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Original Paper

Memory Texture as an Important Factor Affecting Improvement of Subjective Image Sharpness by Using Noise Addition

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Abstract: Our earlier study demonstrated that the subjective sharpness of blurred images is improved by superimposing granular noise on it. We proposed that we have memory of textures of certain familiar objects encountered in daily life, similar to memory color. As described herein, for five objects, we used sample images of six kinds: the original image, a white-noise-added original image, a 1/f-noise-added original image, a blurred original image, a white-noise-added blurred image, and a 1/f-noise-added blurred image. First, observers were asked to recall an object's texture without seeing the real object and to sort the images in descending order, starting with the one closest to the recalled texture. While viewing the actual object, observers were asked to rearrange the images in descending order, starting with the one closest to the actual texture. Finally, observers were asked to rearrange the images in descending order of subjective sharpness. Correlation analysis, partial analysis, and path analysis were conducted for this reported ordering. Correlation was found between the memory texture and subjective sharpness. Results demonstrate that subjective sharpness improved when the texture of the objects in images came to approximate the remembered texture.

Key words: Noise addition, Subjective sharpness, Memory texture

1. Introduction

"Memory texture" refers to the texture that one remembers for an object surface. It is a concept similar to "memory color," which is the color that one associates with and then remembers for specific things, especially familiar objects in daily life. For instance, the red associated with apple, and the yellow associated with banana[1). Memory colors are formed in everyday life when we experience familiar objects and situations, as are memory textures.

As part of an individual's recollection for familiar objects[2)], memory colors have an important characteristic by which people living in the same environment tend to have similar memory colors. An earlier study of memory color revealed that preservation of the actual colors of sky, vegetation, and other natural objects have high preference, whereas reproducing memory colors of facial skin reveals more preferred images than those with the actual color. Not only do memory colors vary greatly among regions or nations, they also vary among genders, generations, and economic conditions[3)].

We propose memory texture as another recollection for familiar objects. It is formed by the same mechanism as that of memory color[4)]. The memory texture concept was obtained after noticing that, preference was actually increased by adding image noise to some images. Such noise has heretofore been regarded as unnecessary and as best eliminated to improve preferability of the images[5)]. Specifically, the texture of familiar objects is more preferred when textures are presented after adding noise to the images.

2. Earlier studies

2.1 Earlier study of image subjective sharpness using single-frequency sinusoidal gratings

Kurihara et al. investigated noise effects on the sharpness perception of an image by superimposing white noise on one-dimensional (1D) and two-dimensional (2D) single-frequency sinusoidal gratings as stimuli[6)]. Stimuli are presented in Figure 1.

Results of this experiment indicate that the noise addition improves the subjective sharpness more effectively when low-frequency stimuli, rather than high-frequency stimuli, are observed. Noise addition is not particularly effective for images that include clear edges. This effect is more pronounced with 2D patterns than with 1D patterns.

2.2 Previous study of subjective sharpness using natural color images

Wan et al. extended Kurihara's study using natural color images (Fig. 2) rather than black and white, single-frequency patterns[7)]. Because sinusoidal gratings can be regarded as blurred rectangular or

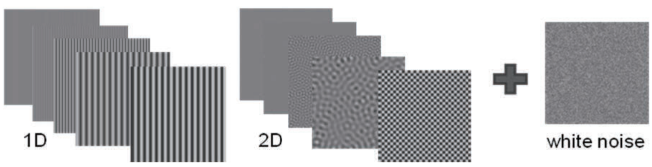

Fig. 1 Stimuli and noise used by Kurihara et al.

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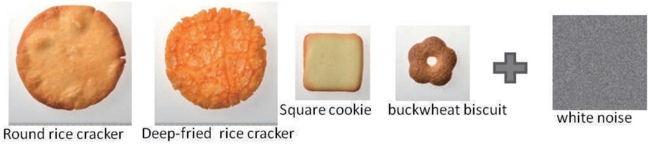

Fig. 2 Objects and noise used by Wan et al.

checkerboard patterns, we used not only clearly focused original images, but also their blurred images as stimuli. Then we added white noise to these images.

The results demonstrate clearly that the noise effects are considerable for images that include clear low-frequency components, and in blurred rather than sharp images. The dependence of subjective sharpness on frequency, as found in this study, is consistent with results obtained from the study conducted by Kurihara et al.

2.3 Previous studies of improvement in preference by noise addition

Kashibuchi et al. suggested improvements in preference achieved through noise addition[5]. Zhao et al. proposed memory textures as a factor affecting the improvement of texture preference[8]. Potatoes, cardboard, tissue, newspaper, onions, wooden chopsticks, and wooden boards were used for the study.

The results are the following: (1) No consistency was found between memory texture and actual texture in evaluations conducted with various scales. (2) Correlation was found between the memory texture and preferred texture of the objects in images.

