Analysis of factors affecting the contrast effect for total appearance

Midori Tanaka, Daisuke Nakayama† and Takahiko Horiuchi†

College of Liberal Arts and Sciences, Chiba University, Japan
†Graduate School of Science and Engineering, Chiba University, Japan
Email: midori@chiba-u.jp

In our everyday lives, we are surrounded by many material objects with various appearances. We judge the total appearance (e.g., glossiness, transparency, and roughness) of objects and their subjective values. In the field of vision science, various low-level visual contrast effects have been studied to determine criteria for the different appearance of target pairs with different colour, luminance, texture, and shape. However, investigations of the high-level contrast effect for total appearance are rare. In this study, we experimentally investigate the generation of the contrast effect for total appearance and analyse factors affecting it using subjective experiments. Two total appearance attributes, that is, roughness and glossiness, were analysed. In our approach, it was assumed that two high-level contrast effects are generated by the combination of low-level contrast effects such as luminance, image-contrast, and sharpness. Based on multiple regression analyses of the psychophysical experiments, the contrast effect of the sharpness influences the roughness (by 50% to 70%). Furthermore, the results indicate that the glossiness contrast effect is affected by approximately 80% of the contrast effects of luminance and image-contrast.

Received 13 September 2019; revised 20 November 2019; revised 24 January 2020; accepted 24 January 2020
Published online: 07 February 2020

Introduction

Various contrast effects have been studied in the field of vision science. For example, based on the simultaneous colour contrast effect, the colour appearance of a central stimulus varies according to the surrounding colour. Two antagonistic mechanisms of the human visual system that are used to estimate the luminance of reflecting objects have been investigated. One mechanism is a local, presumably retinal, neural mechanism that responds to the physical contrast between an object and its surroundings [1]. Another mechanism is responsible for the classical psychological phenomenon of assimilation [2], and an observer's perception of the luminance of an object co-varies with the apparent luminance of the object's surroundings.

In recent years, the total appearance of surfaces and materials have received increased attention. To better elucidate the total appearance, Japan created a national project called “Brain and Information Science on SHITSUKAN (material perception)” [3] in FY2010, bringing together brain scientists, engineering researchers, and psychological researchers to investigate SHITSUKAN from an academic perspective. In 2015, the SHITSUKAN research was continued in a new project called “Innovative SHITSUKAN Science and Technology” [4], expanding its scope to include senses other than vision. In Europe, the Perceptual Representation of Illumination, Shape & Material (PRISM) project [5] was launched in 2012, mainly to clarify the total appearance from a visual psychology viewpoint; the Dynamics in Vision and Touch (DyViTo) project [6] approaches the elucidation of the total appearance in terms of merging the visual and tactile senses. The measurement of appearance has been addressed in other European projects [7-8]. In the United States, the Society for Imaging Science and Technology (IS&T) Electronic Imaging, an international conference, started the meeting of Material Appearance [9] in 2014, based on which the research on the measurement and perception of the total appearance globally accelerated. In the Commission Internationale de l'Éclairage (CIE), the framework for the measurement of visual appearance was initiated and described in CIE (2006) [10]. Recently, the visual appearance was specified as one of the top priority topics, and the JTC 12 technical committee has started to examine methods for the measurement of the gloss and graininess of an object’s surface. These examples show that the total appearance has actively been studied, but there have been few reports on the high-level contrast and assimilation effects on the total appearance of surface and materials. In recent years, there have been a few studies focusing on gloss perception [11-12], but the relationship with low-level contrast effects has not been fully investigated.

The purpose of our study is to investigate the high-level contrast effect for the total appearance the same way as the known low-level contrast effects for luminance and colour and reveal which factors of the known visual contrast effects influence the high-level contrast effect by changing the physical characteristics of surrounding stimuli. It is not difficult to imagine that the low-level contrast effect is generally affected by colour information such as hue and saturation. We excluded the colourfulness from the physical factors in our experiment because the effect of colour information on the perception of the total appearance is known to be large [13]. As factors of the contrast effect, except for colour, conventional studies reported the influence of the brightness [14], texture interaction [15], and spatial frequency [16]. In each of these studies, the low-level contrast phenomenon was investigated by changing the relationship between the central experimental and surrounding stimuli for each factor. We hypothesise that these low-level factors can be used to compare the appearance differences of surface and materials, and propose that the layered perception model of the high-level contrast effect consists of a known low-level contrast effect.

In this study, we focus on two attributes, that is, the roughness and glossiness, to investigate high-level contrast effects. Gloss perception has been actively studied by many researchers [17]. However, insofar the authors know, there is no report which focuses on the contrast effect of glossiness affect to the total appearance obtained from plural stimuli. Therefore, we investigate the generation of the contrast effect for total appearance including roughness contrast and glossiness contrast. We assume that the two high-level contrast effects can be generated by the combination of low-level contrast effects such as luminance, image-contrast, and sharpness (Figure 1). In this study, we investigate how these three low-level contrast effects influence the high-level contrast effects, that is, glossiness and roughness. By changing the factors affecting low-level contrast effects, such as luminance, image-contrast, and sharpness, we investigate the roughness and glossiness and model the influence of the factors for each contrast effect based on the obtained results.

