Effects of Viewing Ultra-High-Resolution Images With Practical Viewing Distances on Familiar Impressions

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***Abstract*—This paper investigated the psychological effects of viewing ultra-high-resolution images. Many subjective evaluation experiments assessing the quality of images have been conducted. However, the psychological effects of viewing ultra-high-resolution images have not been well investigated, especially under non-standard viewing conditions. Although a higher image resolution has been reported to affect the sense of realness, more impressive factors that appeal to the general viewers have not been examined. This paper conducted subjective evaluation experiments, in which images with different resolutions using familiar subjects were presented to viewers with practical viewing distances, and their ratings of impressions were obtained. In addition, we examined the relationship between higher- and lower-order impressions. We found an enhancement of the impressions of "beautiful" or "delicious" with an increase in the resolutions of the presented images. Furthermore, the tendency of this impression enhancement was observed even when viewing it as far as four times the design viewing distance. The results of multiple regression analyses provide insight on the production and processing of ultra-high-resolution images for impression enhancement.**

***Index Terms*—UHDTV, subjective evaluation, 4K, resolution, impression, psychological effect.**

I. Introduction

THE ERA of Ultra High-Definition (UHD) TV [1] has arrived. 4K-UHD has been launched on various media such as terrestrial, satellite, cable TV, IPTV, etc. around the world, and the start of 8K-UHD broadcasting is approaching in Japan. The replacement of the display from HDTV to UHD is also progressing, and the UHD system is expected to be used for various applications besides broadcasting.

The UHD system parameters for displaying 2D images with ultimate quality were determined based on the psychophysical evidence of the perceptual limits of human vision. Specifically, the number of pixels was determined by subjective evaluation experiments on the sense of "being there" [2]–[4], and the frame rate was determined by perceptions of motion blur, stroboscopic effects, and flicker [5], [6]. The visual experience of the viewers is expected to change completely with the extremely fine picture of UHD.

However, for viewers, the advantage of UHD in everyday television viewing experiences is not fully understood, although visual experiments in laboratory environments have shown its remarkable performance in terms of human perception [7]. In daily life, viewers do not appraise the quality of images but enjoy the immersive experiences brought from a TV screen. Therefore, to clarify the advantages of UHD in everyday scenarios, we focused more on the instinctive feelings brought about by the experience of viewing UHDTV.

It is expected that UHD's enhancement effects on viewer's impressions depend on the subjects of the images. It could also be affected by the method of shooting. Given the enhancement effects of UHD presentation, obtaining a quantitative understanding of the visual characteristics that lead to these impressive experiences would not only advance our understanding of the effects of UHD but also provide new insights into effective shooting and editing methods for video creators.

To examine the effects of UHD on impressions familiar to viewers, in this study, we investigate the relationship between image resolution and higher-order impressions, such as "looks delicious," "looks beautiful," "looks real," or "looks fresh" through subjective evaluations. We also investigate how these impressions are modulated by viewing distance, including the design viewing distance and farther. In addition, using multiple regression analyses, we investigate how such higher-order impressions can be explained by lower-order impressions, such as senses of "resolution," "3D (depth)," "vividness," and "glossiness."

In this study, we show that UHD presentation still has remarkable positive effects on impressions even in typical everyday viewing environments, including viewing at four times the design viewing distance. Furthermore, we quantitatively identified the importance of lower-order impressions for each higher-order impression. The quantitative relationship between lower- and higher-order impressions offers new insights into effective shooting and editing methods for enhancing specific higher-order impressions.

II. Related Works

To our knowledge, no studies have quantitatively investigated the relationships between image resolution and various

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impressions closely related to our daily life, such as "looks delicious," "looks beautiful," "looks real," and "looks fresh." It is also unclear how these relationships are modulated by the home environment. Although the UHDTV system was originally designed to enhance viewer's immersive experiences, other effects were not taken into consideration. In this section, we review the subjective aspects of the works that contributed to determining the system parameters of the UHDTV system. Furthermore, we review the recent studies that focused on the impressive effects of UHDTV viewing in practical viewing conditions, not only at a design viewing distance but also at farther distances.

The system parameters of UHD were determined via psychophysical experiments that focused on immersive aspects of the viewer's feelings. For example, the field of view (FOV) angle and screen aspect were determined based on subjective evaluation experiments. Hatada *et al.* [2] characterized the relationship between the FOV angle and the feeling of "being there" as the inductive effect of a wide FOV image presentation on viewer's posture movements, and showed that the sense of "being there" asymptotically increased along with the FOV angle of up to 80 or 100 degrees. Masaoka *et al.* [4] conducted experiments on the sense of "being there" using images of two types of shooting field angles and obtained results similar to those of Hatada *et al.* [2] for both shooting field angles used. According to Narita *et al.* [8], the preferable screen aspect differs depending on the screen area, regardless of the FOV; more specifically, the sense of comfortableness is influenced by the screen aspect but the sense of potency is not when the screen area stays the same. These results suggest viewers' feelings of immersion require a wide-viewing-angle presentation.

The resolution of the UHDTV system was determined based on the human visual acuity to provide a wide-viewing angle presentation with sufficient image quality. ITU-R recommends a "design viewing distance" of 3H for HDTV and 6H for SDTV (H: screen height) [9]–[11]. The image resolution at these viewing distances is about 30 cycles per degree (cpd) or one pixel per arc minute, which corresponds to the separable visual angle at a normal visual acuity of 20/20 in Snellen notation. In this condition, it has been assumed that a person with normal visual acuity cannot discern the pixel structure at the design viewing distance. According to this concept, in order to provide a horizontal FOV angle of 100 degrees, the horizontal pixel count must be about 8000 and the design viewing distance 0.75H. This is the initial design of 8K-UHD. In the case of 4K-UHD, the design viewing distance is 1.5H [12]. Therefore, the viewing distance beyond the design viewing distance is thought to exceed the perception limit, meaning that viewing tests under this condition have little meaning.