3. Objective

By examining the observers' individual data in the experiment on subjective sharpness, we found conspicuous individual differences in the subjective sharpness improvement by noise addition to the images. A few observers for whom the effect was strong had some experience with enlarging a negative to produce black and white prints, where the result of focus adjustment can be determined by the appearance of silver grains. Based on this result, we propose that a relation exists between the effect of noise addition and a person's memory: we hypothesized that adding noise to a blurred image causes observers to recall the object texture from memory, and that this recall exaggerates the subjective sharpness of the image. Improvement of the subjective sharpness if the texture occurs as the noise addition comes to approximate the memory texture. This study examined the relation between the subjective sharpness and memory texture that have not been investigated.

4. Experiment

We took photos using a NIKON D800 (Nikon Corp., Tokyo, Japan) with 7360 * 4912 pixels JPEG file, fine-image quality, F22, and ISO-200. The settings related to sharpness are standard and the Vibration Reduction (VR) of the lens is turned on. The image processing software used in this study were the same as the ones used in our previous study[7].

4.1 Original images of objects

Figure 3 depicts original images we used in this experiment. The objects have various distinctive textures and different spatial frequency characteristics. We used deep-fried rice crackers, round rice crackers, and buckwheat biscuits, as in our previous study[7] of subjective sharpness. Additionally, we used sweet potatoes and tissue for more texture variety. They are similar to the samples used in an earlier study[8] of the memory texture. As the same with our previous study[7], the evaluation experiment was conducted using hard copies. We cut 2048 * 2048 pixels out from the original digital photos to make the hard copies have a resolution of 500 dpi when printed out in 10.4 * 10.4 cm, and all images were adjusted to the actual size of the objects. The images were printed on gloss photographic papers (EPSON KA4100PSKR, Seiko Epson Corp., Nagano, Japan), using an ink-jet printer (EPSON MAXART PX5500, Seiko Epson Corp., Nagano, Japan).

Figure 4 presents the power spectra of the original images. The power spectra of (c) deep-fried rice cracker, (d) round rice cracker, and (e) buckwheat biscuit were slightly different from those in our previous study[7]. (c) was another kind of deep-fried rice cracker a little differed from that used in our previous study[7]. (d) and (e) were the same kinds with those used in our previous study[7] but different individuals.

The order from high mean value to low mean value of power was the following: sweet potato, buckwheat biscuit, deep-fried rice cracker, round rice cracker, and tissue. The objects are divisible into two groups. The first group includes the buckwheat biscuit and deep-fried rice cracker. Their textures are readily apparent: The buckwheat biscuit has a characteristically porous surface. In addition, the

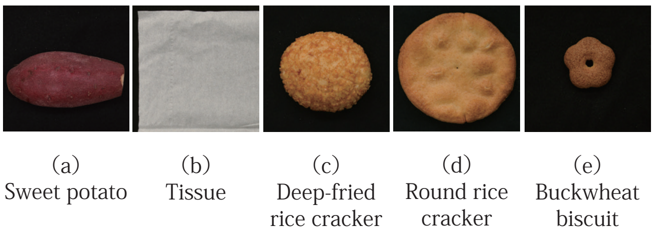

Fig. 3 Objects used for this study.

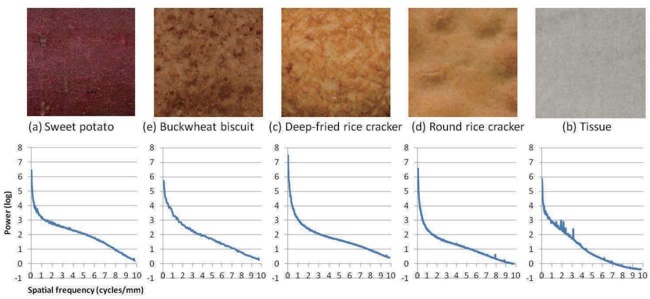

Fig. 4 Power spectra of the original images for respective objects.

Table 1 Mean of power of the original images for each object

	Sweet potato	Buckwheat biscuit	Deep-fried rice cracker	Round rice cracker	Tissue
Mean of power	2.0	1.9	1.8	1.3	1.1

deep-fried rice cracker texture is that of a surface covered with cracks in a linear shape.

The second group includes sweet potato, round rice cracker, and tissue. Their textures appear to be smooth. Although the power spectra demonstrate that sweet potato images contain more high power in wide frequency range, the sweet potato appears to be smooth at a glance. Details of the texture would be difficult for human observers to notice because of its deep color and low brightness.

4.2 Image noise

According to earlier studies of memory texture, there is a suitable noise for the texture of some objects, and that could be white noise or 1/f noise. So we used white noise and 1/f noise as image noise in this experiment. Figure 5 shows the power spectra of white noise and 1/f noise. White noise is characterized by constant power in the spatial frequency region. 1/f noise is characterized by descent power in the spatial frequency region (as shown in (i)). When taking the logarithm of both power and spatial frequency, the slope becomes -1 (as shown in (ii)).

4.3 Stimulus images for evaluation

In our previous study[7] using noise of one kind, we used two blur levels (radius (described later) 8 or 12) and two noise levels (RMS granularity[9] 10 or 20 (referred to RMS 10 or 20 later)). In this study, because we used noise of two kinds, we used one blur level and one noise level to avoid overwhelming the observers with too many images to evaluate. Figure 6 portrays stimulus images for evaluation.