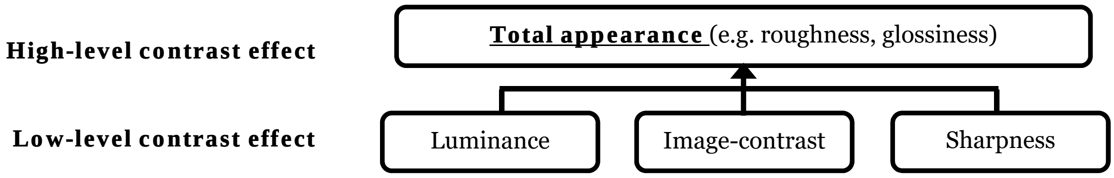


Figure 1: Proposed model of the contrast effect for total appearance.

Experiment

Experimental stimuli

To investigate the contrast effect for the total appearance based on the change of the roughness and glossiness, we prepared the image stimuli for the centre and surrounding positions to change their appearance by modulating the low-level features such as luminance, image-contrast, and sharpness.

We used test images with roughness and glossiness in our experiment as central stimuli. We selected two types of images from the Kylberg Texture Dataset [18] as roughness stimuli: one is a cloth-like image with fine roughness, and the other is a stone-like image with a coarser texture. We then created two types of images as glossiness stimuli by using the Mitsuba renderer [19]. Subjectively, one of the glossiness images has a strong highlight and the other one has a dull luster. The four stimuli for roughness and glossiness are shown in Figures 2(a) and 2(b), respectively. The average luminance of the central stimuli was equalised with the half level in an 8-bit grey image to prevent a luminance contrast effect. As shown in Figure 2(c), the shape of the frequency histogram for each stimulus is similar, except for that for Glossiness #1. This means that the central stimulus of Glossiness #1 has a different glossy appearance and the others have matte appearances [20]. If different results are obtained between the roughness stimuli and Glossiness #2, the high-level contrast effect for the total appearance may be working. However, it cannot be sufficiently explained by the characteristics of the image statistics.

From the two types of images used for the central stimulus, an image with a different roughness was selected for the surroundings from the Kylberg Texture Dataset. We prepared 27 surrounding images by modulating factors, such as the luminance, image-contrast, and sharpness, of the original surrounding stimulus in three steps, as shown in Figure 3. The average luminance of the original stimulus is equivalent to that of the central stimuli; we treated the original stimulus as a standard condition for two factors such as luminance and image-contrast. With respect to the standard luminance, the brightened surrounding was set to +10% luminance and the darkened surrounding was set to -10% luminance (±50% luminance is the maximum luminance (white) and minimum luminance (black), respectively). We classified these three surroundings using three stages of luminance changes: “bright,” “standard,” and “dark.” Surrounding images with high and low contrasts, showing an equal change from the standard surroundings, were prepared for the image-contrast based on the Michelson Contrast using Adobe Photoshop software. The background stimulus was actually aperiodic as shown in Figure 3. However, we applied Michelson Contrast because the background repeatedly changed in luminance due to roughness. We refer to these three surroundings with three stages of image-contrast changes as “high image-contrast,” “standard,” and “low image-contrast.” For the factor of sharpness, we used the Gaussian filter to uniformly modulate the factor. Two-stage smoothing with $\sigma = 1.50$ (7 × 7 window) and $\sigma = 2.25$ (11 × 11 window) was performed for the standard surrounding stimuli using the Gaussian filter; we labelled these three surroundings using three stages of sharpness changes as “high sharpness” (non-modulated), “standard” ($\sigma = 1.50$), and “low sharpness” ($\sigma = 2.25$).

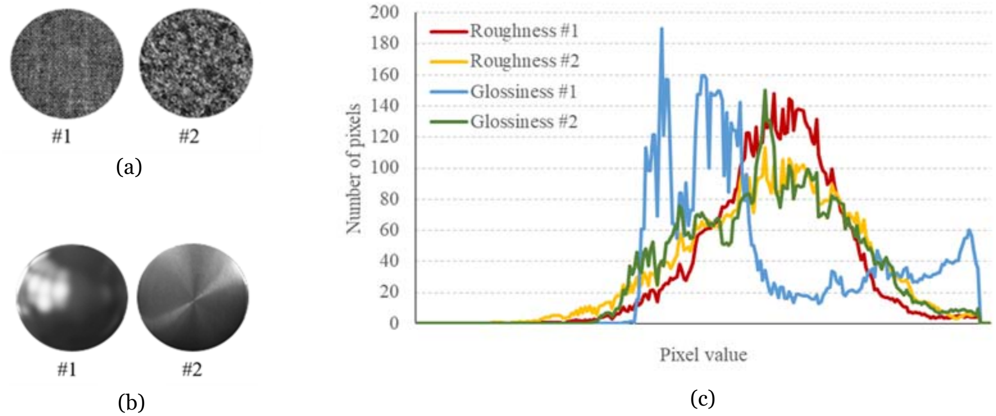


Figure 2: Central stimuli – (a) roughness, (b) glossiness and (c) frequency histograms of the pixel values of the experimental images used as central stimuli.

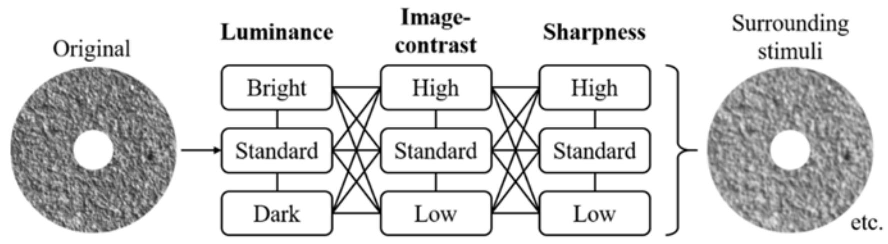


Figure 3: Generation of surrounding stimuli.