Recent studies have shown the significant psychological effects of UHD resolution in various viewing conditions. Masaoka *et al.* [13] investigated the relationship between "angular resolution" and sense of realness. Their results showed that the sense of realness increased along with the angular resolution, even though this sense reached a saturation above approximately 60 cpd (=120 pixels/degree). In other words, the sense of realness is saturated at double the design viewing distance. Tsushima *et al.* [14], [15] examined the relationship between the spatial resolution of a visual image and the depth sensation using primitive stimuli defined by gradual luminance-contrast changes [14] and Gabor patches [15]. They showed that higher-resolution images (even more than 60 cpd) produced a stronger depth sensation even without noticing the resolution difference. Lachat *et al.* [16] investigated the relationship between viewing distances and perceptual qualities for UHD images. Their results showed that the image quality (i.e., the goodness of the presented pictures) of the 4K resolution was much better than was that of the HD at a viewing distance of 1.5H, which was the design viewing distance for 4K, and also slightly better even at a viewing distance of 3H [16]. Although these results only focused on the overall image quality (goodness) and not on further impression factors, the effects provided by UHD images are similar to those in [13]–[15]. These studies suggest that UHD resolution can have various psychological effects on viewers even beyond the design viewing distance.

Impressions can be categorized into two groups: higher-order and lower-order. In this study, we define the lower-order impression as the feelings related to image features, such as sharpness, feelings of depth, and vividness, while higher-order impressions are defined as feelings with more cognitive qualities, such as "sense of being there" [4]. According to this definition, most previous studies would have focused on lower-order impressions. For example, Wallendael *et al.* [17] focused on the lower-order impression, feeling of sharpness, and compared it between upscale HD and UHD. In psychology studies, a number of works have focused on higher-order impressions, such as aesthetics. For example, one study [18] focused on the preferences for artworks and investigated the relationship between visual features (color, brightness, and composition) and preferences. However, the relationships between lower- and higher-order impressions were not investigated in this study. Furthermore, they did not take into account the viewing conditions, such as image resolutions and viewing distances.

III. Experimental Method

We conducted subjective evaluation experiments in which subjects viewed test images shown in different resolutions and different viewing distances and rated them in terms of their impressions. Table I shows the experimental conditions, including the test images, apparatus, room conditions, and evaluation terms. The viewing conditions conform to the laboratory environment of ITU-R BT.500 [19], [20].

A. Test Image

The test images consisted of foods and flowers as shown in Fig. 1. We chose subjects of test images that would elicit viewers' impressions such as "beautiful" and "delicious."

The images were shot using a 4K camera (Canon EOS C500) for D-Cinema and recorded in RAW format. The images were then developed using the gamma and color gamut of the ITU-R BT.2020 in 10 bits-per-pixel precision.

TABLE I
EXPERIMENTAL CONDITIONS

Test images	Cake, fruit, poinsettia, sashimi
Resolution	4K, 2K-equivalent, 1K-equivalent
Display	Canon DP-V3010 (30-inch, 4096 x 2160) Peak luminance level: 170 cd/m^2
Room conditions	Ratio of luminance of inactive screen to peak luminance: 0.001 Other room illumination: low
Viewing conditions	Distance: 1.5H (53 cm), 3H (106 cm), 6H (212 cm) (H: picture height) Maximum observation angle relative to normal: 28° for 1.5H, 14° for 3H, 8° for 3H
Evaluation terms	Lower-order impression: three-dimensional, high-resolution, vivid, glossy Higher-order impression: (looks) beautiful, delicious, fresh, real

We created 2K- and 1K-equivalent images from 4K images by applying a low-pass filter (LPF) that mimics the modulation transfer function (MTF) characteristics of a 2K and 1K camera, respectively. Then, the original 4K images as well as the 2K- and 1K-equivalent images were displayed on the 4K display. Specifically, we designed the LPF for generating 2K-equivalant images based on the MTF characteristics of an actual 2K camera that was reported in [21]. The LPF was designed to satisfy a condition in which the MTF response remained greater than 0.35 at 800 TV line, complying with a condition that TV cameras should satisfy in professional productions. Similarly, we also designed the LPF for generating 1K-equivalent images based on the MTF characteristics with half of those with the 2K camera in a frequency domain, as shown in Fig. 2. Fig. 2 presents the frequency response and the impulse response of the used LPF, while Fig. 3 shows the horizontal power spectrums of the original 4K images.

B. Experimental Procedure

A total of 30 subjects (aged 20–22 years) with normal or corrected-to-normal visual acuity participated in our experiment. Visual acuity was tested using the Tumbling E Eye Chart.

Each subject underwent two trial series with two out of three different viewing distances (1.5, 3.0, and 6.0 H). Further viewing distance was conditioned in the first series of trials. The choice of viewing distance assigned to each subject was determined in a random manner, such that each image (condition) was viewed by 20 subjects in total. Two subjects viewed the presented images, simultaneously. The geometry room setup is shown in Fig. 4.

