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Original Paper

Improving the Perception of Image Sharpness Using Noise Addition

Xiazi Wan*, Naokazu Aoki*, and Hiroyuki Kobayashi*

Abstract: In our previous paper, we investigated the effects of image noise on the perception of image sharpness using white noise, and one- and two-dimensional (1D and 2D, respectively) single-frequency sinusoidal patterns as stimuli. Our results showed that with high-frequency stimuli, sharpness decreased as noise level increased; whereas, with low-frequency stimuli, sharpness reached a maximum value at a certain level. The sharpness of the rectangular grating and the checkerboard pattern, both of which have clear edges, decreases more drastically even than the sinusoidal wave with the highest frequency. This paper builds on our previous study by evaluating color natural images rather than black-and-white, single-frequency patterns. Our results indicate that the effects of noise are more remarkable in images of objects containing more low-frequency components, in blurred rather than sharp images, and in strongly blurred images. The dependence of sharpness on frequency, as found in this study, is consistent with results from the preceding study; the results we obtained using black-and-white, single-frequency patterns were verified using color images of natural objects. Furthermore, we acquired new information on the influence of texture, which we did not investigate in our previous studies, i.e., noise has a negligible effect on images with a large number of edges; whereas, we observed the most significant effects for images without such a texture.

Key words: Noise addition, Perception of image sharpness, Spatial frequency dependence

1. Introduction

1.1 Current Knowledge

Currently, the digital photograph has become comparable to the silver halide photograph in information capacity. However, when considered as a target of appreciation, silver halide photographic prints are excellent in the subjective region, i.e., the region that cannot be physically evaluated. A possible cause is that digital photographs are said to be considerably smooth—there is no granular noise; these photographs appear as a picture for coloring. Some professional photographers intentionally add granular noise to images captured using digital cameras to improve the texture quality of digital photographs because granular noise resembles the graininess of a silver-halide film or photograph [1].

Some studies have suggested the possibility of improving image quality through the addition of noise [2]. Other studies have suggested improvements in likeability by noise addition [3]. There are also studies that highlight the relationship between noise addition and memory of texture [4], with the authors of one study proposing that textures can be recalled in association with familiar objects, in a similar manner as memory color [5].

Further, Kurihara et al. investigated the effects of noise on the sharpness of an image by adding white noise to one- (1D) and two-dimensional (2D) single-frequency sinusoidal gratings as stimuli and comparing them with rectangular and checkerboard patterns, respectively [6]. The stimuli are shown in Fig. 1.

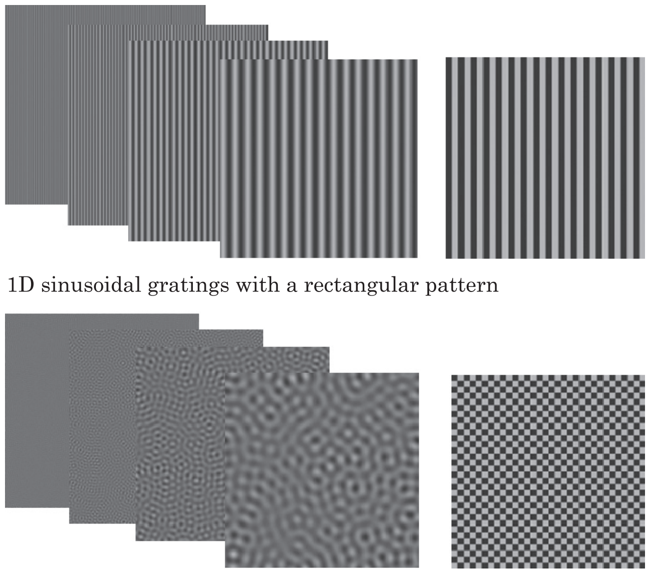

Fig. 1. Stimuli used in the study of Kurihara et al.[1]

The results of this experiment indicate that the addition of noise improves the sharpness more effectively when low-frequency stimuli, rather than high-frequency stimuli, are used. Addition of noise is not particularly effective in images that contain clear

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*Graduate School of Advanced Integration Science, Chiba University, 1-33 Yayoi-cho, Inage-ku, Chiba 263-8522, Japan

(a) Round rice cracker

(c) Square cookie

(b) Deep-fried rice cracker

(d) Buckwheat cookie

Fig. 2. Sample images

edges, such as rectangular and checkerboard patterns. This effect is more pronounced with 2D than with 1D patterns.

1.2 Objective

This paper further develops the ideas of Kurihara et al.'s previously mentioned study by evaluating natural color images as opposed to black-and-white, single-frequency patterns. Our goal is to find whether the results for simple patterns also apply to color images.

