ABSTRACT
Resolution for displays are increasing from 4K-UHD to 8K-Full UHD. We conducted a subjective image quality evaluation to compare the image quality between 4 and 8K by using diverse image stimuli. As a result, we identified perceptual and cognitive characteristics that can be demonstrated in image quality above 8K. Cognitive and synesthetic factors as well as perceptual factors, and color expression were improved in 8K image quality. The research findings suggested that both perceptual and cognitive factors are reinforced in 8K. This tendency was even more reinforced when the main object was placed within the image. Also, the contrast and vividness felt higher at 8K, of which the vividness influenced the cognitive evaluation of the 8K image quality. When compared with 4K, the image quality above 8K was accompanied by optical illusion, which in turn improved the understanding of the main object. These results suggest that cognitive evaluations for a comprehensive understanding of images may be strengthened at a very high resolution of 8K or higher beyond the 'presence' of 4K resolution.

1. Introduction
Display resolutions currently range from 4K-UHD (3840 \times 2160; hereinafter, ‘4K’) to 8K-full UHD (7680 \times 4320; hereinafter, ‘8K’), and are simultaneously progressing towards even higher resolutions (above 8K). Therefore, the image quality characteristics arising from the improved resolution have been considered an important topic in the research on displays. Engeldrum [1] and Yendrikhovskij [2] regarded image quality as an integrated cognitive result based on a ‘subjective impression.’ This definition of image quality is appropriate for explaining the image quality characteristics present in ultra-high-definition (UHD) displays with 4K or higher resolution. There are many cases where ‘subjective impression’ is used to study images with 4K or higher resolutions. First, according to Wallendael [3], the increase in ‘angular resolution’ enhances the sharpness of images. Masaoka [4] observed that the ‘realness’ of an image increases with increased resolution, and Tsushima [5] observed that the increase in resolution reinforces ‘depth perception.’ In particular, a study by Tsushima [5] has shown that ‘depth perception’ is enhanced at a resolution above a certain level even when the difference in resolution is not detected. This indicates that in the case of UHD, a cognitive assessment that requires higher cognitive processing beyond the perceptual evaluation of image quality can be performed. For example, in the study by Shishikui [6], where the difference in image quality owing to the changes in resolution in the 1K–2K–4K range was investigated, the evaluation of ‘delicious’ and ‘fresh’ increased as the resolution increased. ‘Delicious’ and ‘fresh’ are impressions in which visual perception information is processed in combination with other sensory information, indicating that an increase in resolution can enhance the synesthetic impression.

This study was conducted based on the assumption that the earlier-mentioned perceptual, cognitive, and synesthetic assessments will differ between 4K and 8K resolution images. The subjective image quality assessment and the general characteristics of 8K resolution images were examined using images easily encountered in daily life instead of experimental stimuli like the cylinders or Gabor patches that were used in the previous studies. Towards this end, this study conducted subjective image quality assessment using general subjects with various ‘subjective impressions’ and images with mixed background and objects. Through this, the characteristics of 8K resolution images and the cognitive characteristics observed at the super-resolution level were investigated.
2. Theoretical background

Visual perception is achieved by converting light reflected from an object to nerve stimuli in the eye’s retina. This is a physiological phenomenon, which involves bottom-up processing before cognitive processing. In this bottom-up processing of visual perception, optical illusion is observed with a perceptual response different from the actual stimuli. The Mach band effect and Chevreul illusion are examples of such. These optical illusions are caused by the human receptive field, a visual space excited by light at the center and in the surrounding area.

The Mach band effect is enhanced when the circle per degree (CPD) is increased with the increased resolution. This enhances the edge detection and the Chevreul illusion. A continuous gradient with a high resolution shows detailed brightness variation according to the luminance intensity. This optical illusion affects the understanding of a three-dimensional (3D) shape displayed in two dimensions (2D). The perceptual and cognitive effects with increasing resolution were studied in previous studies [3–7]. The comparison of 2 and 4K resolution images showed that the sharpness perception of the image quality had improved with increasing resolution [3]. In addition, according to Shishikui [6], who studied the perceptual and cognitive effects of increasing resolution (1K-2K-4K), the sharpness, 3D-ness, and contrast improve as the resolution increases. In addition, not only the perceptual effect but also the synesthesia cognition of image quality is improved.