In one trial series, images with four different content types and three different bandwidths were randomly presented to prevent the image presentation order from affecting the evaluator's choices. In addition to 4 (image content) x 3 (bandwidth) stimuli, two dummy stimuli were included and placed at the beginning of the sequences to remove initial instability. A mid-grey screen was presented 5 seconds before each trial as shown in Fig. 5. During the 30 seconds presentation, subjects viewed

(a) Cake

(b) Fruit

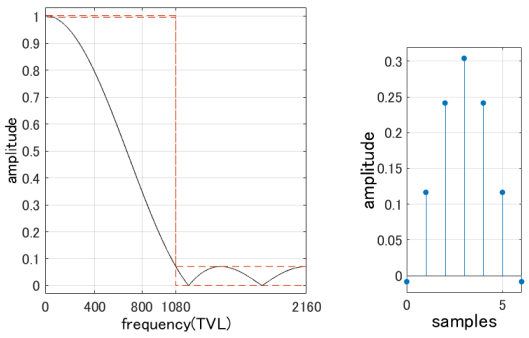
(c) Poinsettia

(d) Sashimi

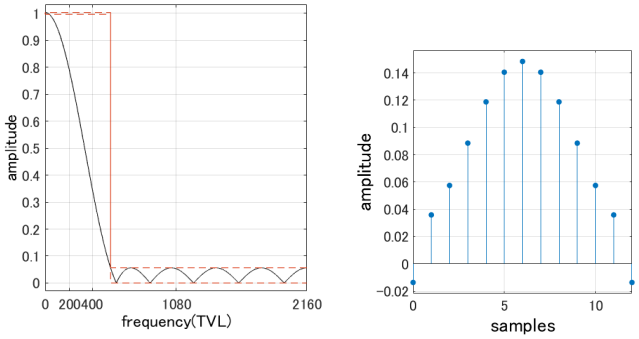
Fig. 1. Test images.

images and filled out a questionnaire consisting of the eight impressions (shown in Fig. 6) with a 7-grade scale ranging from "strongly disagree" to "strongly agree." We adopted the use of a 7-grade scale for evaluation because subjects in our preliminary experiment reported difficulties in their impressions using 5 grades and preferred 7-grade to 5-grade to describe absolute scores.

This study investigated the extent to which the common impressions in our daily life are changed owing to differences in image resolution (i.e., whether the impression can be strengthened by increasing the resolution). We selected the terms "looks beautiful," "looks delicious," "looks fresh," and "looks real" as the evaluation terms expressing popular values. These are evaluation terms of higher-order impressions, which were obtained by combining various image features.



(a) 2K-equivalent



(b) 1K-equivalent

Fig. 2. Frequency response and impulse response of the LPF.

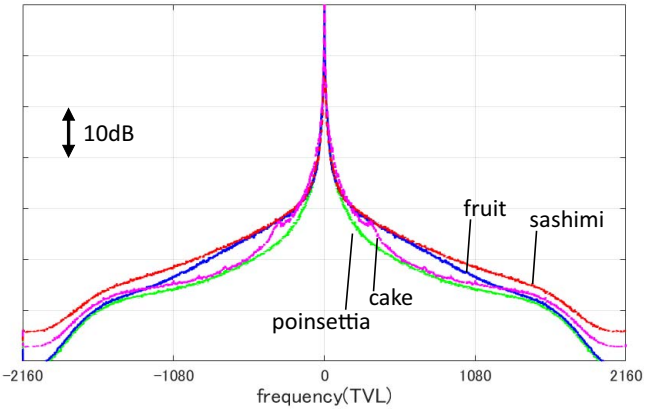


Fig. 3. Power spectrum of test images.

The evaluation terms of lower-order impressions, such as high resolution, color vividness, glossiness, and three-dimensional (3D), were also selected and used in the experiments to analyze their relationship with the physical features.

C. Analysis

We calculated the average values of the results of the subjective evaluation experiment and their 95% confidence intervals based on the t-distribution. A t-test was performed to determine whether there were significant differences in impressions between the resolutions. To directly examine the effects of high-resolution images with each type of content and viewing distance on each impression, we applied multiple t-tests to compare the impression scores between adjacent resolutions for each type of content and viewing distance. As performing statistical tests multiple times causes a multiple comparison problem, which leads to false positives because of the increase in the practical significance level, we adjusted false discovery rates (FDRs) for each p-value using the Benjamini and Hochberg (BH) method [22].

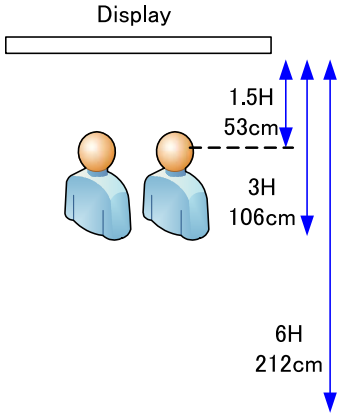


Fig. 4. Geometry room setup.

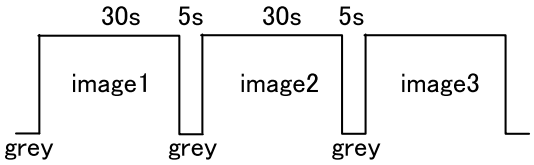


Fig. 5. Presentation of test images.

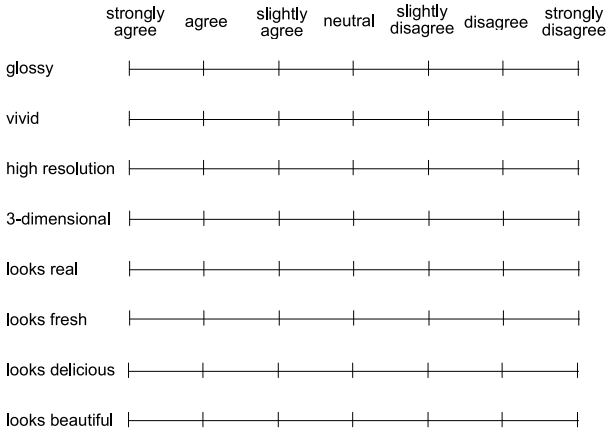


Fig. 6. Score sheet.