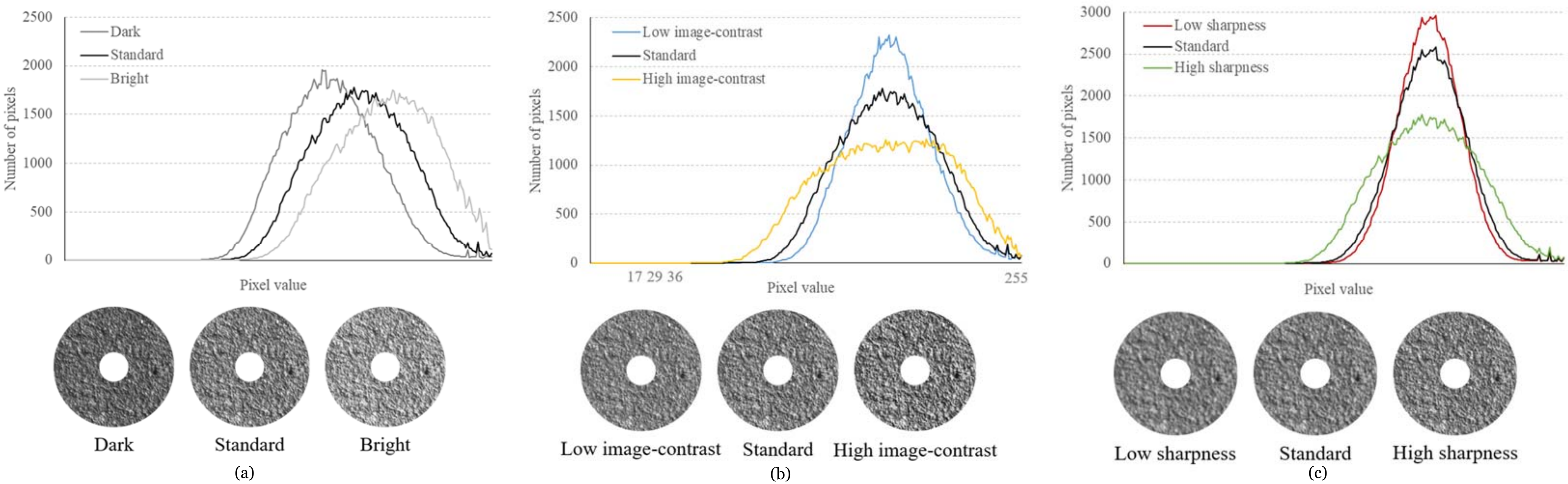


Figure 4: Frequency histograms of the pixel values for the experimental stimuli with the two other factors being fixed to "standard." – (a) luminance change, (b) image-contrast change and (c) sharpness change.

Figure 4 shows the frequency histograms of the pixel values for the experimental stimuli. For each histogram, the other two factors were fixed to the standard conditions. Figures 4(b) and 4(c) show that the average luminance in the two stages of image-contrast and spatial frequency is uniform. By combining these three factors, we generated 27 types of surrounding stimuli.

Preliminary experiment

In this study, it was necessary to exclude factors other than the contrast effects of luminance, image-contrast, and sharpness. All images were converted from the grayscale to eliminate the influence of simultaneous colour contrast effects. As previously explained, nine types of surrounding stimuli with different image-contrasts and spatial frequencies were prepared for each specific luminance. However, a luminance contrast effect might occur when the perceptual luminance of these surrounding stimuli differ. To eliminate this possibility, in a preliminary experiment, we asked observers to adjust the luminance such that the luminance of the nine surroundings are perceptually equal.

The experiment was conducted in a darkroom using a calibrated display device (EIZO ColorEdge CG221) with gamma of 2.2. The white point luminance and background luminance of the display were 127 cd/m^2 and 0.289 cd/m^2, respectively. The viewing distance was 80 cm. The viewing angle of the surrounding stimuli was set to 8° in reference to the experiments of Singer and D'Zmura [21]; observations were performed with both eyes. The observers were six imaging science students (one woman) in their twenties. In this experiment, the observers adjusted the luminance of nine surrounding stimuli at each luminance level, that is, “bright,” “standard,” and “dark,” to become perceptually equivalent. Figure 5 shows a snapshot to compare the luminance between the two surrounding stimuli. For each luminance level, we set the stimulus with “standard” image-contrast and “standard” sharpness as evaluation criteria on the left side of the experimental setup. Eight other surrounding stimuli (six stimuli with “high” or “low” image-contrast for every sharpness condition, two stimuli with “standard” image-contrast for “high” or “low” sharpness) were used as comparison targets on the right side of the experimental setup. For each comparison target, we prepared ten stimuli with slightly different luminance. An evaluation criterion was displayed on the left side of the display, and one stimulus of eight conditions of others was displayed on the right side. The observers compared the luminance of the stimuli and changed the right-side stimulus by using the operation buttons on the experimental display until both sides of the stimuli showed a perceptually equivalent luminance. This experimental procedure was conducted for all luminance levels. The average experimental time for the observers was approximately 15 minutes. Based on the luminance adjustment in this preliminary experiment, we could prepare the experimental stimuli without considering the luminance contrast effect for each observer.

