Original Article

Contribution of luminance to the perceptual "Clarity/Cloudiness" in transparency for achromatic stimuli

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Abstract

Tsirlin et al. (2012) refer to perceptual transparency with clarity as glass-transparency, and that with cloudiness as translucency. The present study involving overlapping achromatic figures examined how glass-transparency and translucency are influenced by overlapping and non-overlapping areas on transparent surfaces and the level of luminance of the background. Experiments were conducted with three different backgrounds (white, black, and light gray) and varying levels of luminance in overlapping (Experiment 1) and non-overlapping (Experiment 2) areas. The subjects were asked about the clarity and cloudiness of the stimuli, and chose from response options including "very clear" and "very cloudy". The results suggested that the larger the difference in the level of luminance between overlapping and non-overlapping areas, and the smaller the difference in luminance between non-overlapping area and the background, the less the "cloudiness", or the greater the "clarity". The results were uniformly explained according to the ratio of differences in the level of luminance between two areas and the level of luminance of the background.

Key words
achromatic perceptual transparency, clarity, cloudiness, ratio of luminance differences, background luminance

1. Introduction

Research on perceptual transparency, discovered by Fuchs, has been conducted by Metelli (1974) in the 1970s and other researchers from the viewpoint of physical optical factors, including reflectance and transmission. However, recent studies have suggested that the visual characteristics of perceptual transparency cannot be thoroughly explained solely by physical optical factors. As a representative example, D'Zmura (1997) showed that if the colors of multiple patches in specific areas in equiluminant Mondrian figures are converged in color space, perceptual transparency is accomplished. Perceptual transparency cannot be explained from the viewpoint of physical optics when the levels of luminance inside and outside an area are equal, and this suggests that it is necessary to discuss perceptual transparency from the standpoint of human visual information processing. In this context, studies to analyze perceptual transparency based on its relation to lightness (Anderson, 1997; Kingdom, 2011) and establish theories of perceptual transparency from a perceptual viewpoint (Sign and Anderson, 2002a) have been conducted.

Furthermore, a recent study conducted by Tsirlin et al. (2012) has suggested that perceptual transparency is classified into the following three types: glass-transparency, translucency, and pseudo-transparency. Whereas clear and transparent materials, such as glass, have glass-transparency, frosted glass and other materials that diffuse light have translucency; opaque and lace-like materials, such as wire mesh, have pseudo-transparency. Although Tsirlin et al. (2012) paid attention to pseudo-transparency, most previous studies on perceptual transparency, including one conducted by Metelli (1974) focused on translucency. D'Zmura (2001) used the term "cloudy" to describe the stimuli in his research on the perceptual transparency of equiluminant chromatic patterns. Kingdom (2011) suggested that materials with surface-reflection characteristics similar to those of opaque glass and oil-proof paper give a milky impression, and Sign and Anderson (2002b) analyzed perceptual transparency related to "translucent surfaces".

Most previous studies focused on translucency, and research on glass-transparency using systematic approaches has not been conducted, except for those reported by Kawai (2001), Kawai and Akita (2003), and Kawai and Ohtani (2014). The relationship between glass-transparency and translucency has also not been clarified.

The present study aimed to identify stimulus factors contributing glass-transparency, and examined the relationship between glass-transparency and translucency. In experiments on achromatic perceptual transparency, stimuli and backgrounds with different levels of luminance were used to examine their influences on glass-transparency and translucency. The experiments aimed to identify indices that can be used to uniformly describe glass-transparency and translucency in relation to achromatic perceptual transparency.

2. Methods

2.1 Stimulus and rating scale

Stimulus patterns were created using an image generation system (VSG 2/5, Cambridge Research Systems), and presented on an LCD (TOTOKU, CV730X, a resolution of 1,024 × 768 pixels, a refresh rate of 60 Hz). As shown in Figure 1, the