2. Experiment

Because sinusoidal gratings can be regarded as blurred rectangular or checkerboard patterns, we used focused original images

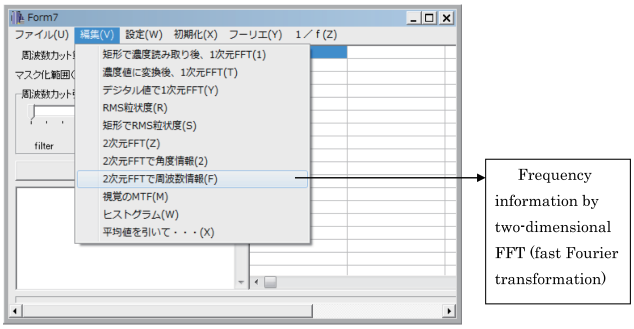


Fig. 3. Interface of frequency analysis program

and their blurred images as stimuli, and then added white noise to these images.

2.1 Original sample images

We chose rice crackers and cookies because they are familiar items that have various textures. Fig. 2 shows the images used.

To prevent shadows, we captured photos under diffuse light. We took photos using a NIKON D800 (Nikon Corp., Tokyo, Japan) with 7360 × 4912 pixels JPEG file, fine-image quality, shutter speed 1/250, F16, and ISO-100. The settings related to sharpness are standard and the Vibration Reduction (VR) of the lens is turned on.

The spatial frequency region where the Visual Transfer Function (VTF) of human eye shows significant values is 0–10 cycles/mm when people observe at the distance of distinct vision (a distance where distinct vision was possible. 25–30 cm in the normal eye). Because 10 cycles/mm = 500 dpi, we cut 2048 × 2048 pixels with 500 dpi (10.4 × 10.4 cm) out from the original photos and all images were adjusted to the actual size of the objects.

2.2 Power spectrum measuring tool and the power spectra of the original images

We used a software *frequency analysis program* as a power spectrum measuring tool (Fig. 3).

The method of calculating the power spectrum is to take the average of the values of all angles (0°–180°) by performing a two-dimensional FFT.