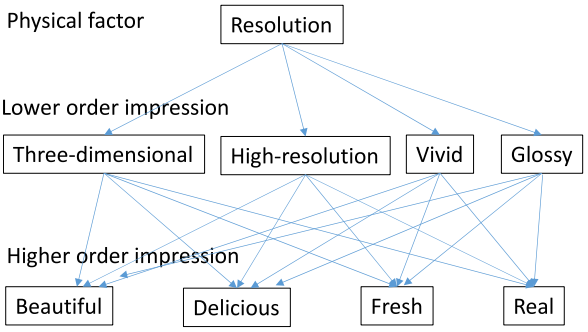


Fig. 7. Hierarchical structure of impressions.

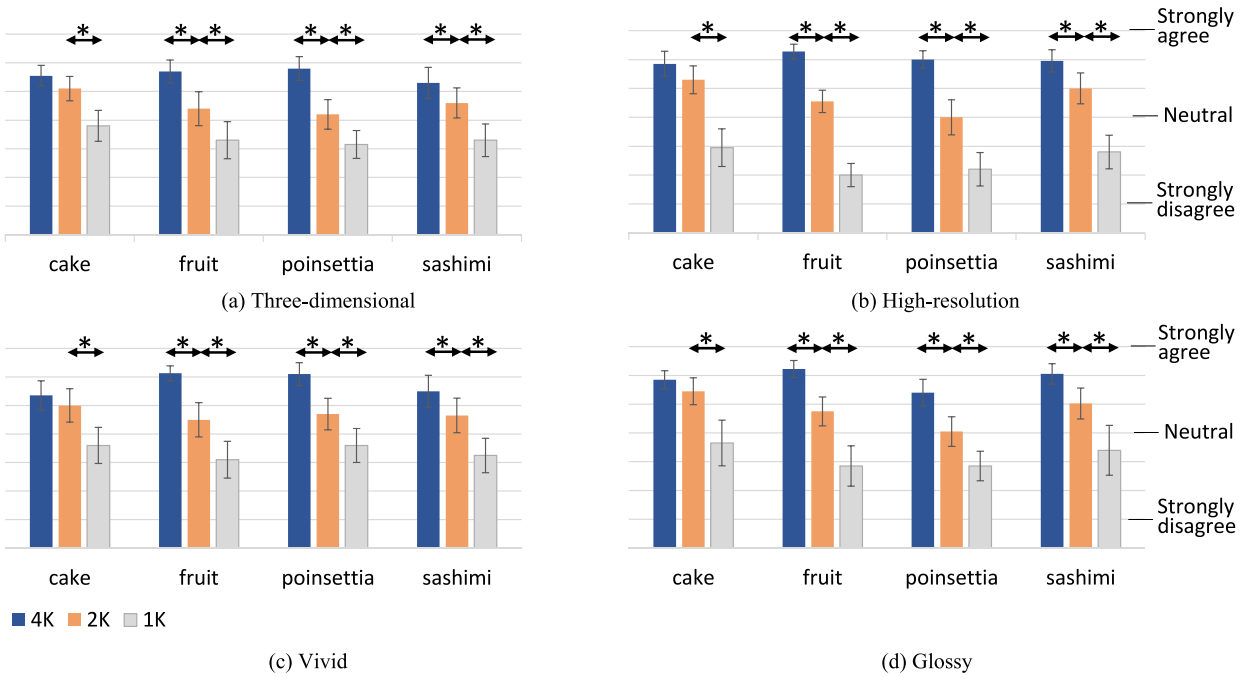


Fig. 8. Comparisons of the lower-order impressions for each image with different resolutions (1.5H).