The perceptual and cognitive effects on resolution increases above 4K have also been studied [4,5,7]. In a study in which experiments were conducted with above 150 cpd (cycle per degree) resolutions, the increase in resolution above a certain level was not perceptible, but the depth perception increased as the resolution increased [5]. In addition, as the resolution increased over a certain level, the reality of the object shown in the image was improved [6]. This means that when the resolution is increased above a certain level, the perceptual cues necessary for interpreting the information of the object shown in an image can be transmitted more effectively. In addition, in the previous research of Park [7], the brightness contrast was improved at 8K, over 4K UHD resolution.

In that study, the improvement of the brightness contrast by increasing the resolution improved the perception of glossiness and the 3D perception of the surface. In addition, the step of changing brightness at 8K was perceived more finely, and as such, the perceived depth of the stimulus was increased in the experimental stimulus where the brightness increased towards the center, such as in a tunnel [7].

From these results, it was confirmed that the optical illusion of the contrast perception improved with increasing resolution, which may affect the perception of the object(s) in an image. In addition, the studies on up to 4K resolutions showed that the perceptual properties of image quality affected the cognitive processing of image quality, such as ‘depth’ and ‘beautifulness.’ Therefore, it is necessary to learn more about the effect of the optical illusion resulting from the more than 4K resolutions on the overall impression of image quality. To date, the perceptual and cognitive studies using a cpd equivalent to 8K or higher as a variable have been fundamental studies using cylinders and Gabor patches, and the descriptions of the perceptual cognitive characteristics that appear in complex images are excluded. Therefore, it is necessary to verify that the complex image presented on high-resolution displays exceeding 60 cpd at a given distance also has cognitive processing of image quality.

3. Experiment

3.1. Stimulation and test environment

The subjective assessment of an image is affected by the image’s content characteristics [8,9]. According to I3A [9], ‘subject illuminance’ and ‘subject distance’ influence the subjective assessment of an image. In other words, the brightness and depth of field of an image may affect the experiment results. Therefore, for the experimental stimuli in this study, a total of 16 images consisting of various color characteristics, the main object in the image, and depth were utilized Figure 1. Each image had two resolutions, 4 and 8K, for a paired comparison experiment comparing the image quality characteristics of a 4K display with those of an 8 K display. 4 and 8 K liquid crystal display (LCD) panels were used for the experiment. The internal parameters and physical properties of the 4 and 8 K displays were the same, and the tone reproduction curves (TRCs) and luminance were adjusted to similar levels (Table 1, Figures 2 and 3). The hardware characteristics of the 4 and 8K displays were the same, and the luminance values were similar Table 1. The gamut and color reproduction properties of the displays were adjusted to similar levels. The illumination of the laboratory was adjusted to a dark environment below 5 lx, and the subjects performed subjective image quality assessment experiments at a distance of 9 feet (2.74 m) from the center of each of the two displays.

3.2. Experiment procedure

Prior to the subjective image quality assessment experiment with general consumers, preliminary experiments
were conducted to obtain the assessment items. The subjects of the preliminary experiments were five 20- to 40-year-old women who had image quality research experiences and were thus familiar with the required adjective extraction for image quality experiments. After the presentation of several 4K images to the said subjects, they wrote down the adjectives that described what they felt about the 4K images they were shown. All the adjectives that they wrote down were then collected, after which those with similar meanings were lumped together. The adjectives that were collected

**Table 1.** Display features.

| Features       | 4K display | 8K display |
|----------------|------------|------------|
| Size (inch)    | 65 inches  | 65 inches  |
| Luminance (cd/m²) | 518.2 cd/m² | 477.0 cd/m² |

**Figure 1.** Stimulation for the subjective image quality assessment experiment.

**Figure 2.** Color gamut of the 4 and 8K displays (CIExy).
Figure 3. Tone reproduction curve (TRC) of the 4 and 8 K displays (x-axis: digital input R = G = B; y-axis: normalized luminance).