Figure 4 shows the power spectra of the images. The abscissa is

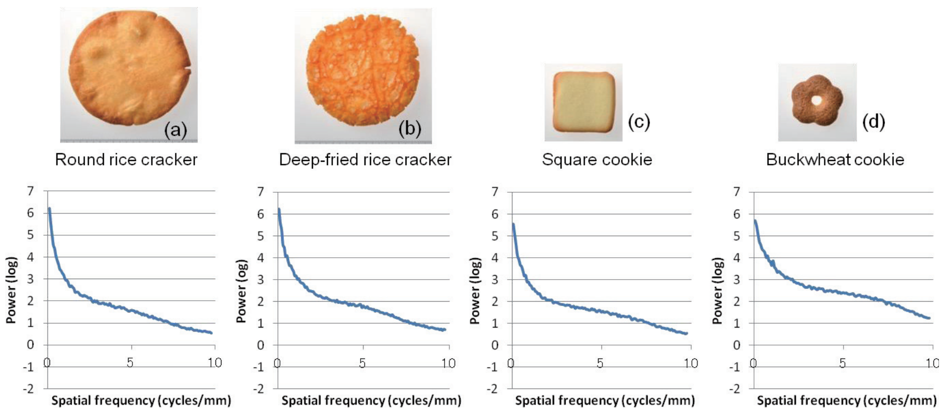


Fig. 4. Power spectra of the sample images

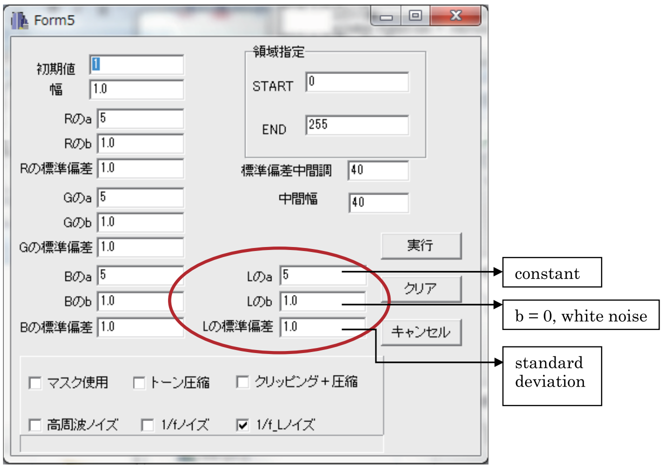


Fig. 5. Interface of color graininess program

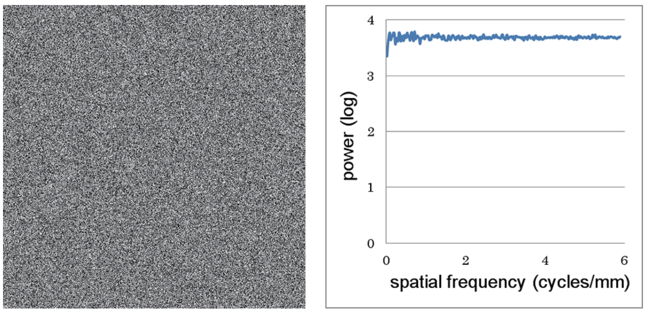


Fig. 6. White noise and its power spectrum

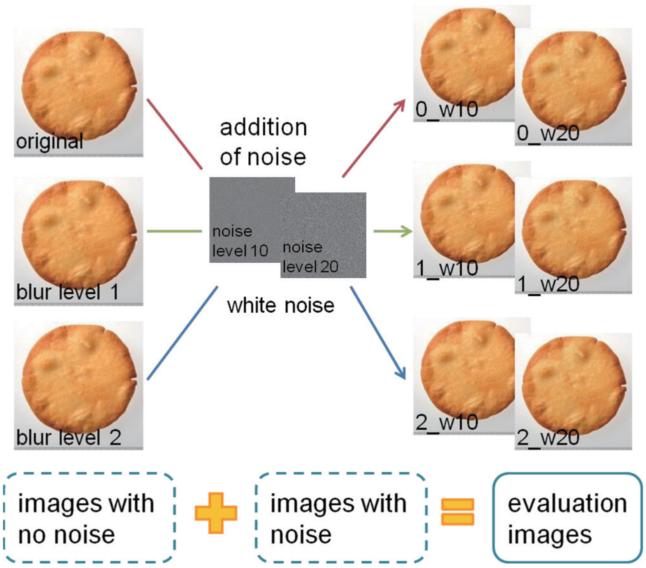


Fig. 7. Preparation of the images for the evaluation: The original images were blurred at two different levels (1 and 2), and then noise was added at two different levels (w10 and w20). For each sample, there were nine images to be evaluated, including images without noise.

the spatial frequency region where the VTF of human eye shows significant values (0–10 cycles/mm) and the ordinate is a logarithm of a power.

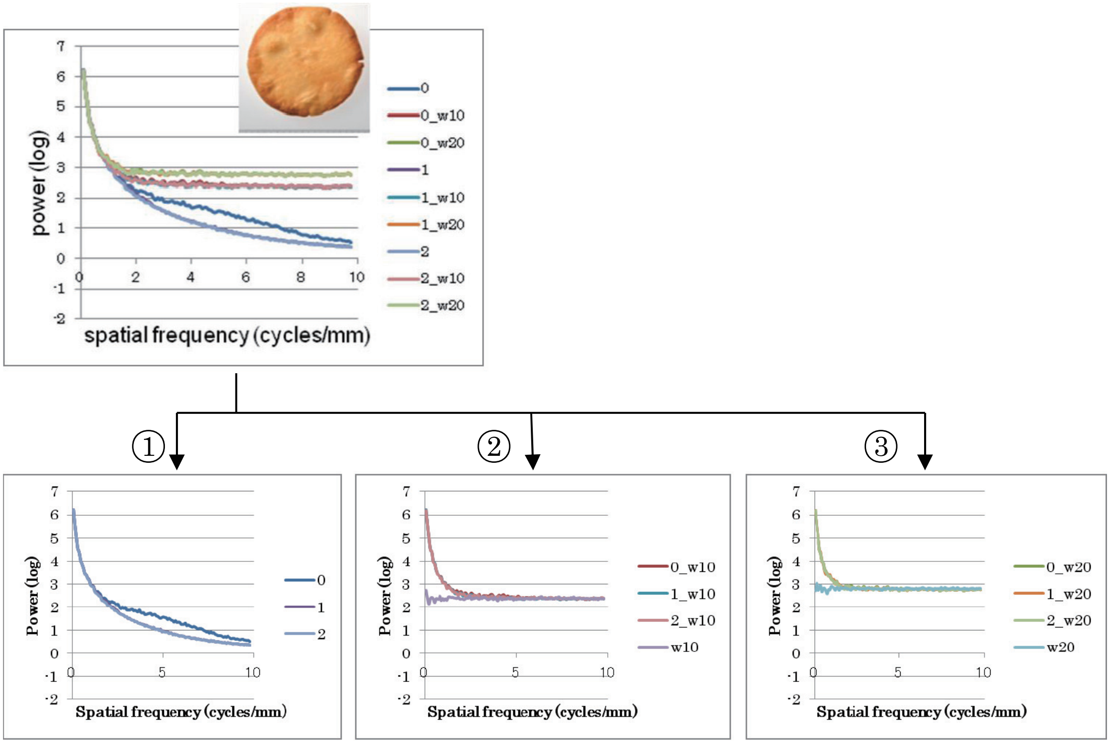
In general, images with many edges have more high-frequency components than images with fewer edges. As expected, the round rice cracker (Fig. 4(a)) and the square cookie (Fig. 4(c)) had many low-frequency components, and the buckwheat cookie (Fig. 4(d)) had many high-frequency components. Surprisingly, the surface of the deep-fried rice cracker (Fig. 4(b)) was not flat, and it did not have many high-frequency components; however, it did have many lines and a distinct texture. Because there are not many high-frequency images in rice crackers and cookies, we chose one high-frequency image and three low-frequency images, all of which have different surfaces.

