheme. On the other hand, the hypotheses that "overall, characters of easily identifiable colors will be more conversational in the discussion phase than the characters of less identifiable colors" and "overall, characters of easily identifiable colors will have less variation in color representation in the discussion phase than the characters of less identifiable colors" were only partially confirmed. In "Among Us," which was used in this experiment, memory is important for recognizing colors and player names while one person performs a given task and talks about one's actions during a discussion. Therefore, although players can discern the color of a player who has just passed them, how long they can remember varies from person to person. It is also possible that factors other than color discrimination may have influenced the results of this experiment.

In this study, we tested the hypothesis that player advantages and disadvantages relating to whether a player has normal color vision or D-type color vision could be controlled using "Among Us." However, this experiment was insufficient to test the hypothesis. The first reason is the bias of the Imposter players. To solve this problem, we intend in the future to change each game's server to eliminate bias. Secondly, the number of times the test was conducted was insufficient for statistical verification. Because we did not cover all patterns in this experiment, we were only able to show in our results the average time to complete the wiring connection task, and we were unable to compare the results using a numerical index such as a score. In the future, in order to measure whether it is possible to statistically control player advantage or disadvantage, we plan to compare the results using a ranking game in which scores can be compared with those of other players without the influence of the opponents' operations.

As a future prospect, we will conduct similar experiments with games such as puzzle games, which are highly competitive and require quick reaction, and further examine colors that are easy to distinguish in both players. In addition, the color vision support for Splatoon described in Chapter 1 does not necessarily mean that the color used can be easily seen by color-variant users. Therefore, we aim to make our method widely available so that appropriate color combinations can be easily used in various games. Specifically, based on our previous research and the findings of this study, we aim to develop a detailed method to control the advantage and disadvantages players experience because of color handicaps, to provide guidelines for game production, and to educate users about normal color vision about the differences in the color vision of color-variant people.

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