Images were prepared for evaluation as follows: first, the original images (no-0) were blurred (blur-0) using the Lens Blur feature of the Blur Filter tool in Photoshop™ (CS4, Adobe Systems Inc.). For this study, we set the blur level at radius 8. The radius setting sets the strength of the lens-blur effect and has a pseudo effect that resembles f-stop setting of lens. Other settings about Lens Blur were all default (speed: Faster, Source: none, Iris Shape: Hexagon, Circularity of the aperture: 0, Rotation: 0, Brightness: 0, Threshold: 255, Amount of noise: 0, Distribution: Uniform, Monochromatic: uncheck). Then white noise and 1/f noise were added, respectively, at level RMS 20.

After blurring the image and adding noise, we clipped the area within which only the object was chosen using the Magic Wand Tool in Photoshop, and combined it with the background of the original sample image. This clipping and combining were done to prevent changes in the object edge and the background from affecting evaluation of the texture and subjective sharpness.

Six images were evaluated for each of the five objects, including images without noise. Consequently, 30 images were evaluated. Figure 7 presents power spectra of the original image and the blurred original image of each object.

4.4 Evaluation environment

The evaluation environment was the same as that used in our previous subjective sharpness experiment[7]. Evaluation was conducted at 700 lx under a natural color evaluation fluorescent lamp with a color temperature of 5000 K (Toshiba Corp., Tokyo, Japan). Participants were asked to observe the images at the distance of distinct vision (about 25 cm for normal vision).

4.5 Evaluation procedures

Experiments evaluating the memory texture, the actual texture, and subjective sharpness were conducted using a normalized rank approach. First, participants were asked to recall the texture of an object in each image without seeing the real object, and to sort the images in descending order, starting with the one most closely approximating the recalled texture. Subsequently, they viewed the real object with a black background identical to that in the stimulus im-

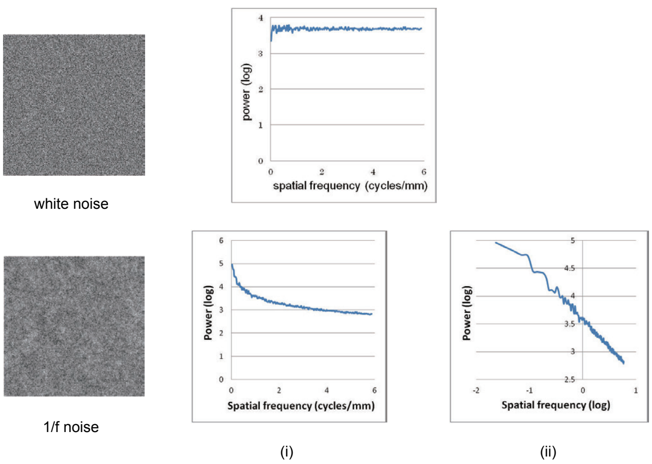

Fig. 5 Power spectra of white noise and 1/f noise.

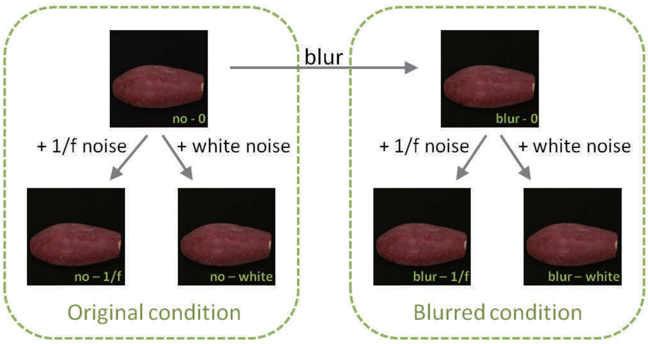

Fig. 6 Images for evaluation. Words before "-" denote blurring. "no" denotes no blur images. "blur" denotes blurred images. Words after "-" denote noise. "0" denotes no noise. "1/f" denotes 1/f noise addition. "white" denotes white noise addition. Therefore, "no-0" denotes no blur image with no noise addition. "no-1/f "signifies that no blur image was combined with 1/f noise. "no-white" signifies that no blur image was combined with white noise. "blur-0" denotes a blurred image with no noise addition. "blur-1/f" signifies that a blurred image was combined with 1/f noise. "blur-white" signifies that a blurred image was combined with white noise. We treated no-0, no-1/f, and no-white as original conditions, and treated blur-0, blur-1/f, and blur-white as blurred conditions.

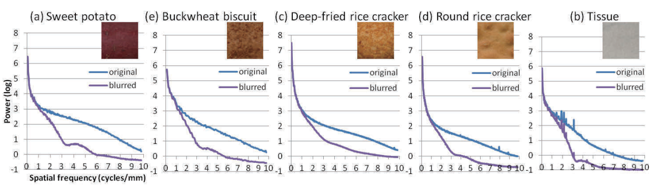

Fig. 7 Power spectra of the original image and the blurred original image of each object

ages. Participants were asked to rearrange the images in descending order, starting with the one nearest to the actual texture. Finally, they were asked to rearrange the images in descending order of subjective sharpness. We conducted correlation analysis, partial correlation analysis and path analysis with results obtained from the two groups of experiments. Fifteen participants conducted these evaluations.