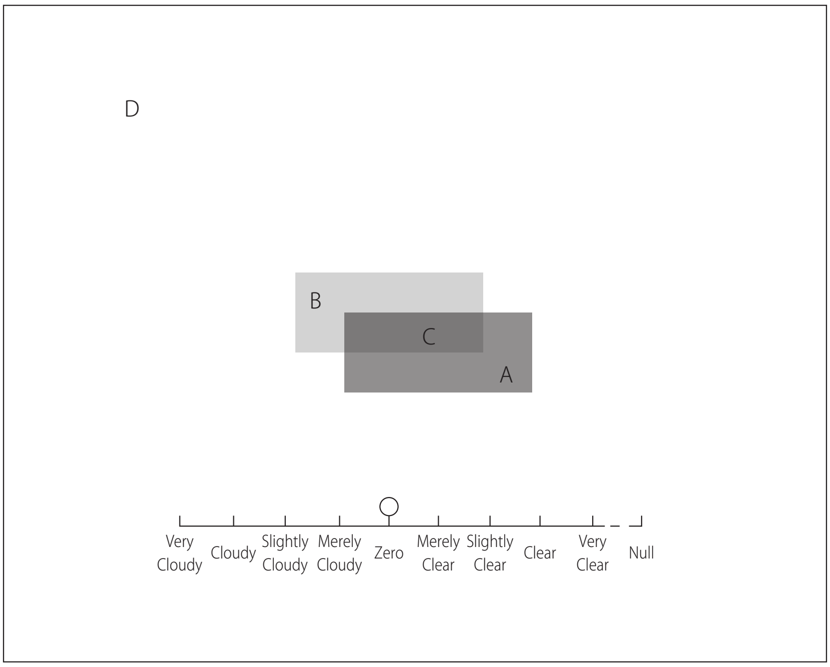

Figure 1: Stimulus configuration and the rating scale in Experiment 1

stimulus pattern presented in the center of the screen is achromatic and consists of three areas (A, B, and C) and a background (D). The test area was A + C. The posterior area was B + C and the size was 3.8 deg. (w) × 1.5 deg. (h).

The size of the overlapping area C was 2.8 deg. (w) × 0.7 deg. (h). White (x = 0.308, y = 0.349, 130 cd/m^2), black (0.4 cd/m^2), and light gray (x = 0.310, y = 0.357, 50 cd/m^2) were used for the background, or area D. In Experiment 1, the level of luminance in areas A and B was invariable, whereas the level in the overlapping area, or area C, was variable. In Experiment 2, the level of luminance in areas B and C was invariable, and the level in area A, a non-overlapping area, was variable.

A scale to rate "clarity/cloudiness" is presented below the stimulus pattern. The scale consists of nine grades (very clear, clear, slightly clear, faintly clear, neutral, faintly cloudy, slightly cloudy, cloudy, and very cloudy), and each of them consists of four subgrades. Collected data were converted into points between +4 (very clear) and –4 (very cloudy) for rating on the scale consisting of a total of 33 grades. Remarks on the stimulus screen were written in English due to restrictions in the experimental system. "Null" at the right end of the scale was selected when no perceptual transparency had been identified in the test area "A + C".

2.2 Procedures and rating criteria

The subjects were instructed to confirm that the test area "A + C" appears over other areas, and answer the questions of the scale for the "rating of the clarity or cloudiness of test areas" using the buttons. Prior to each block of the experiment, the stimulus pattern (reference stimulus) that had been assumed to be the clearest in the block by the experimenter was presented. Following this, a preliminary observation was conducted in which the subjects viewed a series of stimuli starting from the reference stimulus and responded to the questions of the rating scale about the levels of their "clarity/cloudiness". The reference stimulus prepared by the experimenter was determined to be the clearest by the subjects under most of the experimental conditions (the exceptions will be discussed later). In the experiment, the level of luminance in area C or A was randomly changed between trials. Prior to conducting a new trial during the experiment, the background was presented for 7 to 20 seconds to prevent afterimages. The subjects were asked to place their chin on a stand during observation, and the viewing distance was 110 cm. The number of the subjects (including the author) was four. The subjects other than the author participated in a psychological experiment for the first time, and were not informed of the objective of the experiment. After providing the subjects with an explanation of the experiment and obtaining written consent from them, the experiment, including its procedures, was conducted with the approval of the Kyoto Institute of Technology Ethics Committee for Scientific Research Involving Human Subjects.

3. Experiment 1: Effects of the luminance of the overlapping area C and the background

The "clarity/cloudiness" of test area "A + C" was examined under the following condition: the luminance of non-overlapping area A in test area "A + C" (L_A) = 30 cd/m^2, the luminance of posterior area B (L_B) =70 cd/m^2, the luminance of the overlapping area C (L_C) variable between 0.4 and 130 cd/m^2 (Grades 11 and 12 depending on the luminance condition for the background). Although the reference stimulus with a white background for three subjects was L_C = 0.4 cd/m^2, the reference for only one subject (S3) was set at L_C = 8.6 cd/m^2 to achieve perceptual transparency. In each block of the experiment, trials for each subject were conducted twice under a single condition for the luminance of the background. Trials were conducted in two or three blocks under each condition for the luminance of the background.