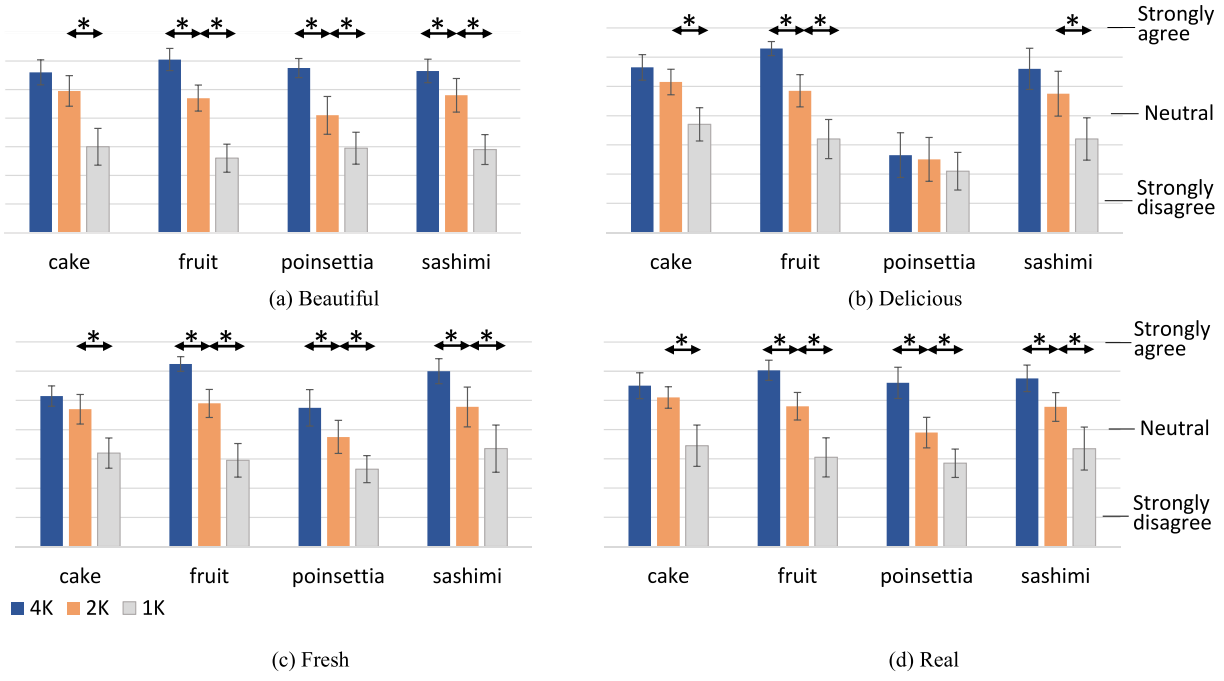
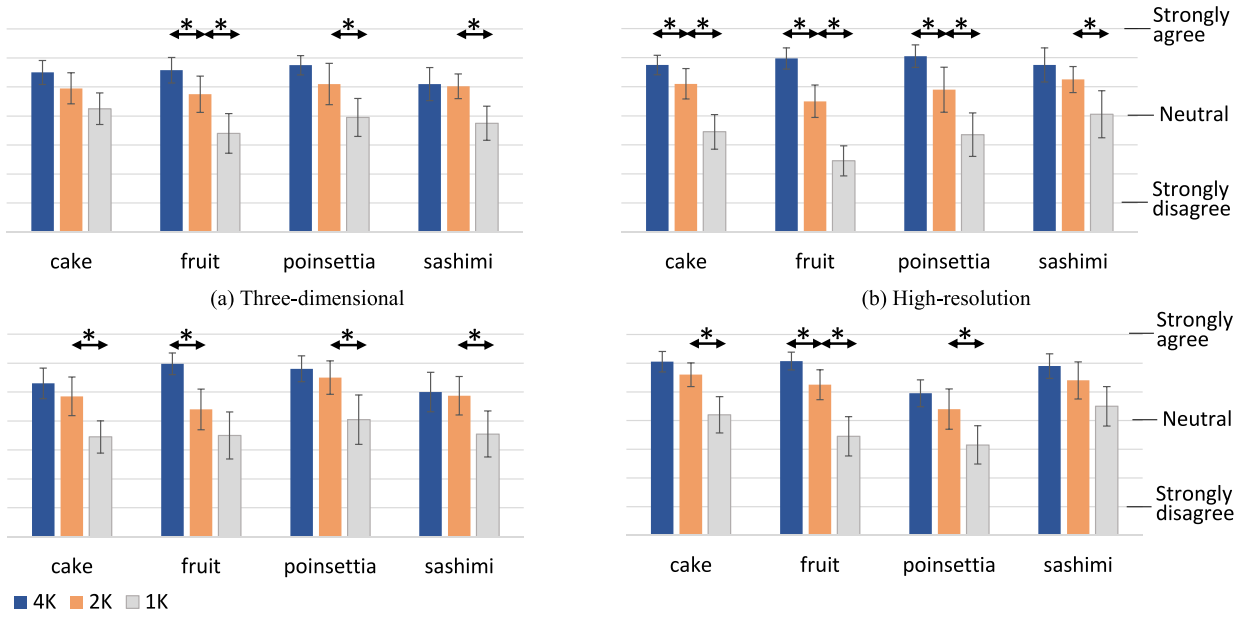


Fig. 9. Comparisons of the high-order impressions for each image with different resolutions (1.5H).

To examine the relationships between lower- and higher-order impressions, we ran multiple regression analyses on the obtained rating scores for the cases where a significant difference was observed in higher-order impressions, regardless of the images or viewing distances. We assumed a linear model with a hierarchical causal relationship between lower- and higher-order impressions with respect to resolution, as shown in Fig. 7. That is, owing to the increase in the resolution, four lower-order impressions are enhanced, which in turn reinforces the higher-order impressions. To compute the degree of contribution of each lower-level impression to each higher-level impression, we used multiple regression analyses in which each higher-order impression was explained by a weighted sum of four lower-order impressions. The estimated weight values (partial regression coefficients) for each lower-order impression can be interpreted as the degree of contribution to the corresponding higher-order impression.



(a) Three-dimensional (b) High-resolution

(c) Vivid (d) Glossy

Fig. 10. Comparisons of the lower-order impressions for each image with different resolutions (3H).

IV. Experimental Results

A. Observation at Design Viewing Distance

Fig. 8 shows the results for the lower-order impressions (e.g., 3D effect, resolution, color vividness, and glossiness) at a viewing distance of 1.5H, wherein an asterisk (*) indicates a difference at the 5% significance level (FDR corrected) observed between the images with two different resolutions. The results showed significant differences between the 4K, 2K, and 1K images, except for the comparison of the 4K and 2K resolutions for the cake image.

Fig. 9 shows the results for the higher-order impressions (e.g., beauty, deliciousness, freshness, and reality). The following observations were derived from Figs. 8 and 9:

– The differences between the 4K, 2K, and 1K images were observed also for higher-order impressions.

– Image-dependent differences were observed. For example, the "poinsettia" did not look delicious regardless of the resolution; the differences for the "fruit" were remarkable regardless of its condition; and only slight 4K–2K differences were observed for "cake" even though a significant difference was found for the 2K and 1K values.

– The significant differences in "sense of resolution" and "look delicious" impressions varied for "fruit," "sashimi," and "cake." Hence, these impressions were independently evaluated. Consequently, the contribution of the resolution to viewers' impressions was found to be dependent on the condition.