5. Results and discussion

5.1 Kendall's coefficient of concordance *W*

We calculated Kendall's coefficient of concordance *W*. Table 2 presents the values and results of significance test[10] of *W* (Chi-squared test). Values in cells with color were found to be significant (significance level 0.5%, 1% or 10%). Deeper colors represent stronger significance (0.5% indicates stronger significance than 1%). Values in cells with no color were not significant.

Table 2 Values and significance of Kendall's coefficient of concordance *W* for each object. Values in cells with color were found to be significant. Deeper colors represent stronger significance. Values in cells with no color were not significant.

	Memory texture	Actual texture	Subjective sharpness
Sweet potato	0.297 (0.5%)	0.065	0.699 (0.5%)
Tissue	0.128 (10%)	0.044	0.289 (0.5%)
Deep-fried rice cracker	0.228 (1%)	0.225 (0.5%)	0.362 (0.5%)
Round rice cracker	0.127 (10%)	0.273 (0.5%)	0.359 (0.5%)
Buckwheat biscuit	0.112	0.306 (0.5%)	0.594 (0.5%)

The low *W* for the buckwheat biscuit memory texture indicates that the individual variance in ratings was large. This large individual variance might derive from differences in participants' familiarity with buckwheat biscuits, which are not a widely appreciated snack.

The individual variances in ratings for actual textures of sweet potato and tissue were large. Surface textures of sweet potato and tissue were difficult for participants to notice. The way to recognize the texture would differ greatly among participants.

5.2 Results of a normalized rank approach

To investigate the memory texture, the actual texture, and subjective sharpness of each object, we obtained scale values of the normalized rank approach and discussed the characteristics. Figure 8 presents the scale values of the normalized rank approach for the respective objects.

In terms of memory texture, the actual texture, and subjective sharpness, scale values of normalized rank approach which show a wide spread in the plot and clear significant differences in Figure 8, also show a large coefficient of concordance in Table 2.

From Figure 8, we can see the stimuli of the blurred condition (blur-0, blur-1/f, blur-white) correspond to the respective stimuli of the original condition (no-0, no-1/f, no-white) eliciting lower ranks of memory texture, actual texture, and subjective sharpness.

In the blurred condition, the stimuli with noise elicited higher subjective sharpness rankings than the stimuli with no noise. That