3.1 Results

Four subjects rated the clarity-cloudiness (C-C) of the overlapping area C with white (a), black (b), and light gray (c) backgrounds, and the scores are presented as the functions of the L_C in Figure 2. The scores represent the means of four to six trials, and the S.D. of the error bars is ± 1. The absence of data plotted in part of the area with an L_C between 0.4 and 130 cd/m^2 shows that perceptual transparency was not achieved in the area "A + C" in one or more trials, e.g., "opaqueness in the area 'A + C' when the L_A = L_C", "A, B, C areas perceptually separated from each other and no perceptual transparency in the area 'A + C'", and "the area 'B + C' was perceived as being on top of, rather than below, other areas".

The mean C-C score provided by the four subjects when the background was white (a) and the L_C was the lowest was +3 ("clear"). The higher the L_C, the lower the C-C score, and perceptual transparency was not achieved when the L_C = L_A (30 cd/m^2). When the L_C was higher than the L_A, perceptual transparency was achieved; when the difference was insignificant, the mean C-C score provided by three subjects was −3.5 to −1 points (Very cloudy ~ Slightly cloudy), and one subject (S3) gave −1 to −2 points. When the L_C was significantly higher than the L_A, the three subjects rated that the area was less cloudy (the C-C score was closer to "0").

When the background was black (b), no perceptual transparency was achieved in areas in which the L_C was lower than the L_A. When the L_C was higher than the L_A, the C-C score was −3.8 ("very cloudy") or lower; the score increased as the L_C became higher. When the L_C was almost equal to the L_B, perceptual transparency was not achieved. However, when the L_C was higher than the L_B, the C-C score increased to +3.0 ("clear").

When the background was light gray (c), perceptual transparency was achieved only if the L_C was higher than the L_A and lower than the L_B (70 cd/m^2). As the L_C increased, the C – C score rose to −2.3 ("slightly cloudy") through to +2.5 to 3 ("slightly clear" ~ "Clear").

According to a report on the clarity/cloudiness under stimulus conditions with a high C-C score, when the background was white and the L_C was lower than the L_A, the test area was clear but slightly blackish like the color of a neutral density filter. When the background was black and the L_C was higher than the L_A, the test area appeared to be lit from behind. When the background was light gray and the L_C was higher than the L_A and close to the L_B, the test area was grayish and its clarity was high.

4. Experiment 2: Effects of the luminance of the non-overlapping area A and the background

The results of Experiment 1 suggested that the luminance of the overlapping area C had a significant influence on "clarity/cloudiness", and that the effect varied depending on the luminance of the background. In Experiment 2, the "clarity/cloudiness" of the "non- overlapping area A", part of the test area "A + C" and adjacent to background area D, with varying levels of luminance was examined.

4.1 Procedures

The same stimulus pattern as used in Experiment 1 was adopted, and the L_A was variable between 0.4 and 130 cd/m^2 (11 grades). L_Cs for Experiments were determined based on the L_Cs that had provided the highest level of clarity for each subject: (white background: L_C = 0.4 cd/m^2 for three subjects

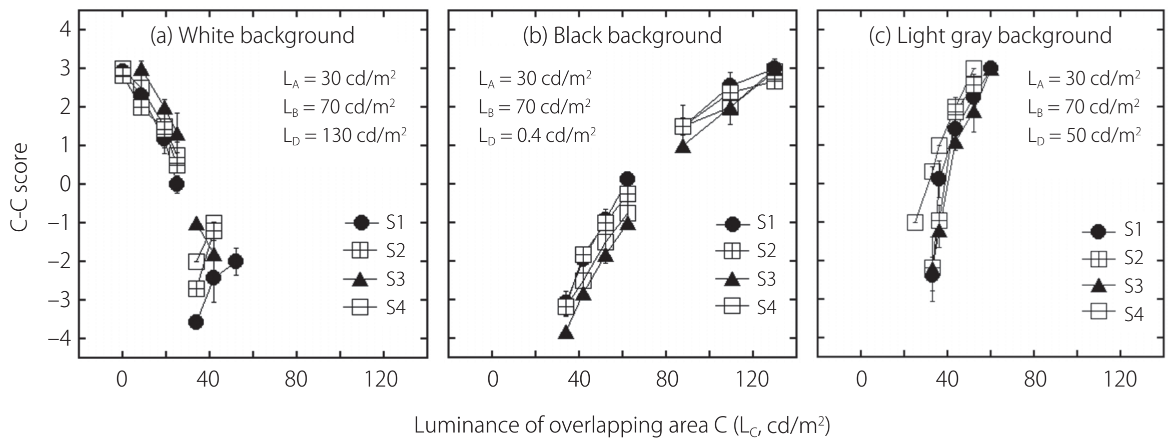

Figure 2: Experiment 1: The effects of the luminance of the overlapping area C on C-C scores

and L_C = 8.6 cd/m^2 for one), (black background: L_C = 130 cd/m^2 for four subjects), and (light gray background: L_C = 51.8 and 60 cd/m^2 for two subjects each). Other procedures were the same as those adopted in Experiment 1.