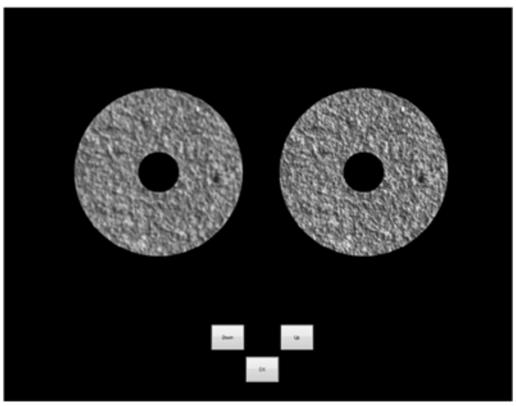


Figure 5: Snapshot of an example of the stimuli in the preliminary experiment.

Main experiment

The experimental environment and observers were the same as that of the preliminary experiment. The experimental stimulus was a combination of a surrounding stimulus with perceptually equalised luminance and a central stimulus with roughness or glossiness. Each experimental stimulus was randomly presented to the observers on the left and right sides. The observers evaluated the different roughness and glossiness attributes of the image stimuli displayed on the left and right sides. There were 729 combinations of experimental stimuli for each central stimulus, which consisted of 27 types of surrounding stimuli each, on the left and right sides. These 729 combinations of stimuli were randomly presented on the left and right sides, as shown in Figure 6. As an evaluation method, two-alternative forced-choice (2AFC) was used, and the observers selected the central stimulus with stronger roughness or glossiness attributes from the two stimuli. There was no time limit for the selection. The average total experimental time was approximately 80 minutes.

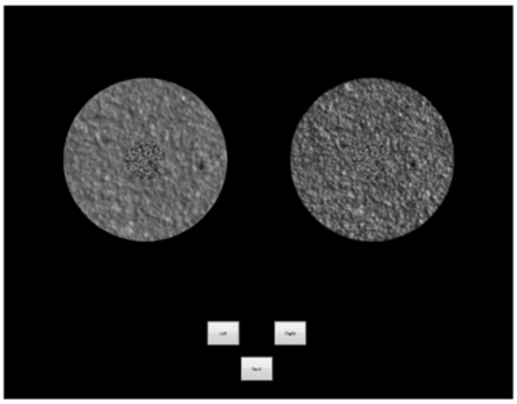


Figure 6: Snapshot of an example of the stimuli in the main experiment.

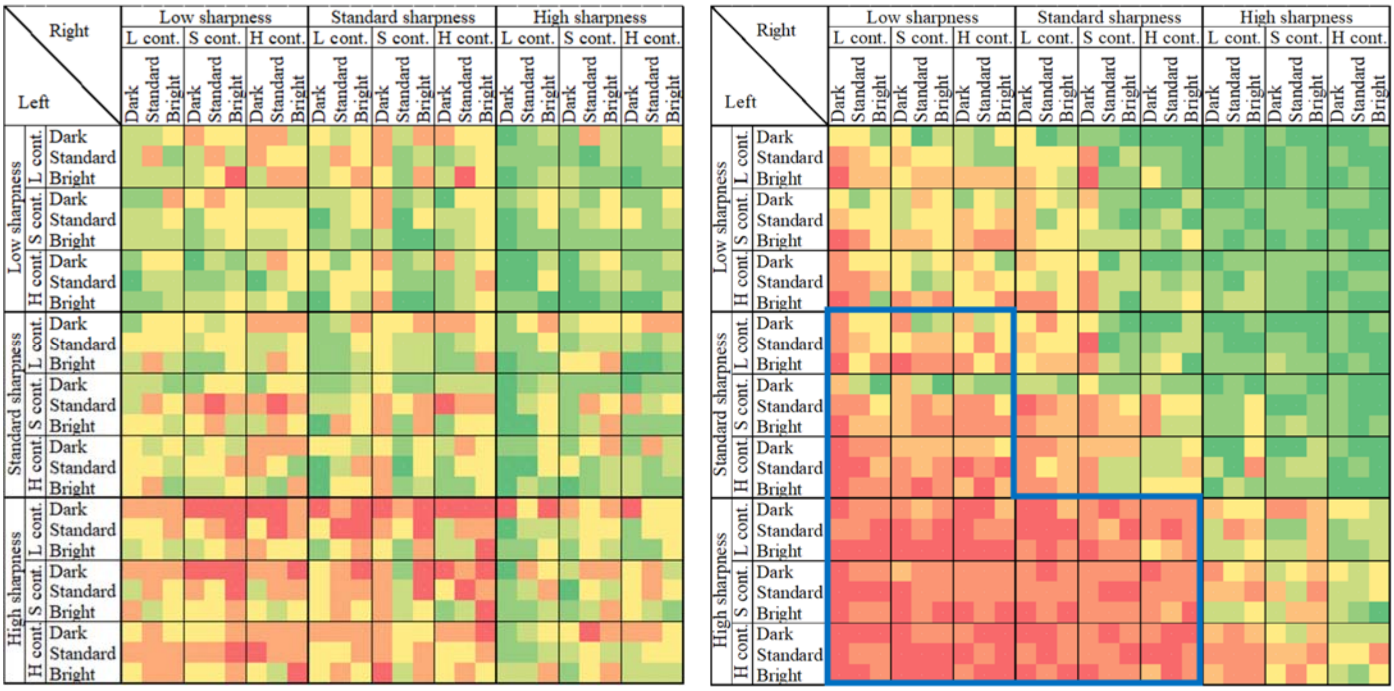
Response evaluation

To analyse the experimental results, we first calculated the correlation of each response from the observers and excluded answers that showed a significant negative correlation with others ($N > 700$, $p < -0.06$) as outliers.