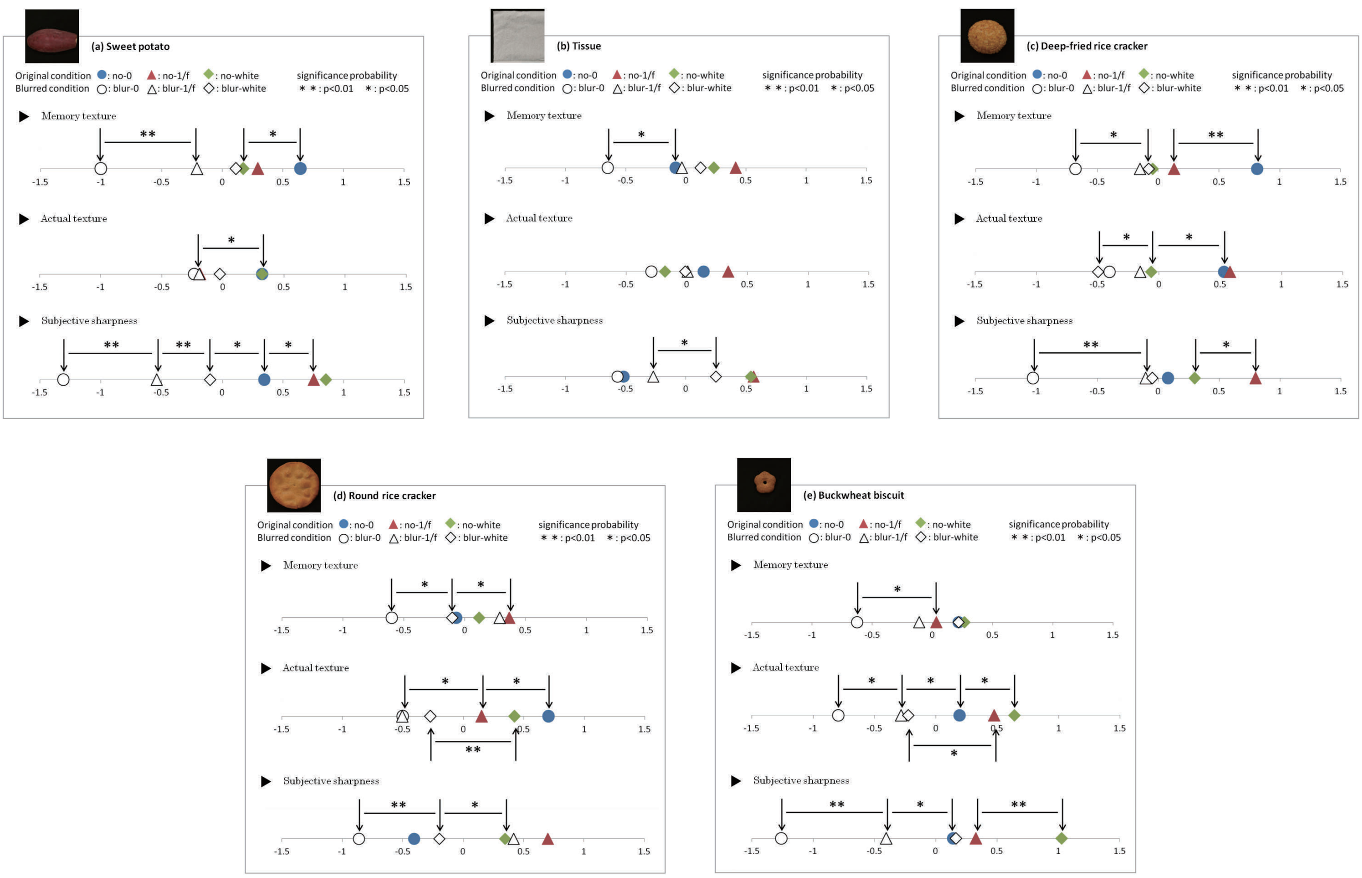

Fig. 8 Results of the normalized rank approach for the respective objects. The abscissa is the scale values. Higher scale value represents higher rank. The mark (*) indicates significant differences with a significance level of 5%, and (**) indicates 1%.

result is consistent with results obtained from our previous study[7].

For objects with lower frequency and for which the texture was not clearly visible, such as tissues and round rice crackers, little difference was found between the original (no-0) and the blurred original (blur-0). However, for objects with higher frequency such as sweet potato, deep-fried rice cracker, and buckwheat biscuit, a great difference was found between original and blurred images.

For (a) sweet potato, blur-white was ranked higher than blur-1/f, and there was significant difference between blur-white and blur-1/f in subjective sharpness. For (b) tissue, no-1/f was ranked high in memory texture, actual texture and subjective sharpness. There was significant difference between blur-white and blur-1/f in subjective sharpness. For (c) deep-fried rice cracker, there were significant differences between no-1/f and no-white both in actual texture and in subjective sharpness. For (d) round rice cracker, both no-1/f and blur-1/f were ranked high in memory texture and subjective sharpness. There was significant difference between blur-1/f and blur-white in subjective sharpness. For (e) buckwheat biscuit, no-white was ranked high in memory texture, actual texture and subjective sharpness. There were significant differences both between no-white and no-1/f and between blur-white and blur-1/f in subjective sharpness. Table 3 presents the first place of images in the original condition and in the blurred condition for each object in terms of the memory texture, the actual texture, and subjective sharpness.

The stimuli with noise elicited higher ranking in terms of the subjective sharpness. The first places of the blurred condition on memory texture are the same as first places of blurred condition for subjective sharpness. The stimulus evaluated as the most subjectively sharp was the nearest to the memory texture. The noise effects were more evident in blurred images. These results are consistent with results obtained from our previous study[7].

Actually, 1/f noise did not appear for sweet potato or buckwheat biscuit in Table 3. In some cases, the 1/f noise also had some effect, but not as much as white noise. This result demonstrates that white noise is more suitable for textures of sweet potatoes and buckwheat biscuits. However, for round rice cracker, only 1/f noise appeared in memory texture or subjective sharpness in Table 3. These results suggest that using two kinds of noise was meaningful.

5.3 Correlation analysis

The scale values obtained from the normalized rank approach fitted a normal distribution. Therefore, we can calculate Pearson's correlation coefficient (Pearson product-moment correlation coefficient) r between the scale values. Between the ranks of the scale value, we can calculate Spearman's rank correlation coefficient ρ and Kendall's rank correlation coefficient τ. We calculated the three kinds of correlation coefficients to see whether the results of them were the same.

First, we calculated the correlation coefficient for each object. For instance, for sweet potatoes, we collected the scale values of memory texture, actual texture, and subjective sharpness, and obtained a rank, respectively, as Table 4 shows.

Table 3 First place of original condition and blurred condition for each object on memory texture, actual texture, and subjective sharpness

	Memory texture		Actual texture		Subjective sharpness	
	Original condition	Blurred condition	Original condition	Blurred condition	Original condition	Blurred condition
Sweet potato	0	white	0	white	white	white
Tissue	1/f	white	1/f	1/f	1/f	white
Deep-fried rice cracker	0	white	1/f	1/f	1/f	white
Round rice cracker	1/f	1/f	0	white	1/f	1/f
Buckwheat biscuit	white	white	white	white	white	white

Table 4 Scale values and ranks of memory texture, actual texture, and subjective sharpness for sweet potato. Each column has six values because six stimulus images exist for each object.

	scale value			rank		
stimuli	Memory texture	Actual texture	Subjective sharpness	Memory texture	Actual texture	Subjective sharpness
no-0	0.642	0.320	0.344	1	2	3
no-1/f	0.290	-0.187	0.751	2	4	2
no-white	0.171	0.321	0.851	3	1	1
blur-0	-1.004	-0.234	-1.307	6	6	6
blur-1/f	-0.210	-0.194	-0.539	5	5	5
blur-white	0.112	-0.026	-0.101	4	3	4

Ranks, scale values and corresponding stimulus images for sweet potato on memory texture, actual texture, and subjective sharpness. Each column has six values because six stimulus images exist for each object.