4.2 Results

Four subjects rated the clarity-cloudiness (C-C) with varying backgrounds, and the scores are presented as the functions of the L_A in Figure 3. The scores represent the means of four to six trials, and the S.D. of the error bars is ±1.

When the background was white (a) and the L_A was the lowest, the C-C score was –3.2. As the L_A increased, the score constantly increased to +3.7. Whereas the test area provided perceptual transparency for three subjects in all measurement areas except when the L_A was equal to the L_D (130 cd/m^2), perceptual transparency for one subject (S3) was provided only when the L_A was between 10.5 and 50.7 cd/m^2.

When the background was black (b) and the L_A was the lowest, the C-C score was +4.0. As the L_A increased, the score constantly decreased to –3.5. The test area provided perceptual transparency for all four subjects in all measurement areas except when the L_A was equal to the L_D (0.4 cd/m^2).

When the background was gray (c), perceptual transparency was only provided in a narrow range of L_A (30 to 44.5 cd/m^2), and changes in the C-C score (–1.0 to +2.5) were smaller than those under other background conditions. In addition, there were differences in the pattern of changes in the C-C score according to the increase of the L_A among individual subjects; as the L_A increased, the C-C score given by two of the four subjects (S1 and S2) sharply increased and then decreased, one subject (S3) constantly increased, and the other one subject (S4) constantly decreased.

As suggested by a report on stimulus conditions with a high C-C score, when the background was white and the L_A was higher than the L_C or similar to the L_D of the background, the test areas provided an appearance of neutral density filters with a high transmittance rate or cellophane. When the background was black and the L_A was lower than the L_C (130 cd/m^2) or similar to the L_D of the background (0.4 cd/m^2), the test areas appeared to be dimly lighted and clear. When the background was light gray, the maximum C-C score was approximately +2.5, and the test areas did not provide high clarity.

5. Discussion

5.1 Effects of differences in the luminance of areas A and C, and D and A

In the present study, involving overlapping achromatic figures, an experiment (Experiment 1) was conducted to examine changes in the "clarity/cloudiness" of test areas, depending on the luminance of overlapping areas and the background. In Experiment 2, the "clarity and cloudiness" of test areas with varying levels of luminance in non-overlapping areas, or different backgrounds, were examined. The results suggested that the luminance of two areas (overlapping and non-overlapping areas) included in a transparent area significantly influenced the "clarity/cloudiness" in perceptual transparency. The results also suggested that the effects varied depending on the luminance of the background. The present paper discusses the development of frameworks to uniformly describe and understand the effects in those areas.

The results of one subject, S3, were excluded from the analyses (replotting the results of Experiment 2 as the functions of differences between the L_A and L_C) for the following reasons: when the background was white in Experiment 1, the C-C score given by S3 decreased and the scores given by the other three subjects increased in the area in which the L_C was higher the L_A; the L_C (determined based on the results of Experiment 1) of S3 (8.6 cd/m^2) was significantly different from those of the other three subjects.

According to the results of Experiments 1 and 2, it is clear that $|L_A - L_C|$, the difference in the luminance between non-overlapping and overlapping areas, was the primary factor determining the "clarity/cloudiness". Figures 4 (a) and (b) pres-

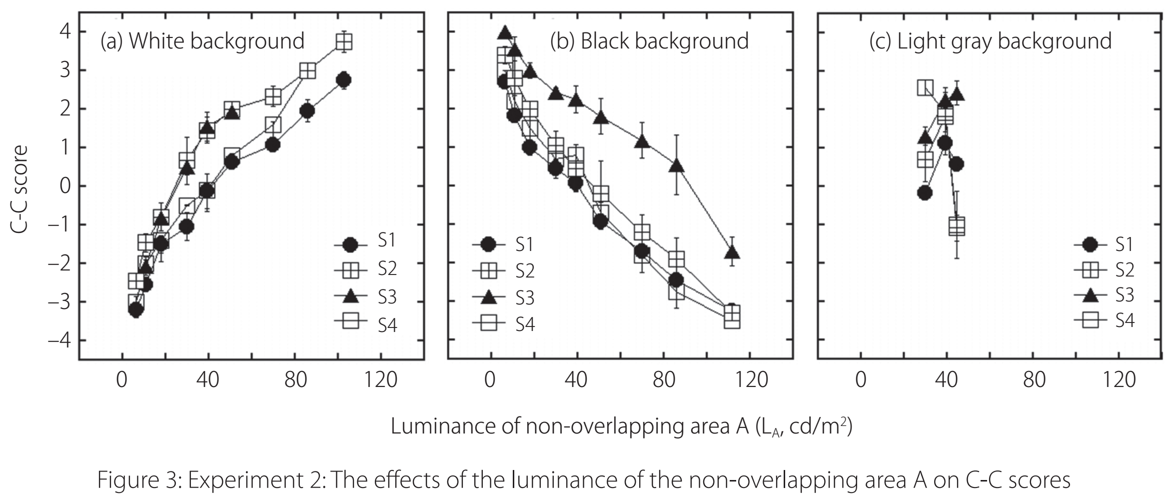

Figure 3: Experiment 2: The effects of the luminance of the non-overlapping area A on C-C scores