The results of the evaluation of the central stimuli for roughness and glossiness are shown in Figures 7 and 8, respectively. In total, 729 squares correspond to the experimental stimuli. Each row or column is represented by a three-layer hierarchy of the degree of sharpness, image-contrast, and luminance of the surrounding stimuli. The rows and columns show a surrounding stimulus displayed on the left and right sides, respectively. The red square indicates that the total appearance of the stimuli displayed on the left was felt strongly; the green square indicates the opposite. Based on the figures, roughness and glossiness show different trends. Because Roughness #2 in Figure 7(b) and Glossiness #1 in Figure 8(a) have strong tendencies, we consider them as examples.

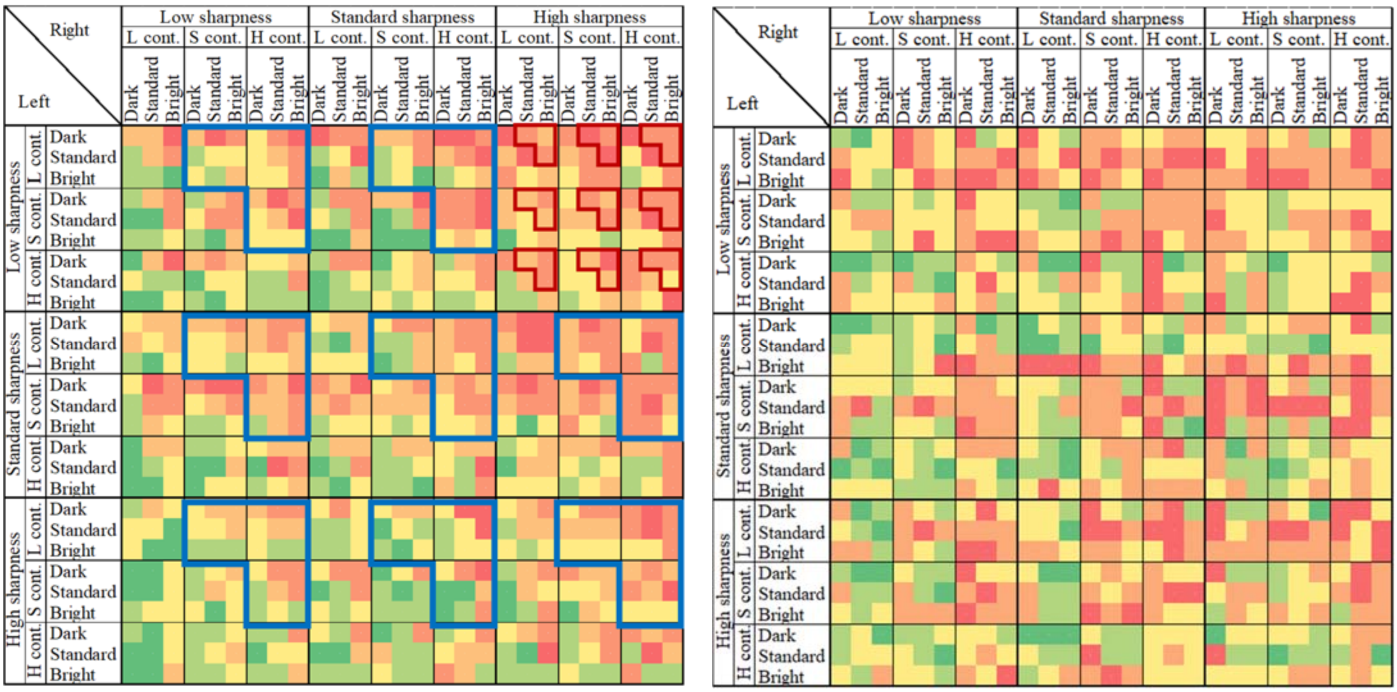
Figure 7(b) shows that red squares with a high response for roughness are distributed on the lower left side (surrounded by a bold blue line). On the other hand, green squares with a low response for roughness are distributed on the upper right side. These results suggest that the central stimulus surrounded by a lower sharpness was perceived as having a greater roughness. Figure 8(a) shows that the red squares with a high response for glossiness are distributed in the upper right section (surrounded by a thick frame, bold blue line). However, green squares with a low response for glossiness are distributed in the lower-left section (surrounded by the thick frame). These findings indicate that the central stimulus surrounded by higher image-contrasts was perceived as having a greater glossiness.

Furthermore, the areas marked by bold red lines indicate that the luminance of the surrounding stimulus contributes to the glossiness perception of the central stimulus.



(a) (b)

Figure 7: Evaluation of the roughness. Red square indicates that six observers out of six (6/6) answered that the total appearance of the stimulus displayed on the left was felt strongly. Reddish orange square: (5/6), orange square: (4/6), yellow square: (3/6), yellow-green square: (2/6), light green square: (1/6), green square: (0/6) – (a) roughness #1 and (b) roughness #2.