were emotional ones. After the collected adjectives were grouped into similar semantic groups, 11 representative items (sharpness, brightness, vividness, contrast, 3D-ness, spaciousness, realness, temperature, heaviness, beautifulness, and fatigue) were derived. Test questions were then formulated for the subjective image quality assessment experiment with general consumers. The test questions were presented in 12 sentences, including the 11 adjectives derived from the preliminary experiment and the image quality item. Each item was evaluated based on a 7-point Likert scale, where 4 (same) points were to be given when the 4 and 8 K display image qualities were perceived to be the same, 7 points for a higher 8K display image quality, and 1 point for the opposite case. Prior to this experiment, the subjects were not given any information about the displays, and 4K was named ‘A-display’ while 8K was named ‘B-display.’ Examples of the questionnaire items that were used in the experiment are shown in Table 2. The total number of subjects for the subjective image quality assessment experiment was 30 (3 males, 27 females), and the mean age was 26.5 years. The paired comparison method was used for the experiment. The subjects evaluated the image quality characteristics of the 8 K display in contrast to the 4 K display, in response to the 12 evaluation items, while viewing the same image presented on both displays for approximately 2 min. A total of 16 experimental images were presented randomly, and the experiment took about 30 min.

3.3. Analysis

First, prior to the analysis of the collected data, the subjective image quality assessment result values for the 16 experimental images were consolidated into one dataset and organized by evaluation item. The experiment results were interpreted in three analysis stages, based on the integrated results. First, the reliability of the evaluation items was checked through the reliability and factor analyses of the 12 evaluation items, and the correlations among the evaluation items were analyzed. Second, the characteristics of the 8 K resolution image quality were derived in contrast to the 4 K resolution image quality, by comparing the mean value of the evaluated items and identifying the characteristics of the 8 K resolution images according to the images’ content characteristics using t-test. Finally, multiple regression analysis confirmed the effect of the perceptual characteristics of 8 K resolution images on the cognitive assessment of image quality.

According to a previous study, in the impression assessment of the image quality according to the resolution enhancement, low-order impressions (3D, high resolution, vivid, glossy) belonging to perceptual factors affected high-order impressions (beautiful, delicious, fresh, real) [6]. In the study, low-order impressions were related to image features, and high-order impressions were classified as items requiring cognitive processing, such as ‘sense of being there’ [6]. Therefore, in this study, nine assessment items, excluding brightness, fatigue, and image quality, were divided into cognition factor items (3D-ness, temperature, heaviness, realness, spaciousness, and beautifulness) and perceptual factor items (contrast, vividness, and sharpness), and multiple regression analysis was performed.

4. Results

4.1. Factor analysis

Factor analysis was performed on the 11 adjectives derived from the preliminary experiment, but not on the image quality assessment item. The adequacy of the assessment items in this study was statistically significant (Cronbach’s alpha = 0.876; KMO = 0.916), as with their reliability (Cronbach’s alpha = 0.876). In the said factor analysis, the correlations among the items were very high (KMO = 0.916). The Bartlett sphericity test showed that the study model was appropriate (Chi square = 2708.933; p = 0.00). The total of 12 assessment items were divided into two factors Table 3.

Table 2. Experiment questionnaire.