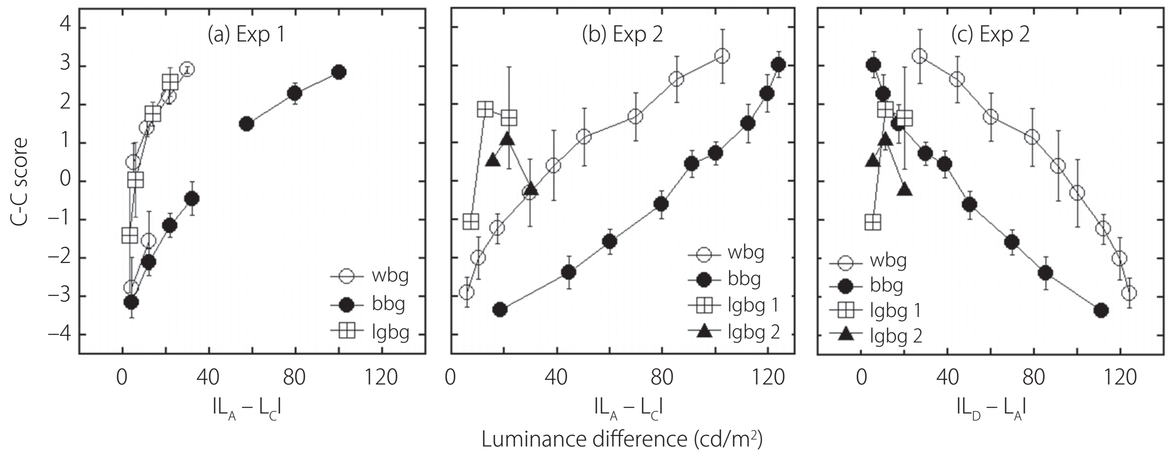

Figure 4: Differences in the luminance of areas that provide perceptual transparency and C-C scores (wbg: white background, bbg: black background, lgbg: light gray background, lgbg 1: $L_C = 51.8 cd/m^2$, lgbg 2: $L_C = 60\ cd/m^2$)

ent the results of the two experiments as the functions of $|L_A - L_C|$. The plots express the means of the three subjects, and the S.D. of the error bars is ±1. As suggested by these two panels, the C-C score increased with an increase of $|L_A - L_C|$ except when the background was light gray in Experiment 2.

Another possible factor was $|L_D - L_A|$: the difference in the luminance of the non-overlapping area A (L_A) and the background area D (L_D) adjacent to A. In Experiment 1 in which the L_A was invariable, there were no differences in $|L_D - L_A|$ under varying background conditions. On the other hand, in Experiment 2 in which the L_A was variable, there were differences in both $|L_A - L_C|$ and $|L_D - L_A|$. The results of Experiment 2 were plotted as the functions of $|L_D - L_A|$, as presented in Figure 4 (c), and the C-C score was expressed as the monotonically decreasing function of $|L_D - L_A|$ except when the background was light gray. An observation report also provided foundation for $|L_D - L_A|$ being a primary factor. As presented in 4.2, area A presented "an appearance of neutral density filters with a high transmittance rate or cellophane" when the background was white and the L_D was similar to the L_A in Experiment 2, and the area was dimly lighted but clear when the background was black. Under all background conditions, the clarity of the area "A + C" was significantly high.

These results suggested that the larger the difference $|L_A - L_C|$, or the smaller the $|L_D - L_A|$, the greater the C – C score. The simplest index to represent these characteristics is the ratio of differences in the luminance: $|L_A - L_C| / |L_D - L_A|$. Figure 5 presents the results of the two experiments replotted as the functions of the ratio of differences in the luminance. In Experiment 2, when the background was light gray, two types of stimulus were used (Figures 4(b), (c): lgbg 1, lgbg 2) and different results were obtained depending on the subject. Since it was inappropriate to determine the means, the data were not plotted in the above-mentioned figure, and excluded from the following analyses:

5.2 Analyses of C-C scores according to the ratio of differences in the luminance

As presented in Figure 5 with the horizontal axis to express the ratio of differences in the luminance logarithmically, the increase in the C-C score was correlated with the increase in the ratio when the background was white or black in Experiment 1 or 2 and light gray in Experiment 1. The figure suggests that there were no systemic changes in the increase rate of C-C scores under varying background conditions. On the other hand, the position on the horizontal axis was rightmost when the background was white, followed by light gray and black.