(a) (b)

Figure 8: Evaluation of glossiness – (a) glossiness #1 and (b) glossiness #2.

Modelling of the contrast effect for the total appearance

It is a big issue to figure out how complex each low-level cue affects. In this section, we consider a linear cue combination as a simple model. We derived models that can express how much the luminances, image-contrast, and sharpness of the surroundings contribute to the perceptions of roughness $R_{Roughness}$ (count values in Figure 7) and glossiness $R_{Glossiness}$ (count values in Figure 8) based on t-values obtained by multiple regression analysis.

$$R_{Roughness} = w_1^{(R)} L_L + w_2^{(R)} C_L + w_3^{(R)} S_L + w_4^{(R)} L_R + w_5^{(R)} C_R + w_6^{(R)} S_R + w_7^{(R)}, \quad (1)$$

$$R_{Glossiness} = w_1^{(G)} L_L + w_2^{(G)} C_L + w_3^{(G)} S_L + w_4^{(G)} L_R + w_5^{(G)} C_R + w_6^{(G)} S_R + w_7^{(G)}, \quad (2)$$

where L_L, C_L and S_L represent parameters corresponding to the normalised luminance value, Michelson contrast value, and standard deviation of Gaussian filtering of the left stimulus, respectively; and L_R, C_R and S_R represent the parameters for the right stimulus. The w coefficients represent the weights of the regression. Ideally, there is no reason that the multiple regression has different parameters for the left and right stimuli. However, in this study, each raw data was used for regression as it was to grasp the trend. Here, there is no noticeable characteristics for the sign of t-values and weights.

The evaluation values estimated for the central stimuli with roughness and glossiness are shown in Figures 9 and 10, respectively. Based on the comparison of Figures 7 and 8, we can confirm that the features of the appearance contrast are well represented by the regression model. The correlations (r) between the response values obtained in the experiment and values estimated from our model are 0.617 and 0.804 for the two test stimuli with the roughness attribute. The correlations for the two stimuli with the glossiness attribute are 0.494 and 0.504.

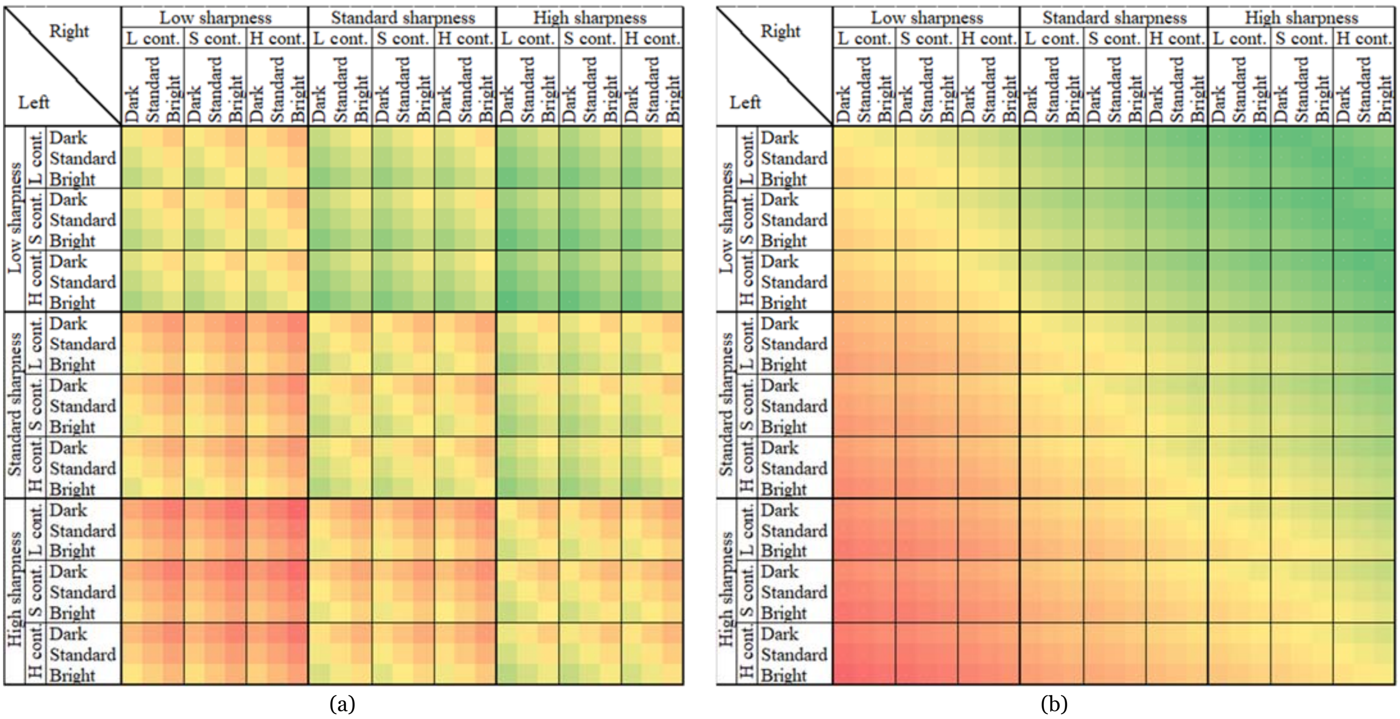
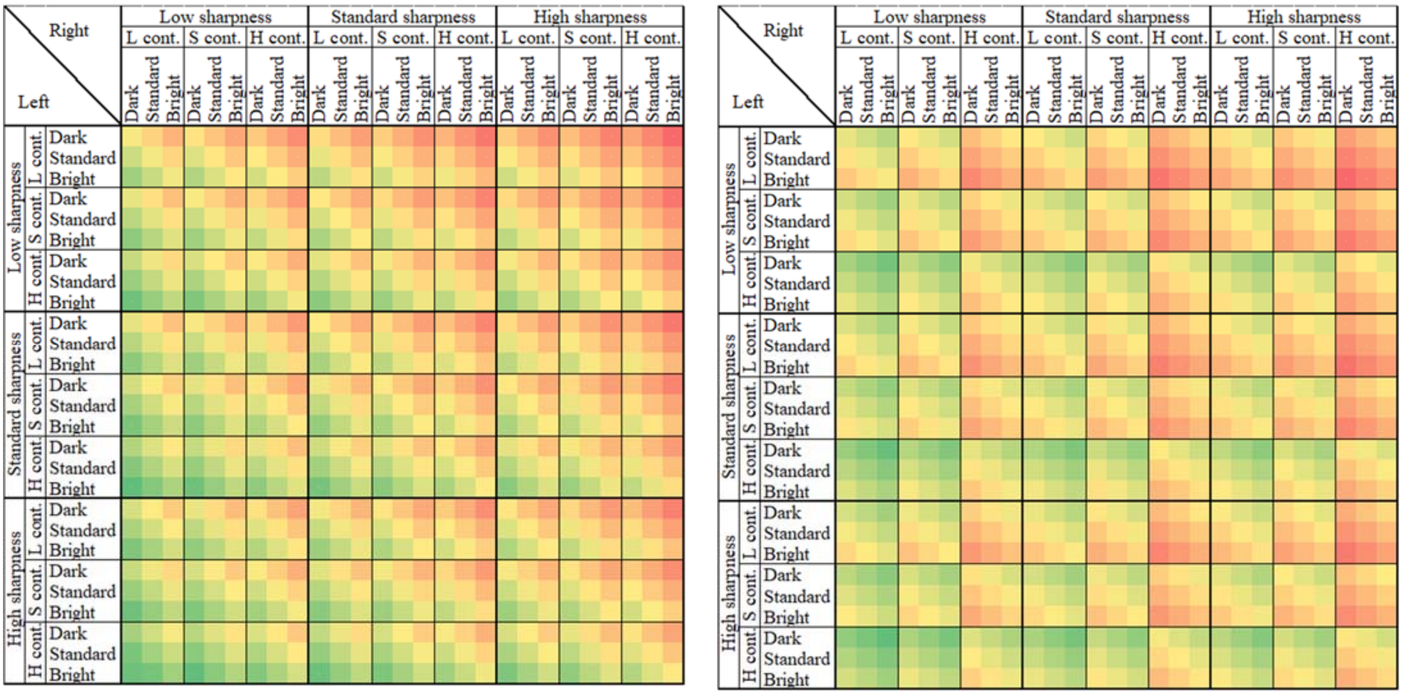