Fig. 8. Examples of blur levels (magnified twice)

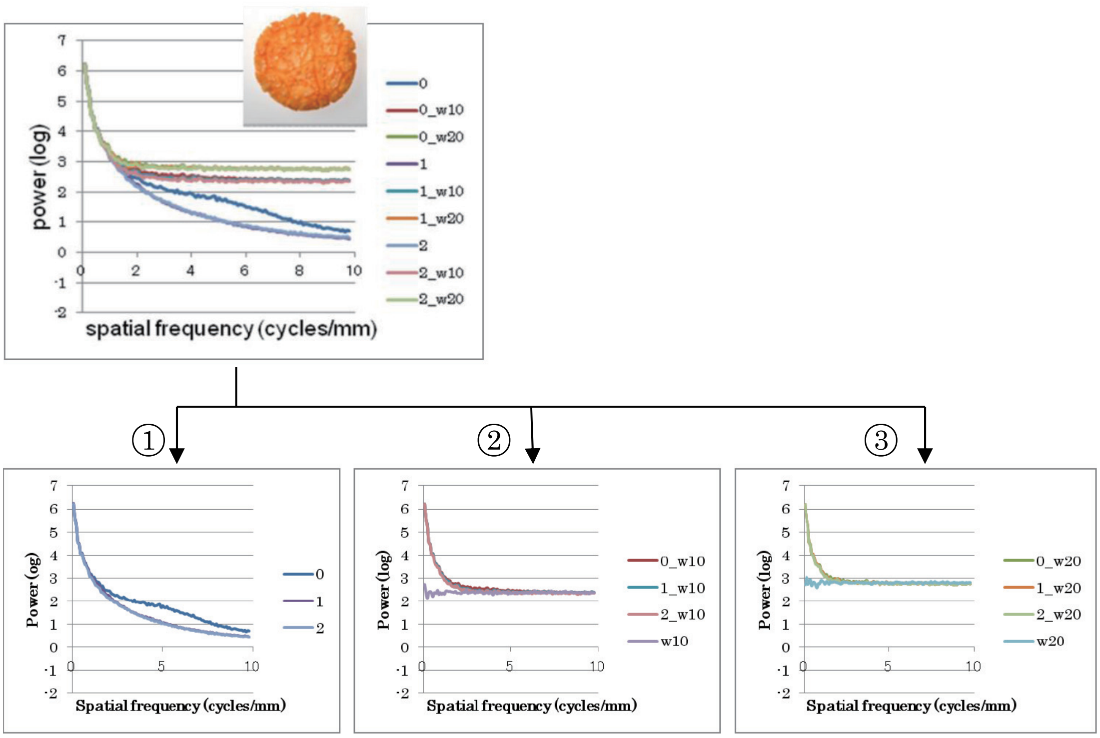
2.3 Noise addition tool

We used a software *color graininess program* as a noise addition tool (Fig. 5). “a” is a constant that can change the amplitude of noise. “b” is the slope of the double logarithmic power spectrum of the noise. By setting the value of “b” to zero, we can add white noise to the image. Further, we can control the RMS granularity value by changing the value of the *standard deviation* field.

The first step of the creation of white noise is to generate a two-dimensional noise using a Gaussian random number, and then the two-dimensional noise is added to the image data.