B. Observation Beyond Design Viewing Distance

Figs. 10 and 11 show the results at the viewing distance of 3H (twice the design distance). A similar tendency in the average score was observed. However, the variation in the score of the evaluator was large, and the cases where a significant difference was found decreased. A significant difference between 4K and 2K images was observed for lower-order impressions with "fruit" and "poinsettia," and for higher-order impressions with "fruit."

Figs. 12 and 13 show the results at the viewing distance of 6H (four times the design distance). A significant difference between 4K and 2K was observed for the "delicious" impression with the "fruit" image.

C. Regression Analysis

Based on the multiple regression analyses with the hierarchical impression model shown in Fig. 7, we observed significant differences in the degree of contribution of each lower-order impression to each higher-order impression, as shown in Fig. 14. The contributions were computed based on the absolute values of T statistics with 5% significance level obtained in the multiple regression analysis for each higher-order impression term, as shown in Table II.

V. Discussion

The experimental results revealed that UHD presentation of images enhanced both higher- and lower-order impressions for practical viewing distances, including distances farther than the design viewing distance. Furthermore, we found that higher-order impressions can be explained by their lower-order impressions, and the degree of contribution of each lower-order impression was different in each higher-order impression. These results suggest that the distinguishable positive effects of UHD presentation are observable even when the viewing distance is farther than the design viewing distance, which was previously believed to be too far to obtain such differences.

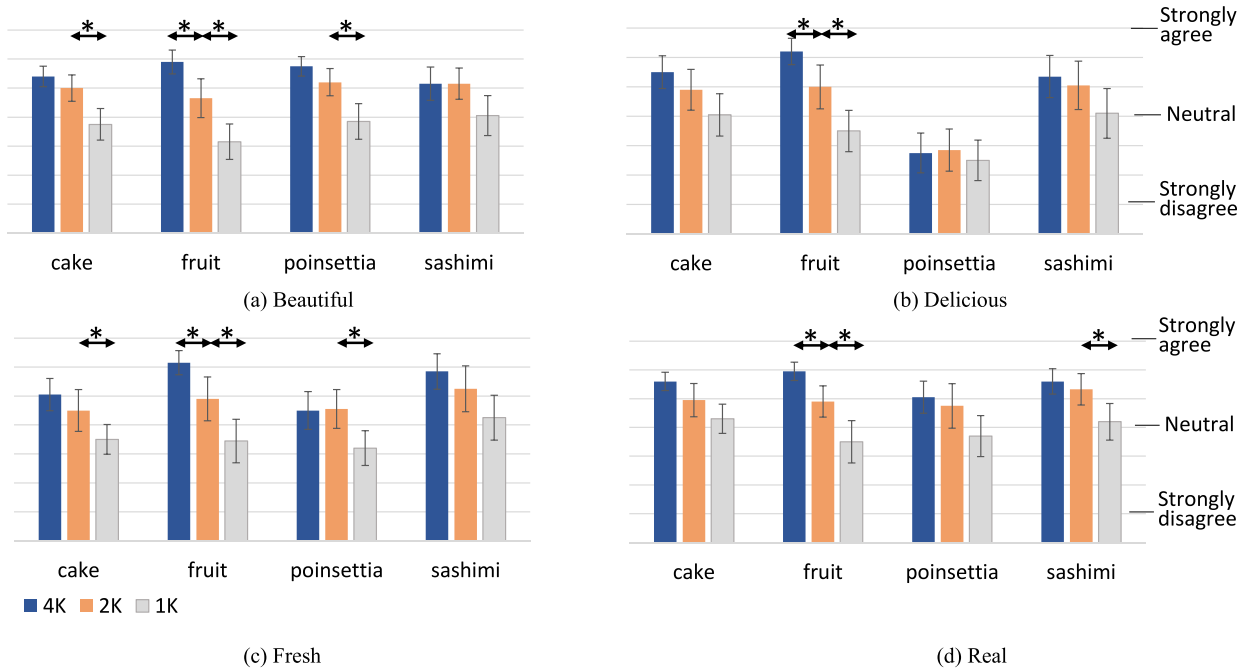


Fig. 11. Comparisons of the higher-order impressions for each image with different resolutions (3H).