| Item                                                                 | Scale |
|----------------------------------------------------------------------|-------|
| B looks brighter than A.                                             | 1     |
| B seems to have more contrast than A.                                | 2     |
| ...                                                                    |       |
| The image quality of B is better than that of A.                      | 12    |
| Extremely disagree | Same | Extremely agree |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
The subjective image quality assessment experiment showed that the 8K resolution image was perceived to be better in all the assessment items except ‘brightness’ and ‘fatigue’ Figure 2. This is because, as mentioned earlier, the brightness of the 4K display was set slightly higher than that of the 8K display. In the 8K resolution image, the cpd increased, allowing a more detailed expression of the contrast and color levels than the 4K resolution image, in the same field of view. These technical characteristics affect the processing of visual perception in humans, and lead to the Mach band effect when viewing 8K resolution images. In terms of image quality, the Mach band effect can deliver a richer contrast ratio and color hue than an actual image, which can lead to an image quality preference. Due to the subjective image quality assessment, the contrast, vividness, and sharpness items of the 8K resolution image were observed to be higher than those of the 4K resolution image. The subjects perceived the 8K resolution image to be slightly darker in terms of brightness, whereas they perceived a more abundant contrast and vividness in the 8K resolution image. This is believed to be due to the detection of the Mach band effect with increasing resolution. This is partly inconsistent with the study results obtained by Tsushima [5], which indicate that perceptual resolution differences cannot be detected at resolutions above 4K; the present study indicates that the resolution of 8K resolution images can be perceived to be better perceptually and cognitively. The image quality, 3D-ness, temperature, heaviness, realness, spaciousness, and beautifulness assessment results also showed that the 8K resolution image had higher scores than the 4K resolution image. This indicates that the quality of 8K resolution images is superior not only in the assessment of the resolution, brightness, contrast, and color, which depend on visual perception, but also in the assessment of the overall impression of the image quality mixed with various sensory information, prior experience, and knowledge. Notably, independent t-test was performed by dividing the experimental images into images with and without a central object, and consequently, the image quality assessment values of the images with a central object were higher in all the assessment items, except for brightness and fatigue Figure 3. Among the assessment items, the difference between the 8 and 4K resolution images was large in the realness and 3D-ness items, indicating that the presence of a central object in an 8K resolution image may improve the image. Thus, it was confirmed that the technical and perceptual characteristics of the 8K resolution image had a positive effect on the assessment of the impression of the image, and also positively affected the perception and cognitive assessment of the image’s central object (Figures 4 and 5).

### 4.2. 8K image quality: images with a central object

The subjective image quality assessment experiment showed that the 8K resolution image was perceived to be better in all the assessment items except ‘brightness’ and ‘fatigue’ Figure 2. This is because, as mentioned earlier, the brightness of the 4K display was set slightly higher than that of the 8K display. In the 8K resolution image, the cpd increased, allowing a more detailed expression of the contrast and color levels than the 4K resolution image, in the same field of view. These technical characteristics affect the processing of visual perception in humans, and lead to the Mach band effect when viewing 8K resolution images. In terms of image quality, the Mach band effect can deliver a richer contrast ratio and color hue than an actual image, which can lead to an image quality preference. Due to the subjective image quality assessment, the contrast, vividness, and sharpness items of the 8K resolution image were observed to be higher than those of the 4K resolution image. The subjects perceived the 8K resolution image to be slightly darker in terms of brightness, whereas they perceived a more abundant contrast and vividness in the 8K resolution image. This is believed to be due to the detection of the Mach band effect with increasing resolution. This is partly inconsistent with the study results obtained by Tsushima [5], which indicate that perceptual resolution differences cannot be detected at resolutions above 4K; the present study indicates that the resolution of 8K resolution images can be perceived to be better perceptually and cognitively. The image quality, 3D-ness, temperature, heaviness, realness, spaciousness, and beautifulness assessment results also showed that the 8K resolution image had higher scores than the 4K resolution image. This indicates that the quality of 8K resolution images is superior not only in the assessment of the resolution, brightness, contrast, and color, which depend on visual perception, but also in the assessment of the overall impression of the image quality mixed with various sensory information, prior experience, and knowledge. Notably, independent t-test was performed by dividing the experimental images into images with and without a central object, and consequently, the image quality assessment values of the images with a central object were higher in all the assessment items, except for brightness and fatigue Figure 3. Among the assessment items, the difference between the 8 and 4K resolution images was large in the realness and 3D-ness items, indicating that the presence of a central object in an 8K resolution image may improve the image. Thus, it was confirmed that the technical and perceptual characteristics of the 8K resolution image had a positive effect on the assessment of the impression of the image, and also positively affected the perception and cognitive assessment of the image’s central object (Figures 4 and 5).