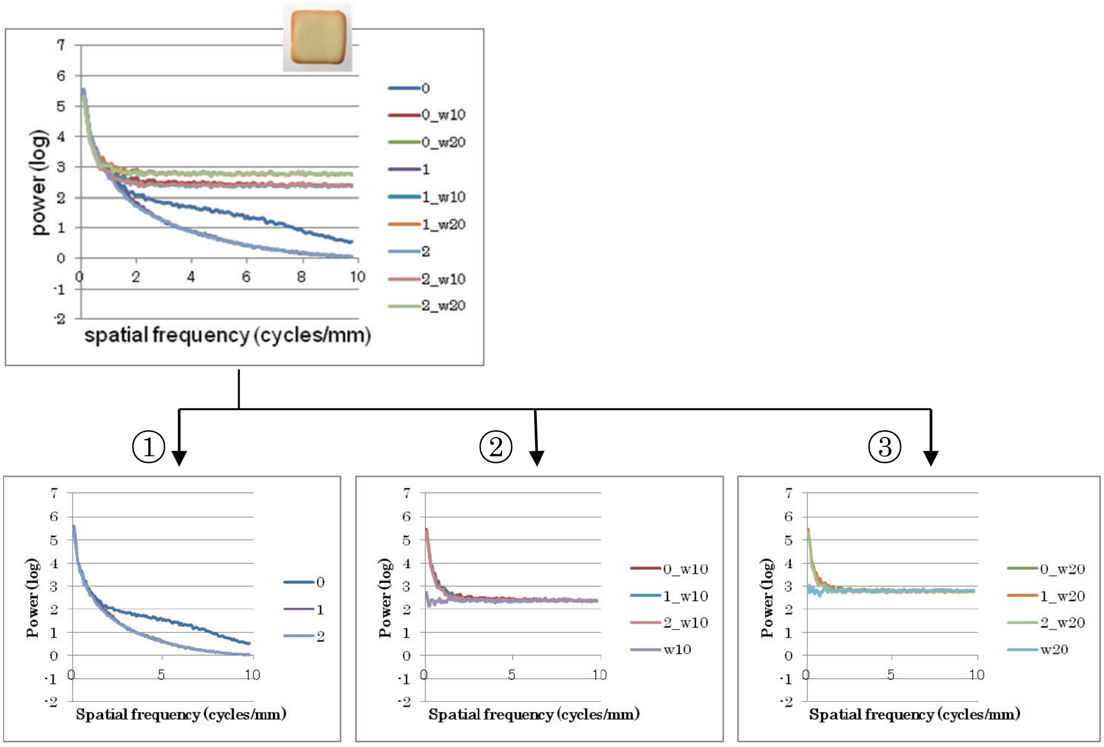
(a)



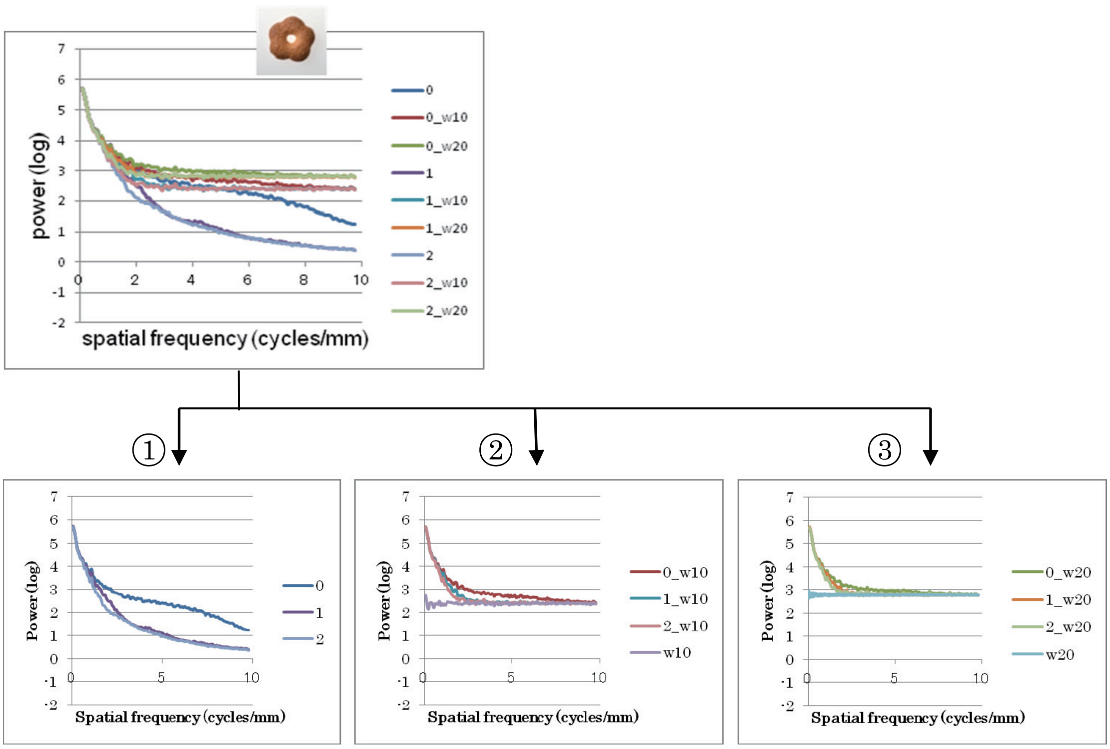
(b)

Fig. 9. (a) (b) Power spectra of images for evaluation

		Noise level		
		0	w10	w20
Blur level	0	0	0_w10	0_w20
	1	1	1_w10	1_w20
	2	2	2_w10	2_w20
		Graph ①	Graph ②	Graph ③



(c)



(d)

Fig. 9. (c) (d) Power spectra of images for evaluation

2.4 White noise image

Figure 6 shows the image and power spectrum of white noise. White noise is characterized by constant power in the spatial frequency region, where the VTF shows significant values. We generated the noise image by adding white noise to a gray patch of digital value 128, and then measured the power spectrum of it using the frequency analysis program.