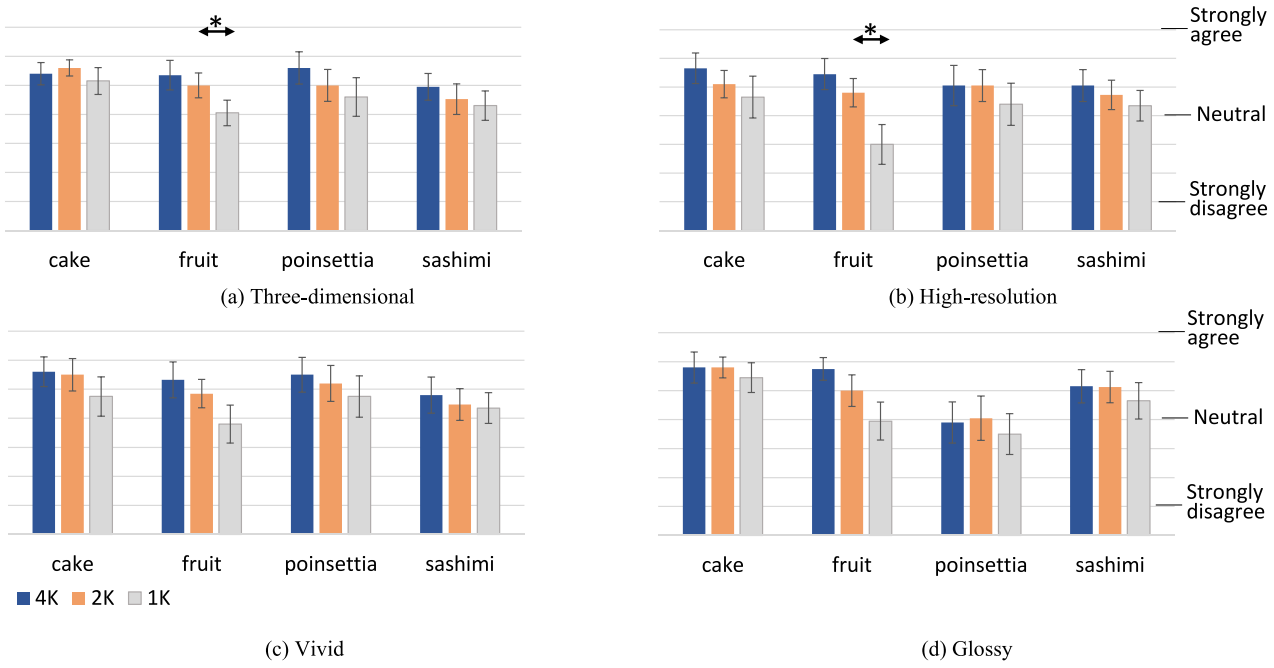


Fig. 12. Comparisons of the lower-order impressions for each image with different resolutions (6H).

Specifically, significant differences were observed not only for the design viewing distance but also for the (maximum) four times the design viewing distance. As described in chapter II, previous studies have shown that differences in each evaluation criteria were perceived even under conditions that exceed so-called perceptual limits [13]–[16]. The human visual system has the ability to perceive differences in images even when those differences are smaller than the diffraction limit of the ophthalmologic optical system, which is called visual hyper acuity [23]. It has been explained that the human visual system utilizes not only a local pixel structure but also the entire image structure by synthesizing visual features on multiple scales. Hence, we believe that our results with the farther viewing distance are reasonable. Although it has been thought that viewing 4K/8K resolution at more than a distance of 1.5 H/0.75 H is meaningless, our findings are definite evidence against that.

The multiple regression analyses showed that the lower-order impressions of "vivid" and "glossy" contribute to the higher-order impression of "delicious"; "glossy" and

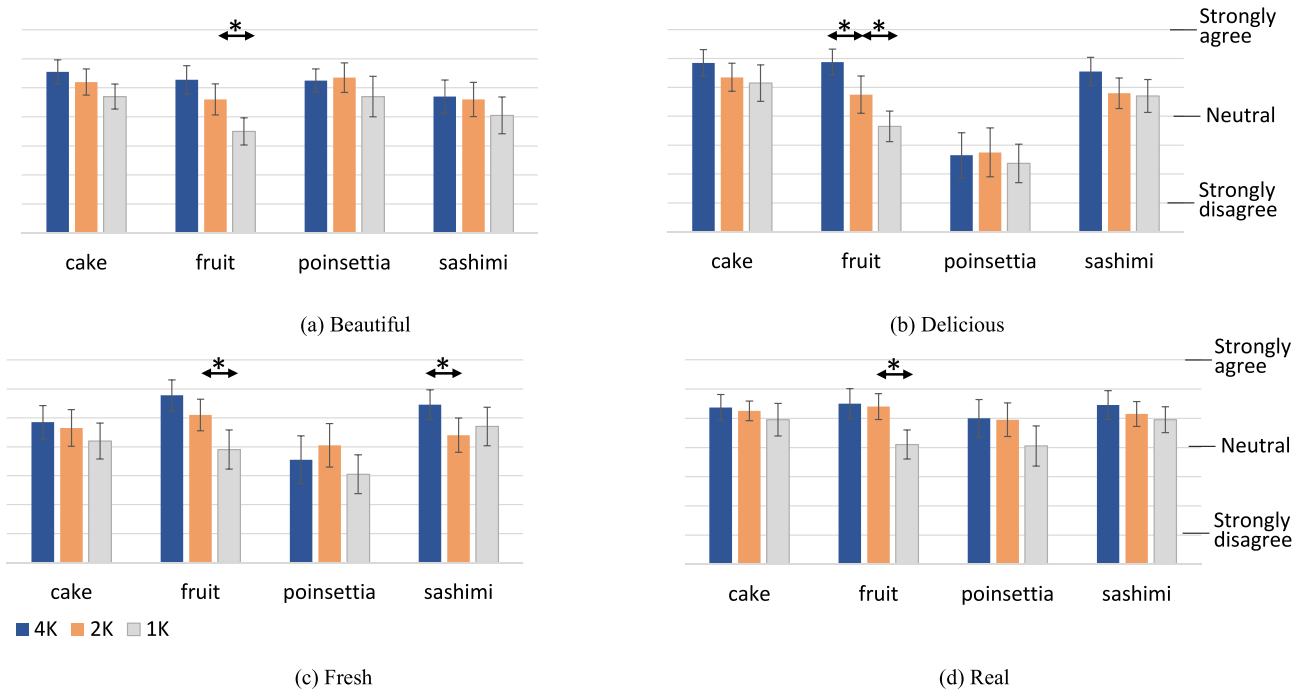


Fig. 13. Comparisons of the higher-order impressions for each image with different resolutions (6H).