To examine these characteristics quantitatively, the data obtained from trials conducted under different conditions

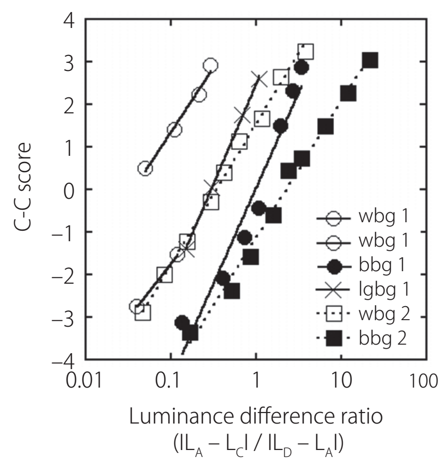

Figure 5. Relationship between C-C scores and the ratio of differences in the luminance of two areas, and the effects of the luminance of the background

Note: The numbers represent experimental numbers.

were approximated using the following formula (1):

$$C - C \text{ score} = \alpha * \log (x / \beta) \quad (1)$$

In this formula, x, α, and β represent the ratio of differences in the luminance ($|L_A - L_C| / |L_D - L_A|$), the slope of the function, and the parameter of the horizontal shift, respectively.

Since data were plotted at two points when the background was white and the L_C was higher than the L_A in Experiment 1, α, and β were directly calculated based on the two coordinates. Other data were considered to be appropriately approximated using Formula (1) because their determination coefficients were higher than 0.94.

As presented in Figures 6 (a) and (b), the values of α and β obtained from all experimental conditions (including the white background and $L_C > L_A$ in Experiment 1) were plotted as the functions of the background luminance L_D. The results suggested that whereas α was not significantly dependent on the luminance of the background, β decreased as the luminance of the background increased. α and β were approximated by logarithmic functions ($k_1 \log L_D + k_2$; k_1 and k_2 were parameters) to verify this point. $k_1 = -0.249$ and $R^2 = 0.136$ for α, and $k_1 = -0.539$ and $R^2 = 0.709$ for β, which confirmed the above-mentioned results. β values for different backgrounds were estimated using the logarithmic functions described above, and the data in Figure 5 were horizontally shifted using the estimated β values, as presented in Figure 7. According to the results, when the ratio of difference in the luminance was high in Experiment 1 (Experiment 1: four points when the background was white (○), three points when the background was black (●), two points when the background was light gray (×)), the C-C score was higher (the data points were higher). Under other conditions, the results were consistent as suggested by the horizontal shift depending on the background luminance L_D. All data were approximated by the logarithmic function, and the determination coefficient was $R^2 = 0.716$.

The results suggest that C-C scores are uniformly explained by "$|L_A - L_C| / |L_D - L_A|$", or the ratio of differences in the luminance of overlapping (C), non-overlapping (A), and background (D) areas, and the luminance of the background.

Regarding the relationship between glass-transparency and translucency, whereas glass-transparency is provided in areas with a high C-C score, translucency is provided in areas with a low C-C score. Therefore, Figure 7 presents the process of shifting from translucency to glass-transparency as the ratio of luminance differences.

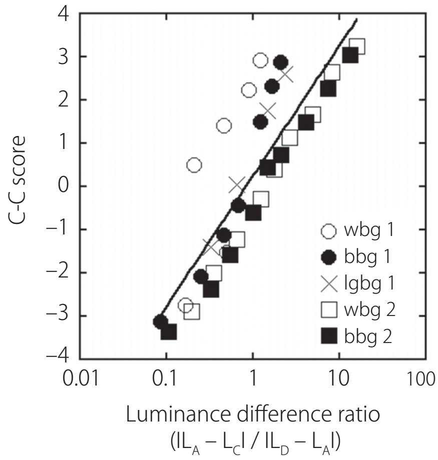

Figure 7: Relationship between C-C scores and the ratio of differences in the luminance of two areas

5.3 Relationships with previous studies

Previous studies discussed luminance factors influencing perceptual transparency for approximately 40 years. Metelli (1974) developed an arithmetic model using a notched disk (an episcotister). The model determines the elements of