2.5 Images for evaluation

The images for the evaluation were prepared by the following process: first, the original images were blurred at two different levels, and then, noise was added at two different levels, RMS 10 and 20 (Fig. 7).

We blurred the images using the Lens Blur feature of the Blur Filter tool in Photoshop. We can change the blur level by adjusting the Radius value. In this study, we set radius 8 as blur level 1, and radius 12 as blur level 2.

Figure 8 shows the local enlarged views of the deep-fried rice cracker so that it is easier to observe the different blur levels.

For each of the four samples, there were nine images to be evaluated, including images without noise; therefore, there were a total of 36 images.

All 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). We checked the printed image of black lines cleared 500 dpi.

2.6 Power spectra of images for evaluation

Figure 9 shows the power spectra of the images for the evaluation of (a), (b), (c), and (d), respectively. The low-frequency images (a), (b), and (c) show the same characteristics; whereas the high-frequency image (d) shows different characteristics.

For each sample, graph ① shows power spectra of the original (0), blur level 1 (1), and blur level 2 (2). The power spectra of blurred images decrease. Graph ② shows the power spectra of images with noise RMS10 compared with white noise RMS10. Graph ③ shows the images of noise RMS20. We can observe that following the addition of noise, the power spectra of the low-frequency images are almost the same as the power spectra of white noise.

2.7 Evaluation environment

The evaluation was carried out at 700 lx under a natural color evaluation lamp of 5000 K (Toshiba Corp., Tokyo, Japan). The subjects were asked to observe the samples at the distance of distinct vision, but the distance was not specified.

2.8 Evaluation method

Images were evaluated using a normalized ranking method. The research participants were asked to rearrange images according to the following instructions: “A sharp image means that an image appears to be clear, and in focus. Please sort these images in the descending order of sharpness for each sample (nine imag-

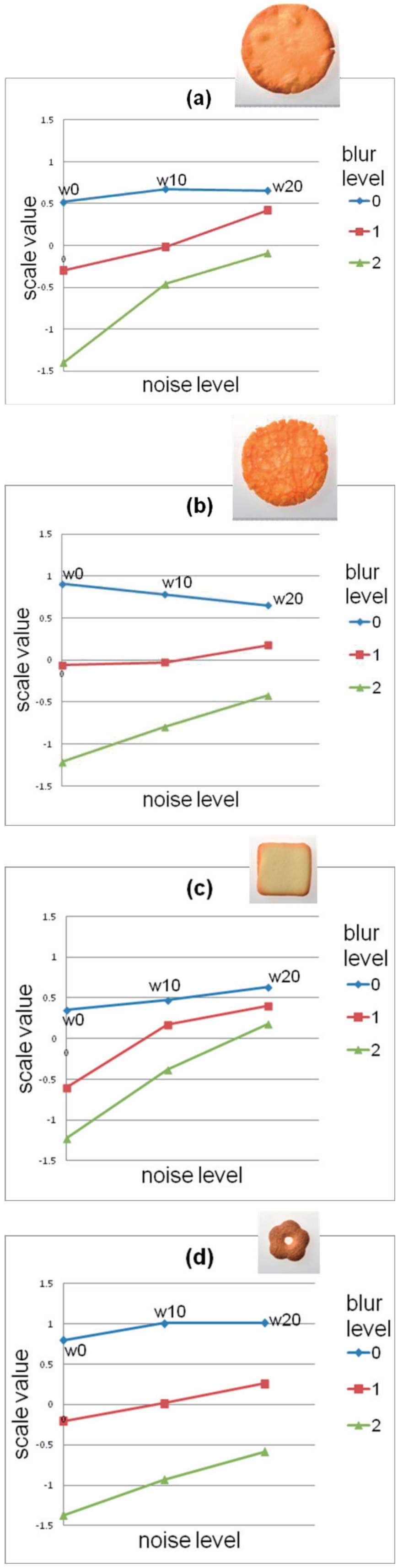


Fig. 10. Results for the subjective evaluation of image sharpness. Sharpness depends on noise level and blur level.