Memory texture			Actual texture			Subjective sharpness		
rank	scale value	stimuli	rank	scale value	stimuli	rank	scale value	stimuli
1	0.642	no-0	1	0.321	no-white	1	0.851	no-white
2	0.290	no-1/f	2	0.320	no-0	2	0.751	no-1/f
3	0.171	no-white	3	-0.026	blur-white	3	0.344	no-0
4	0.112	blur-white	4	-0.187	no-1/f	4	-0.101	blur-white
5	-0.210	blur-1/f	5	-0.194	blur-1/f	5	-0.539	blur-1/f
6	-1.004	blur-0	6	-0.234	blur-0	6	-1.307	blur-0

We calculated the correlation between the memory texture and the actual texture. We obtained Pearson's correlation coefficient r using scale values. Then we calculated Spearman's rank correlation coefficient ρ and Kendall's rank correlation coefficient τ using ranks. Additionally, we obtained the respective significance probabilities p of these correlation coefficients. We calculated the correlation between memory texture and subjective sharpness and the correlation between actual texture and subjective sharpness. Additionally, we calculated correlation coefficients in the same way as sweet potato for the other four objects. Finally, we calculated correlation using data from five objects with six image conditions.

The values of correlation coefficients and results of significance test (t - test) are presented in Table 5. We show cells of $p < 0.001$, $p < 0.01$, $p < 0.05$, and $p < 0.1$ in different colors. Cells with color are significant. Deeper colors represent greater significance.

From the differences in color of the cells, we can see that there were differences among the results of Pearson's correlation coefficient, Spearman's rank correlation coefficient and Kendall's rank correlation coefficient. It might be because that the participants were not enough to result significances for all the three kinds of correlation coefficients.

The results of correlation for each object (Table 5) show correlation between the memory texture and subjective sharpness. For tissues and round rice crackers, correlation was found only between the memory texture and subjective sharpness. Aside from memory, the texture is an important clue for judging subjective sharpness. For objects with more low frequency and for the texture of which was not clearly visible, such as tissues and round rice crackers, there was little texture as a clue for subjective sharpness. Therefore, memory shows a consistent influence on subjective sharpness.

Results of all stimuli showed strong correlation between the memory texture and subjective sharpness. Strong correlation was also found between the actual texture and subjective sharpness, and between the memory texture and the actual texture.

Objects for which no correlation was found between memory texture and actual texture, such as tissue and round rice crackers, revealed little correlation, little partial correlation (Table 6) and little casual relation (Table 7) between actual texture and subjective sharpness. From these results, we infer that correlation existed between the actual texture and subjective sharpness for the other objects (sweet potato, deep-fried rice cracker and buckwheat biscuit) in correlation analysis is a consequence of the correlation between the actual texture and the memory texture. Moreover, this idea is supported by the result that no object was found with correlation only between the actual texture and subjective sharpness.

Table 5 Correlation coefficients and their significance level for each object and all stimuli. We show cells of $p < 0.001$, $p < 0.01$, $p < 0.05$, and $p < 0.1$ in different colors. Cells with color are significant. Deeper colors represent greater significance. Significance level of cells without a p value are p values greater than 0.1.

Sweet potato	Memory texture vs. Subjective sharpness	Actual texture vs. Subjective sharpness	Memory texture vs. Actual texture
Pearson	0.857 ($p < 0.05$)	0.615	0.658
Spearman	0.771 ($p < 0.1$)	0.829 ($p < 0.05$)	0.714
Kendall	0.600 ($p < 0.1$)	0.733 ($p < 0.05$)	0.600 ($p < 0.1$)

Tissue	Memory texture vs. Subjective sharpness	wActual texture vs. Subjective sharpness	Memory texture vs. Actual texture
Pearson	0.858 ($p < 0.05$)	0.317	0.670
Spearman	1 ($p < 0.001$)	0.429	0.429
Kendall	1 ($p < 0.01$)	0.200	0.200

Deep-fried rice cracker	Memory texture vs. Subjective sharpness	Actual texture vs. Subjective sharpness	Memory texture vs. Actual texture
Pearson	0.601	0.682	0.762 ($p < 0.1$)
Spearman	0.829 ($p < 0.05$)	0.771 ($p < 0.1$)	0.771 ($p < 0.1$)
Kendall	0.733 ($p < 0.05$)	0.600 ($p < 0.1$)	0.600 ($p < 0.1$)