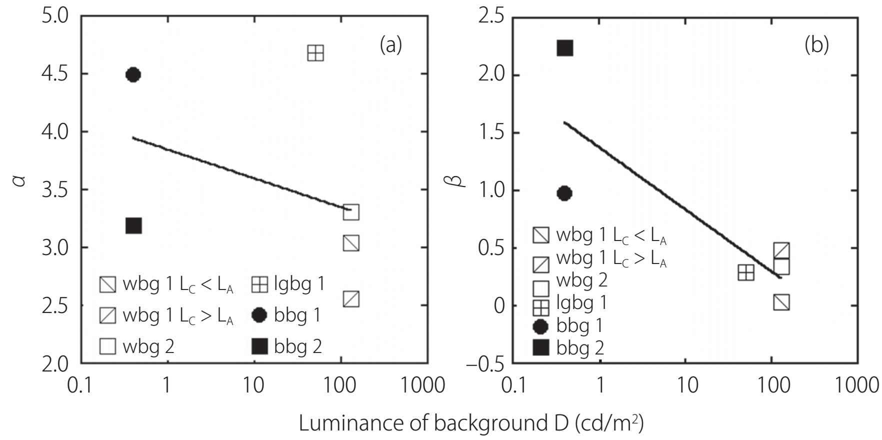

Figure 6: Relationship between the slope (α), the parameter of the horizontal shift (β) of the function described by formula (1) and the luminance of the background

Note: The numbers represent experimental numbers.

transmitted and reflected light based on the degree of the notched part of the episcotister, and explains optic restrictions on perceptual transparency (Metelli, 1985). Based on Metelli's arithmetic model, Gerbino proposed an episcotister luminance model focusing on the luminance of transmitted and reflected light (Gerbino et al., 1990; Gerbino, 1994). Adelson and Anandan (1990) and Anderson (1997) emphasized the elements of stimulus spatial configuration and the relationships among the levels of luminance of the four areas of the X-junction to explain the requirements for perceptual transparency. Delogu et al. (2010) adopted the concept of luminance differences between stimulus areas, and proposed the rule to determine the perceptual order of depth. Furthermore, Fukiage et al. (2014) focused attention on luminance differences in stimulus configuration and proposed an index similar to Michelson Contrast to explain the characteristics of the perceptual judgment of depth order of the overlapping figures.

These studies emphasized the requirements for perceptual transparency and the perception of the order of depth in perceptual transparency. Although some of the studies were conducted across the fields of translucency and glass-transparency, few examined differences in their clarity/cloudiness.

The present study focused on "clarity/cloudiness" in perceptual transparency, and proposed a formula: formula (1). To further promote research on perceptual transparency, it is necessary to examine the relationships between a variety of formulas developed by previous studies and the results of the present study.

5.4 Future challenges

As described in 5.2, differences in "clarity/cloudiness" are uniformly explained by the ratio of differences in the luminance of two areas and that of the background. The following three points are the restrictions and challenges of the present study:

Firstly, in both Experiments 1 and 2 of the study, the stimulus with the highest clarity was adopted as the reference stimulus according to the luminance of the background, and the "clarity and cloudiness" of each stimulus was rated based on the reference stimulus in each block of the experiments. This was because a single reference stimulus could not be adopted for the two experiments and the luminance conditions for the background. Due to this procedure, in some cases, there were differences in C-C scores for the same stimulus combinations, including a combination of the L_A and L_C, in the two experiments, as suggested by the following examples: in Experiment 1, the mean C-C score for the stimulus with a black background was the highest when the L_C and L_A were 130 and 30 cd/m^2, respectively, and the mean score received by the four subjects was between 2.6 and 3 points. However, in Experiment 2 conducted under the same condition, the mean score was lower (0.5 to 2.4). In Experiment 2, conducted based on the results of Experiment 1, the reference stimulus was determined by setting the L_C and L_A at 130 and 6.2 cd/m^2, respectively, because lower clarity had been provided when the L_A was higher than 30 cd/m^2. Therefore, rating scores for "clarity/cloudiness" when the L_A had been set at 30 cd/m^2 were lower than the scores in Experiment 1. In other words, scores in Experiment 1 when the L_A had been set at 30 cd/m^2 were higher than those in Experiment 2. Outliers from some trials of Experiment 1, as presented in Figure 7, are presumably due to differences in the reference stimulus caused by varying conditions. Despite the above-mentioned restrictions, the present study has suggested that rating scores obtained under different conditions can be explained by the same functions.

Secondly, when the background was gray in Experiment 2, the function of "clarity/cloudiness" varied depending on the subject. Under this condition, as the L_A increased, the C-C score given by two subjects sharply increased and then decreased, one subject constantly increased, and the other one subject constantly decreased. Based on the results of Experiment 1, the L_C was set at 51.8 cd/m^2 (2 subjects) or 60 cd/m^2 (2 subjects) depending on the subject. According to a report on the observation, the subjects had varying impressions: "The overlapping area was bright, and the entire test area was blackish and clear"; "The overlapping area was dark, and the entire test area was whitish and transparent". The C-C score varied among individual subjects, presumably depending on what aspect of these visual characteristics was adopted to rate the "clarity/cloudiness" of areas.