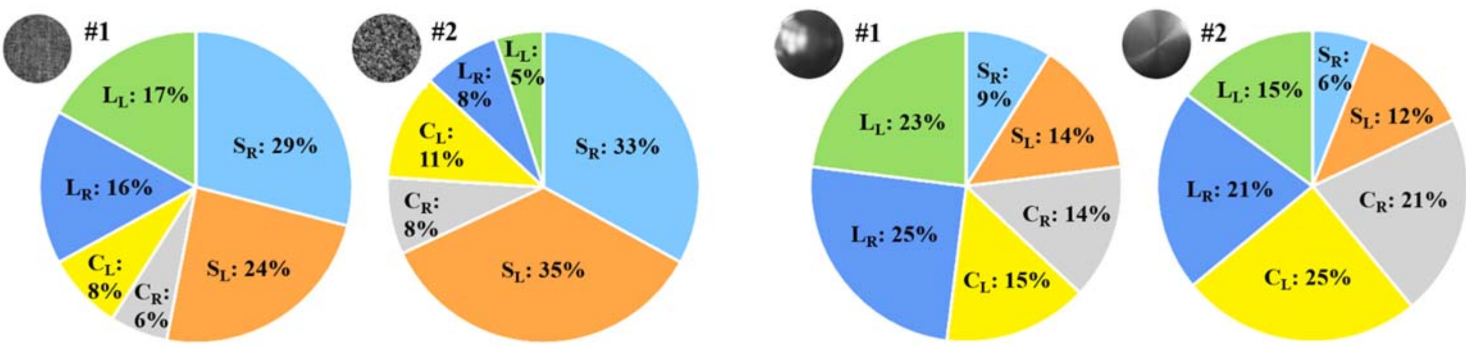
Figure 9: Evaluation values estimated for roughness – (a) roughness #1 and (b) roughness #2.



(a) (b)

Figure 10: Evaluation values estimated for glossiness – (a) glossiness #1 and (b) glossiness #2.