Round rice cracker	Memory texture vs. Subjective sharpness	Actual texture vs. Subjective sharpness	Memory texture vs. Actual texture
Pearson	0.960 ($p <0.01$)	0.162	0.270
Spearman	0.943 ($p <0.01$)	-0.086	0.086
Kendall	0.867 ($p < 0.05$)	-0.067	0.067

Buckwheat biscuit	Memory texture vs. Subjective sharpness	Actual texture vs. Subjective sharpness	Memory texture vs. Actual texture
Pearson	0.910 ($p < 0.05$)	0.931 ($p < 0.01$)	0.781 ($p < 0.1$)
Spearman	0.826 ($p < 0.05$)	0.943 ($p <0.01$)	0.771 ($p < 0.1$)
Kendall	0.733 ($p < 0.05$)	0.867 ($p < 0.05$)	0.600 ($p < 0.1$)

All stimuli	Memory texture vs. Subjective sharpness	Actual texture vs. Subjective sharpness	Memory texture vs. Actual texture
Pearson	0.813 ($p < 0.001$)	0.563 ($p < 0.01$)	0.568 ($p < 0.01$)
Spearman	0.836 ($p < 0.001$)	0.543 ($p < 0.01$)	0.547 ($p < 0.01$)
Kendall	0.651 ($p < 0.001$)	0.398 ($p < 0.01$)	0.389 ($p < 0.01$)

5.4 Partial correlation analysis

Partial correlation analysis is often used as a method of multivariate analysis. As seen in the results of correlation analysis, correlation existed both between memory texture and subjective sharpness, and between actual texture and subjective sharpness. In order to further clarify the correlation between memory texture and subjective sharpness, and between actual texture and subjective sharpness, we used subjective sharpness as the dependent variable, with memory texture and the actual texture as independent variables.

We calculated the partial correlation coefficient between the memory texture and subjective sharpness, with the effect of the actual texture removed, and the partial correlation coefficient between the actual texture and subjective sharpness, with the effect of memory texture removed, using scale values. Results of a comparison with the Pearson's correlation coefficient are presented in Table 6.

Results for the respective objects (Table 6) were consistent for both single correlation and partial correlation. Results of all stimuli indicate partial correlation between memory texture and subjective sharpness; although no partial correlation was found between actual

Table 6 Comparison of single correlation and partial correlation

		Memory texture vs. Subjective sharpness	Actual texture vs. Subjective sharpness
Sweet potato	Single correlation	0.857 ($p < 0.05$)	0.615
	Partial correlation	0.763 ($p < 0.1$)	0.132
Tissue	Single correlation	0.858 ($p < 0.05$)	0.317
	Partial correlation	0.916 ($p < 0.05$)	-0.673
Deep-fried rice cracker	Single correlation	0.601	0.682
	Partial correlation	0.172	0.434
Round rice cracker	Single correlation	0.960 ($p < 0.01$)	0.162
	Partial correlation	0.964 ($p < 0.01$)	-0.359
Buckwheat biscuit	Single correlation	0.910 ($p < 0.05$)	0.931 ($p < 0.01$)
	Partial correlation	0.803 ($p < 0.1$)	0.850 ($p < 0.05$)
All stimuli	Single correlation	0.813 ($p < 0.001$)	0.398 ($p < 0.01$)
	Partial correlation	0.724 ($p < 0.001$)	0.211

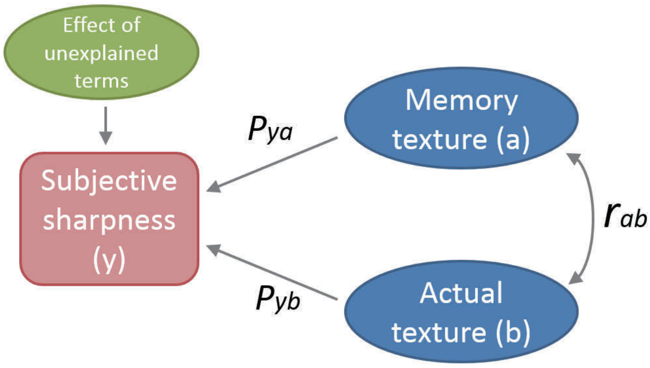

Fig. 9 Path diagram. Effects of the memory texture and the actual texture on subjective sharpness are the following. P_{ya} represents the direct effect of memory texture on subjective sharpness. P_{yb} denotes the direct effect of the actual texture on subjective sharpness. The correlation effect of memory texture on subjective sharpness through the actual texture is *rab** P_{yb}. Correlation effects of the actual texture on subjective sharpness through memory texture is *rab** P_{ya}. Total effects of memory texture on subjective sharpness is P_{ya}+ *rab** P_{yb} (=*ray*). Total effects of Actual texture on subjective sharpness is P_{yb}+ *rab** P_{ya} (=*rby*).