Thirdly, although the luminance of areas A and C, part of an area that provides perceptual transparency, and background area D was systematically changed in the present study, the effects of the luminance of posterior area B were not taken into consideration. In preliminary examination in both Experiments 1 and 2, when the L_B was changed with the L_C and L_A that provided the highest clarity under each background condition, the L_B had no influence on test areas with a white or black background, whereas the C-C score for stimuli with a light gray background decreased as the L_B increased. As a future challenge, it is necessary to examine whether or not the same characteristics of perceptual transparency are presented for other combinations of L_A and L_C.

6. Conclusion

The present study examined the "clarity/cloudiness" of overlapping achromatic stimuli to discuss the following three points in relation to perceptual transparency, focusing on glass-transparency and translucency.

- There were systematic changes in glass-transparency and translucency depending on three conditions: the luminance of overlapping, non-overlapping, and background areas.

- When the difference in the luminance of overlapping and non-overlapping was small and the difference between non-overlapping and background areas was large, high translucency was provided. When the difference in the luminance of overlapping and non-overlapping was large and the difference between non-overlapping and background areas was small, high glass-transparency was provided.
- These differences in the "clarity/cloudiness" scores were uniformly explained by the ratio of differences in the level of luminance between two areas and the level of luminance of the background.

References

Adelson, E. H. and Anandan, P. (1990). Ordinal characteristics of transparency. *Paper presented at the AAAI-90 Workshop on Qualitative Vision*, Boston, MA.

Anderson, B. L. (1997). A theory of illusory lightness and transparency in monocular and binocular images: The role of contour junctions. *Perception*, Vol. 26, 419-453.

Delogu, F., Fedorov, G., Belardinelli, M. O., and van Leeuwen, G. (2010). Perceptual preferences in depth stratification of transparent layers: Photometric and non-photometric factors. *Journal of Vision*, Vol. 10, No. 2:19, 1-13.

D'Zmura, M., Colantoni, P., Knoblauch K., and Laget, B. (1997). Color transparency. *Perception*, Vol. 26, 471-492.

D'Zmura, M., Colantoni, P., and Hagedorn, J. (2001). Perception of color change. *COLOR Research and Application*, Supplement Vol. 26, 186-191.

Fukiage, T., Oishi, T., and Ikeuchi, K. (2014). A simple photometric factor in perceived depth order of bistable transparency patterns. *Journal of Vision*, Vol. 14, No. 5: 2, 1-27.

Gerbino, W., Stultiens, C., Troost, J. M., and de Weert, C. (1990). Transparent layer constancy. *Journal of Experimental Psychology, Human Perception and Performance*, Vol. 16, 3-20.

Gerbino, W. (1994). Achromatic transparency. In A. L. Gilchrist (Ed.), *Lightness, brightness, and transparency*. Hillsdale, NJ, US: L. Erlbaum Associate, 215-255

Kawai, S. (2001). A phenomenal observation on transparency and layer of depth. AIC 2001, Washington: The International Society for Optical Engineering, *Proceedings of SPIE*, 331-334.

Kawai, S. and Akita, M. (2003). Perceptual transparency and a sense of clarity observed at overlapping figures. *Journal of the Color Science Association of Japan*, Vol. 27, No. 4, 277-284.

Kawai, S. and Ohtani, Y. (2014). Contribution of chromatic and achromatic information to perceptual clarity in transparency: an analysis in the early stage of chromatic information processing. *Journal of the Color Science Association of Japan*, Vol. 38, No. 1, 13-20.

Kingdom, F. A. A. (2011). Lightness, brightness and transparency: A quarter century of new ideas, captivating demonstrations and unrelenting controversy. *Vision Research*, Vol. 51, 652-673.

Metelli, F. (1974). The perception of transparency. *Scientific American*, Vol. 230, No. 4, 90-98.

Metelli, F. (1985). Stimulation and perception of transparency. *Psychological Research*, 47, 185-202.

Singh, M. and Anderson, B. L. (2002a). Toward a perceptual theory of transparency. *Psychological Review*, Vol. 109, No. 3, 492-519.

Singh, M. and Anderson, B. L. (2002b). Perceptual assignment of opacity to translucent surfaces: The role of image blur. *Perception*, Vol. 31, 531-552.

Tsirlin, I., Allison, R. S., and Wilcox, L. M. (2012). Perceptual asymmetry reveals neural substrates underlying stereoscopic transparency. *Vision Research*, Vol. 54, 1-11.

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