TABLE II
RESULTS OF THE MULTIPLE REGRESSION ANALYSES

Beautiful: $R^2 = 0.7176$, Adjusted $R^2 = 0.7175$

	Coefficients	T Stat	P-value
Intercept	0.3316	2.1788	0.0299
3-dimensional	0.1702	3.9449	9.290E-05
Resolution	0.3500	8.1800	3.0754E-15
Vivid	0.2408	6.2170	1.1785E-09
Glossy	0.1506	3.8371	0.000143

Delicious: $R^2 = 0.6964$, Adjusted $R^2 = 0.6928$

	Coefficients	T Stat	P-value
Intercept	0.3847	1.9848	0.04797
3-dimensional	0.0810	1.5691	0.1175
Resolution	0.1873	3.6214	0.000337
Vivid	0.3921	7.3887	1.15E-12
Glossy	0.2879	5.2918	2.17E-07

Fresh: $R^2 = 0.6046$, Adjusted $R^2 = 0.6000$

	Coefficients	T Stat	P-value
Intercept	0.3945	1.7740	0.076959
3-dimensional	0.1000	1.6814	0.093607
Resolution	0.2496	4.2769	2.471E-05
Vivid	0.2311	3.9601	9.143E-05
Glossy	0.3159	5.6729	3.025E-08

Real: $R^2 = 0.7084$, Adjusted $R^2 = 0.7056$

	Coefficients	T Stat	P-value
Intercept	0.6497	4.2830	2.29E-05
3-dimensional	0.4038	9.3918	3.83E-19
Resolution	0.3628	8.8230	3.04E-17
Vivid	-0.0553	-1.3569	0.1755
Glossy	0.1758	4.3103	2.03E-05

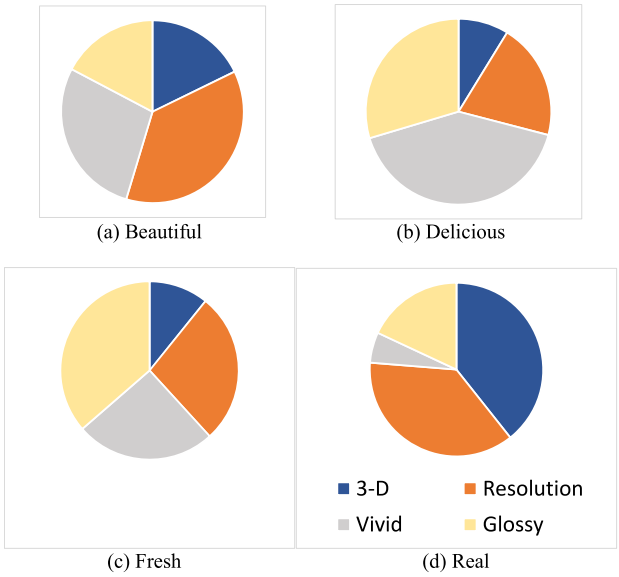


Fig. 14. Degree of contribution of lower-order impressions to the determination of higher-order impressions (ratio of absolute value of T statistics obtained for each partial regression coefficient).

"resolution" contribute to "fresh" (while "three-dimensional" does not); and "three-dimensional" and "resolution" contribute to "real." For the impression of "beautiful," "resolution" had the greatest contribution, but every factor contributes somewhat equally. The results seem to intuitively valid and conform to those of the previous studies. For example, Arce-Lopera *et al.* [24] showed that the perception of freshness is predicted by luminance features rather than color. Although the underlying mechanism has not been well understood, psychophysical studies suggest that the human visual system has a function called "visual attention" that selects a subset from all the available visual information, such as area in visual fields and specific visual features, on a top-down basis [25]. Therefore, asking about high-order impressions drove the

attention function in viewers, and then the related lower-visual features were selected based on viewers' prior knowledge and experiences and used in the subsequent high-order cognitive processing. Hence, for example, because people know that foods with good color and gloss are often "delicious," the impression of low-order impression, vividness, and luster were enhanced. Video creators usually try to find ways to effectively convey their higher-order ideas, and their expertise contributes substantially to the specific ways they express these ideas. Our results would provide useful guidelines for image generation and processing intended to enhance impressions by highlighting cues that are intuitively related to lower-order features and can be manipulated by creators.

The contribution of a sense of "high resolution" varied for each higher-order impression, suggesting that complex cognitive processing is involved during the induction of impressions. It is reasonable that the sharpness (sense of high-resolution) is enhanced with increasing resolution. It would also be reasonable to infer that higher resolution has indirect enhancement effects on perceptions of color vividness, three-dimensionality, and glossiness. Accordingly, we might expect that "resolution" has a significant contribution to all higher-order impressions; however, this was unlikely. Even when resolution was manipulated, the major contribution to higher-order impressions was not always perception of resolution. Further psychological investigations are needed to clarify the mechanisms.

There are some limitations to this study. Although we found that the higher-order impressions can be explained by the lower-order psychological factors, our design precludes validation of the causal relationship between them. Furthermore, the choice of evaluation terms was heuristic. Other evaluation factors should be taken into account to validate the findings of this study. The results of this study were also obtained using a small number of images. Experiments with more variations would be required.

VI. Conclusion

The relationship between the display resolution and the impression of familiar images was investigated through subjective evaluation experiments using ultra-high-resolution images. We conducted evaluation experiments wherein the viewing distance exceeded the design viewing distance, which is an unconventional condition in a subjective experiment.

The increase in resolution from HD to UHD enhanced the lower-order impressions of familiar images, which in turn enhanced the higher-order impressions. Further, this effect was found even beyond the design viewing distance. These are specific indications of the benefits that UHD brings to TV viewing in the audience's daily lives. In addition, the results of the multiple regression analyses provide insight into the production and processing of UHD images.

For future work, we will verify our findings with a larger number of subjects and conduct experiments that focus on image resolutions, a wide color gamut provided by BT.2020, and a high dynamic range.

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