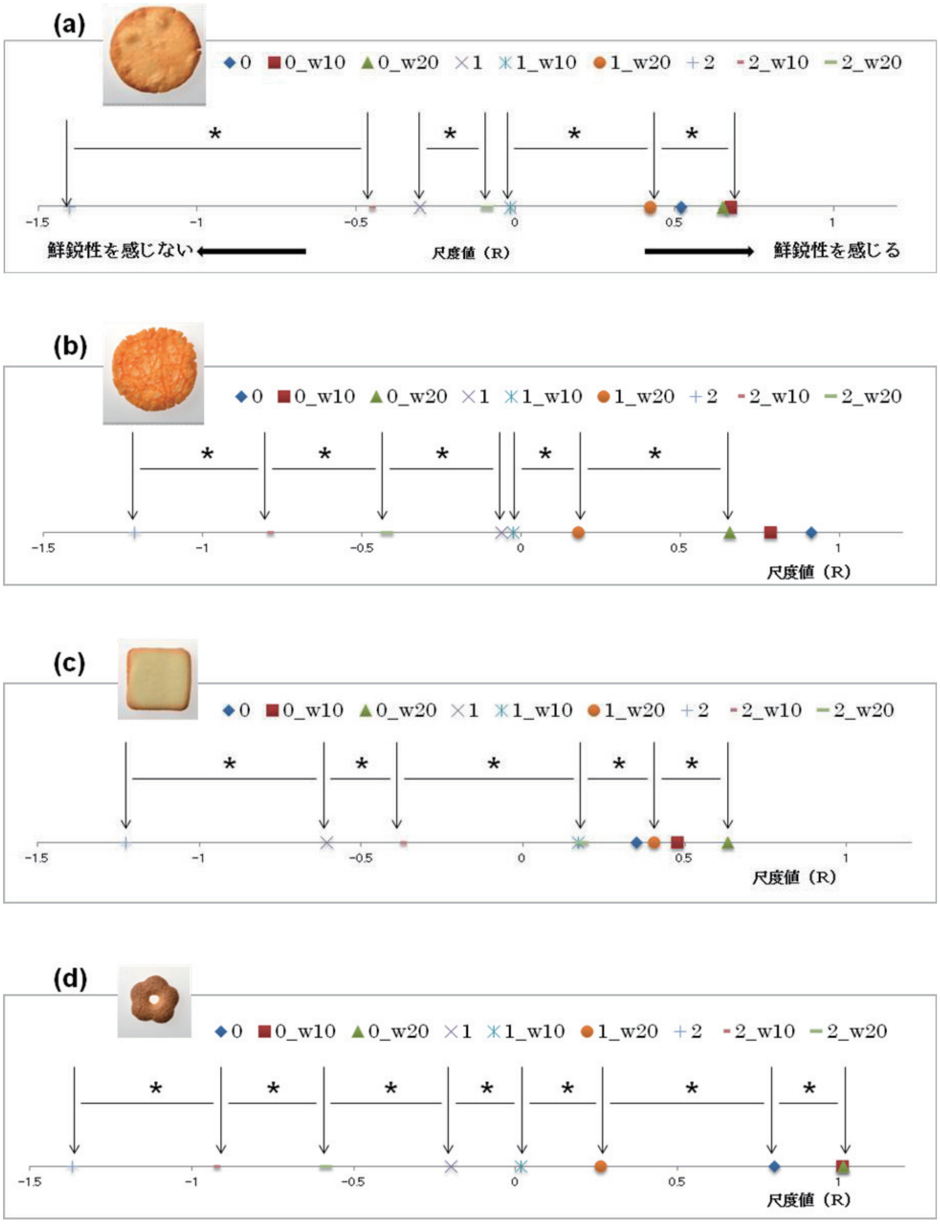


Fig. 11. Results for the subjective evaluation of image sharpness. The mark (*) indicates significant differences, with a significance level of 5%.

es) at the distance of distinct vision." Participants had to rearrange nine images per each sample, for (a), (b) (c) and (d). Based on their answers, we calculated the sharpness values.

2.9 Observers

Seventy-eight subjects, between the age group of 10 and 60 years, participated in this experiment.

3. Results and discussion

Figure 10 shows the results of the sharpness evaluation. The abscissa is the noise level (w0, w10, w20) and the ordinate is the scale value, which represents sharpness perception. Each line corresponds to a blur level (blue ●0, red ■1, green ▲2).

The mark (*) in Fig. 11 indicates significant differences with a significance level of 5%. For non-blurred images, in (a) and (b), there is no significant difference among 0, 0_w10 and 0_w20; in (c) and (d), significant differences only appear between 0 and 0_w20. These results indicate that for sharp images, noise is not effective. For blurred images, except 1 and 1_w10 in (b), there are significant differences between 1 and 1_w10, 1_w10 and 1_w20, 2 and 2_w10, and 2_w10 and 2_w20.