### 4.3. Cognitive understanding of the image quality of an 8K resolution image

Based on the results of the multiple regression analysis that was done after dividing the nine assessment items except brightness, fatigue, and image quality into cognitive and perceptual factor assessment items, 3D-ness was observed to be greatly affected by all the three perceptual factors, and sharpness had the greatest impact on 3D-ness. In contrast, temperature, heaviness, realness, spaciousness, and beautifulness were affected only
by vividness and sharpness among the perceptual factors, and between these two items, the impact of vividness was greater Table 4. This difference appears to have been due to the difference between the perception and cognition processing of the five cognition factor assessment items. In this study, 3D-ness was classified as a cognitive factor assessment item, but in the previous studies, impression assessment of 3D-ness was classified as a perceptual factor impression assessment [6]. 3D-ness is an assessment of the prominence or depth of the object or space in an image, which is assessed using visual perception cues like contrast and perspective. In other words, bottom-up processing can be regarded as having a considerable effect on the subjective impression assessment of image quality. Therefore, resolution information that describes the surface characteristics of objects in detail is processed with sensitivity. In contrast, for the temperature, heaviness, realness, spaciousness, and beautifulness assessment items, cognitive processing is performed by linking visual sensory information with information from other senses, and such processing can be regarded as that of synesthetic characteristics.

In particular, temperature and heaviness indicate visual tactility, which is a result of the tactile impression expressed through visual perception. In addition, in terms of perceiving the object appearing in an image as real, the impression of the space, and the beauty of the image, cognitive factors like the previous experiences and values of the subjects are actively involved, in addition to the processing of visual perception. In other words, the five cognitive assessment items except 3D-ness can be regarded as being greatly influenced by top-down
processing. In the subjective impression evaluation of image quality according to the top-down process in this study, the influence of the vividness item was greater than the resolution. This suggests that in the case of cognitive quality evaluation of images with an 8 K or higher resolution, the visual illusion effect owing to the increase in resolution may have a greater effect than the estimation of the resolution.

5. Discussion

Through the subjective image quality impression assessment that was performed in this study, it was confirmed that the optical illusion is enhanced in the 8 K or higher image resolution than in 4 K. As a consequence of the experiment, the luminance and color contrasts were improved. Especially, the brightness was set higher at 4 K than at 8 K, leading to a higher brightness assessment value at 4 K; in the case of contrast perception items like contrast and vividness, the assessment values were higher at 8 K. This shows that as the resolution increases from 4 to 8 K, the actual physical values are amplified to enhance the perceived optical illusion.

Optical illusions appearing at resolutions above 8 K improve the 3D-ness and realness and boost the comprehensive understanding of image quality. As a result of the previous study, the 3D-ness and realness were improved according to the optical illusion at 8 K image quality [7]. The results of the study showed better separation of the foreground and background at 8 K when the brightness contrast between the object and the background was low [7]. This indicates that increasing the resolution enhances the brightness contrast perception, and that the Mach band effect, a typical brightness contrast optical illusion, increases. In that experiment, some subjects made an interesting comment. In perceiving the background and foreground, an object on the 4k display appeared to be floating in a 2D grid, but on the 8 K display, the object was perceived as an object with volume placed on the floor surface. In particular, in 8 K, the boundary between the background and the object was perceived to be a shadow of the bulky object. This response is consistent with the Chevreul illusion described earlier, which refers to the perception of the continuous surface being enhanced as the Mach band’s phase becomes denser. In other words, the smooth luminance change with increasing pixel density causes the interface between the object and the background to be perceived as a continuous flow rather than as a segmented area. During this process, the volume of the object seems to be perceived strongly. Such a cognitive response increases the realness of the object shown on an 8 K resolution image.

The fact that the assessment values of 3D-ness and realness were high at 8 K in the subjective impression assessment experiment in this study is associated with the above. In particular, as characteristics of the 8 K resolution image quality, the 3D-ness and realness of the image with a central object were much higher than those of the image without a central object. This shows that luminance contrast improvement with a more than 8 K resolution increase leads to a distinct separation of the central object and the background, improves the 3D-ness, and expresses the visual information of the object surface in greater detail, thereby also improving the realness. As 4 K UHD TVs have been commercialized and are currently widely used, their psychological effects have been studied in various aspects [4–6,10]. As a result, a high resolution above 4 K is required to improve the depth perception and visual realness. In this study, the perceptual and cognitive impression assessment of the 8 K image resolution was higher than that of the 4 K image resolution. Especially, the result of the improved realness of
the object is consistent with the results of the previous studies.