Figure 11 represents the ratios of the absolute values of t-values in the experiments for roughness and glossiness, respectively. The two pie charts in each figure show the results for the two central stimuli #1 and #2. The figures show that the sharpness of the surrounding stimuli largely contribute to the roughness perception of the central stimulus in both experimental sets. The contrast effect of the sharpness influences the roughness contrast effect (by 50% and 70%) of the #1 and #2 central stimuli. The luminance and image-contrasts of the surroundings largely contribute to the glossiness perception of the central stimuli in both experimental sets. The contrast effects of the luminance and image-contrasts influence the glossiness contrast effect (by ~80%) in both experimental sets.



(a) (b)

Figure 11: The ratios of the low-level contrast effects contributing to the high-level contrast effect for the total appearance. The symbols correspond to Equations 1 and 2 – (a) roughness and (b) glossiness.

Conclusions

In this study, the contrast effect for the total appearance of surface and materials was investigated by hypothesising that high-level contrast effects, that is, roughness and glossiness, are generated by the combination of low-level contrast effects such as luminance, image-contrast, and sharpness. The surrounding stimuli consist of luminance, image-contrast, and sharpness, which were varied in three steps for each central stimulus. The central stimuli are images that depict roughness and glossiness. In this study, it was investigated whether the perception of the central stimuli changes based on the surrounding stimuli.

The results show that the contrast effect of the sharpness influences the roughness contrast effect (by 50% to 70%). The obtained results show that the glossiness contrast effect is also influenced (by ~80%) due to the contrast effects of the luminance and image-contrasts.

Acknowledgement

This work was supported by JSPS KAKENHI Grant Number JP15H05926 (Grant-in-Aid for Scientific Research on Innovative Areas "Innovative SHITSUKAN Science and Technology").

References

1. Heinemann EG (1955), Simultaneous brightness induction as a function of inducing- and test-field luminances, *Journal of Experimental Psychology*, **50** (2), 89-96.
2. Helson H (1963), Studies of anomalous contrast and assimilation, *Journal of the Optical Society of America*, **53** (1), 179-184.
3. Integrative studies of neural mechanisms and advanced information technologies for perception of material and surface qualities (Brain and Information Science on SHITSUKAN (material perception)) (FY2010-2014), Grant-in-Aid for Scientific Research on Innovative Areas. [http://www.shitsukan.jp/BISS/content/137 – last accessed 24 January 2020].
4. Understanding human recognition of material properties for innovation in SHITSUKAN science and technology (Innovative "SHITSUKAN" Science and Technology) (FY2015-2019), Grant-in-Aid for Scientific Research on Innovative Areas. [http://shitsukan.jp/ISST/en/index.html – last accessed 24 January 2020].
5. Perceptual Representation of Illumination, Shape & Material (2013-2016), EU-funded research and training network. [http://www.allpsych.uni-giessen.de/prism/ – last accessed 24 January 2020].
6. Dynamics in Vision and Touch - the look and feel of stuff (FY2017 2H-FY2021 1H), European Union's Horizon 2020 research and innovation programme. [https://dyvito.com/ – last accessed 24 January 2020].
7. Multidimensional reflectometry for industry (2013-2016), The European Association of National Metrology Institutes. [https://www.xdreflect.eu/ – last accessed 24 January 2020].
8. Bidirectional Reflectance Definitions (2017-2020), The European Association of National Metrology Institutes. [https://www.birdproject.eu/ – last accessed 24 January 2020].
9. Material Appearance. (2019), IS&T International Symposium on Electronic Imaging. [http://www.imaging.org/site/IST/IST/Conferences/EI/EI_2019/Conference/C_MAAP.aspx – last accessed 24 January 2020].
10. CIE (2006), A framework for the measurement of visual appearance, *Technical Report*, CIE 175:2006.
11. Marlow PJ, Kim J and Anderson BL (2012), The perception and misperception of specular surface reflectance, *Current Biology*, **22** (20), 1909-1913.
12. Hansmann-Roth S and Mamassian P (2017), A glossy simultaneous contrast: Conjoint measurements of gloss and lightness, *iPerception*, **8** (1), 1-16.

13. Tanaka M and Horiuchi T (2015), Investigating perceptual qualities of static surface appearance using real materials and displayed images, *Vision Research*, **115-B**, 246-258.
14. Adelson EH (1993), Perceptual organization and the judgment of brightness, *Science*, **262**, 2042-2044.
15. Chubb C, Sperling G and Solomon JA (1989), Texture interactions determine perceived contrast, *Proceedings of the National Academy of Sciences of the USA*, **86** (23), 9631-9635.
16. Klein S, Stromeyer III CF and Ganz L (1974), The simultaneous spatial frequency shift: A dissociation between the detection and perception of gratings, *Vision Research*, **14** (12), 1421-1432.
17. Leloup FB, Obein G, Pointer MR and Hanselaer P (2014), Towards the soft metrology of surface gloss: A review, *Color Research and Application*, **39** (6), 559-570.
18. Kylberg G (2011), Kylberg texture dataset. [http://www.cb.uu.se/~gustaf/texture/ – last accessed 24 January 2020].
19. Jakob W (2010), Mitsuba renderer. [http://www.mitsuba-renderer.org/ – last accessed 24 January 2020]
20. Motoyoshi I, Nishida S, Sharan L and Adelson EH (2007), Image statistics and the perception of surface qualities, *Nature*, **447**, 206-209.
21. Singer B and D'Zmura M (1995), Contrast gain control: a bilinear model for chromatic selectivity, *Journal of the Optical Society of America*, **12** (4), 667-685.

 ISSN 2227-1309