Table 7 Direct effect, correlative effect, total effect, and coefficient of determination (R^2) of memory texture and actual texture for each object and all stimuli

		Direct effect	Correlative effect	Total effect	Coefficient of determination (R^2)	Effect of unexplained terms
Sweet potato	Memory texture	0.798	0.059	0.857	0.740	0.510
	Actual texture	0.090	0.525	0.615		
Tissue	Memory texture	1.170	-0.312	0.858	0.855	0.380
	Actual texture	-0.466	0.784	0.318		
Deep-fried rice cracker	Memory texture	0.194	0.408	0.602	0.481	0.720
	Actual texture	0.535	0.148	0.683		
Round rice cracker	Memory texture	0.988	-0.028	0.960	0.931	0.262
	Actual texture	-0.105	0.267	0.162		
Buckwheat biscuit	Memory texture	0.470	0.440	0.910	0.953	0.218
	Actual texture	0.563	0.367	0.930		
All stimuli	Memory texture	0.728	0.085	0.813	0.676	0.570
	Actual texture	0.150	0.414	0.564		

texture and subjective sharpness. Results support a relation between the memory texture and subjective sharpness.

5.5 Path analysis

Path analysis is another common method of multivariate analysis. It provides estimates of the magnitude of hypothesized causal connections between sets of variables. We investigated the magnitude of effects of memory texture on subjective sharpness and the magnitude of effects of actual texture on subjective sharpness, using path analysis. Figure 9 depicts the path diagram of the path analysis, with subjective sharpness as the dependent variable, and the memory texture and the actual texture as independent variables. Results of path analysis are presented in Table 7.

For sweet potato, tissue, and round rice cracker images, both large direct effects and total effects of memory texture on subjective sharpness were found. As grouping with spatial frequency characteristics and surface textures, the textures of the three objects appear to be smooth. For the tissue and round rice cracker, a large difference in direct effects was found between the memory texture and the actual texture, and the same for total effect. No such a large difference was found for sweet potato, which is possibly true because, as the power spectra indicates, tissue, and round rice cracker showed lower power in a wide frequency range, whereas sweet potato showed higher power in a wide frequency range.

For the deep-fried rice cracker and buckwheat biscuit, a large direct effect of the actual texture on subjective sharpness was found. The textures of the two objects were clearly visible. However, little difference was found between the total effects of memory texture and actual texture. For buckwheat biscuit, both total effects were large. For deep-fried rice cracker, both total effects were small. The coefficient of determination R^2 was small, meaning that other factors played a great role in the judgment of subjective sharpness of the deep-fried rice cracker. Small R^2 is expected to result from the surface property of deep-fried rice crackers, which are covered with linear cracks. The appearance of lines served as clues for judgment of subjective sharpness. Moreover, it might be true because the contrast and stereoscopic effects are evaluated differently among stimuli. Those differences affected the evaluation of the subjective sharpness.

For all stimuli, both direct effects and total effects of memory texture on subjective sharpness were large. Memory strongly affected the subjective sharpness.

6. Conclusion

Results of correlation analysis, partial correlation analysis and path analysis were mutually consistent, demonstrating consistently that subjective sharpness is related to the memory texture. These results suggest that the memory texture of objects is an important factor affecting the subjective sharpness of images.

The influences of other factors which could affect the judgment of subjective sharpness cannot be ignored either, as seen in the path analysis. And it is also because that there was effect of noise on subjective sharpness in the experiment used sinusoidal gratings which have no texture.

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References

1) The Color Science Association of Japan, "Handbook of Color Science", third Edition, University of Tokyo Press, Tokyo, 2011, p. 501.
2) C. J. Bartleson, "Memory Colors of Familiar Objects", J. Opt. Soc. Am., 50, 73–77 (1960).
3) P. Deng, N. Aoki, H. Kobayashi, "Comparison of Impression Received from Some Flesh Color between Japanese and Chinese and the Determination Factors", J. Soc. Photogr. Imag. Japan, 76, 63–69 (2013).
4) N. Takesue, N. Aoki, H. Kobayashi, "Memory texture and its relationship with object's texture", PPIC08, June 27, 2008 (Tokyo).
5) Y. Kashibuchi, N. Aoki, M. Inui, and H. Kobayashi, "Improvement of description in digital print by adding noise," J. Soc. Photogr. Sci. Technol. Japan, 66(5), 471–480 (2003).
6) T. Kurihara, N. Aoki, H. Kobayashi, "Analysis of Sharpness Increase and Decrease by Image Noise", J. Imaging Sci. Technol., 55, 030504 (2011).
7) X. Wan, N. Aoki, H. Kobayashi, "Improving the Perception of Image Sharpness using Noise Addition", Bull. Soc. Photogr. Imag. Japan. Vol. 24 No. 2, 19-26 (2014)
8) H. Kobayashi, Y. Zhao, N. Aoki, "Memory Texture as a Mechanism of Improvement in Preference by Adding Noise", 2014 Electronic Imaging, 9014-13 (2014).
9) J. C. Dainty, R. Shaw, "Image Science", Academic Press, London, 1976, p. 284–287.
10) Walter Ledermann, Emlyn Lloyd, "Handbook of Applicable Mathematics Volume VI: Statistics", A Wiley-Interscience Publication, Chichester, 1984, p. 209.