In addition, the subjective image quality impression assessment experiment in this study showed that the vividness assessment was significantly higher at 8K. This means that the optical illusion with increasing resolution can improve both the color and luminance contrasts. Thus, 8K or higher resolution not only provides clearer details but also shows enhanced luminance and color contrasts compared with the actual physical properties. This enhances the perception of the continuous surfaces of objects shown in the image, in the same way as a Mach band effect and the Chevreul illusion. These phenomena had a positive effect on the temperature, heaviness, realness, spaciousness, and beautifulness, which were set as the cognitive factors of image quality in this study. These results show that the cognitive comprehension, a combination of existing memories, value judgments, and various sensory information, increases in the 8K or higher resolution image quality, and how the subject perceives the colors in the image quality in abundance positively affects the assessment and impression of the image quality. In other words, as the resolution increases, an optical illusion can affect the subjective impression of image quality and the top-down processing. The effect of top-down processing on the subjective impression assessment of image quality can be confirmed by the memory color example. It has been reported that when the brightness and saturation of an image are adjusted to be similar to the memory color with higher brightness and saturation than the actual color, the preference for the image quality improves [11]. Thus, 8K or higher resolution not only provides clearer details but also shows enhanced luminance and color contrasts compared with the actual physical properties. This enhances the perception of the continuous surfaces of objects, and enhances the cognitive interpretation, including synesthesia.

6. Conclusion

This study confirmed through a subjective image quality impression assessment experiment that the cognitive and synesthetic factors like ‘realness,’ ‘temperature,’ and ‘beautifulness’ as well as the perceptual factors like ‘vividness,’ ‘contrast,’ and color expression were improved in 8K or higher image quality. Furthermore, the 8K resolution image showed more details, contrast, and color with a further increase in resolution, and these technical characteristics were amplified in the perceptual stage by optical illusions like the Mach band effect and the Chevreul illusion. These effects enhanced the understanding of the objects shown in the image, in the same way as a sense of reality is provided by increasing the density of the contrast expression in the photos in two dimensions (2D). In other words, the technical and perceptual characteristics of 8K resolution images can have a positive impact on the cognitive assessment of image quality, which requires top-down processing. Consequently, cognitive assessment that contributes to the comprehensive understanding of an image and understanding of the central object in it with continuous surface characteristics can be enhanced with an 8K or higher resolution, more than the ‘presence’ of 4K.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

[1] P.G. Engeldrum, J. Imaging Sci. Techn. 48 (5), 447–457 (2004).
[2] S. Yendrikhovskij, Colour Image Science: Exploiting Digital Media (2002), pp. 393–420.
[3] G. Van Wallendaal, P. Coppens, T. Paridaens, N. Van Ketts, W. Van den Broeck, and P. Lambert, presented at the 2016 Eighth International Conference on Quality of Multimedia Experience (QoMEX), 2016 (unpublished).
[4] K. Masaoka, Y. Nishida, M. Sugawara, E. Nakasu, and Y. Nojiri, IEEE T. Broadcast. 59 (1), 72–83 (2013).
[5] Y. Tsushima, K. Komine, Y. Sawahata, and T. Morita, Front. psychol. 7, 242 (2016).
[6] Y. Shishikui and Y. Sawahata, IEEE T. Broadcast. 64 (2), 498–507 (2018).
[7] D. Park, Y. Kim, and Y. Park, presented at the SID Symposium Digest of Technical Papers, 2019.
[8] S.R. Fernandez, M.D. Fairchild, and K. Braun, J. Imaging Sci. Techn. 49 (1), 96–104 (2005).
[9] I. I. I. Association, Fundamentals and Review of Considered Test Methods (2007).
[10] Y. Tsushima, K. Komine, Y. Sawahata, and N. Hiruma, Sci. Rep. 4, 6687 (2015).
[11] C. Boust, H. Brettel, F. Viénot, G. Alquié, and S. Berche, J. Imaging Sci. Techn. 50 (1), 1–11 (2006).