To observe the differences among samples more clearly, we present a magnified image of some samples in Fig. 12. Overall, the effect of the addition of noise is more evident in strongly blurred images than in weakly blurred images. In particular, for the flat, round rice cracker (a) and the square cookie (c), the original low-frequency and flat-textured images, sharpness increases with an increase in noise level to the extent that the blurred images appear similar to the non-blurred images. On the other hand, for the buckwheat cookie (d), the high-frequency image, the addition of noise was not as effective. For image (b), which has many lines and a distinct texture but a low-frequency image, noise had only a minor effect in contrast to the effects seen in (a) and (c).

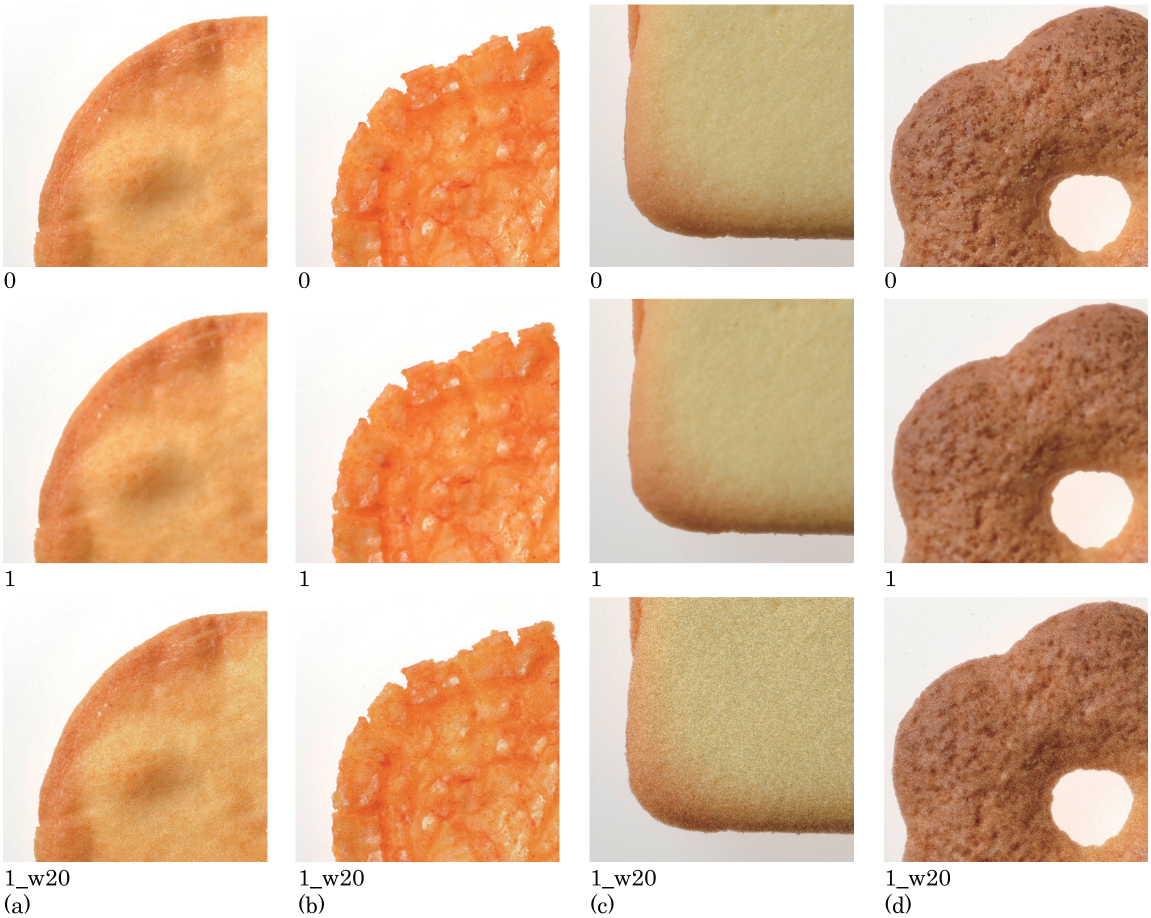


Fig. 12. Magnified images to observe differences among samples more clearly
(a) Magnified 120% (b) Magnified 130% (c) Magnified 190% (d) Magnified 200%

It is possible that the addition of noise erased the lines on the surface of the deep-fried rice cracker (b), resulting in a loss of texture.

4. Conclusion

We found that the effect of noise in improving image sharpness was frequency-dependent, i.e., its effects were more evident in blurred images than in sharp images, and in strongly rather than weakly blurred images. The conclusion is consistent with results from previous studies. In addition, results obtained using black-and-white, single-frequency patterns were verified in color images of natural objects. Further, we obtained new information on the influence of texture, i.e., because the addition of noise can erase edges, it may have no significant effect, even on low-frequency images.

Further work is required to elucidate the mechanisms involved in increasing sharpness through noise addition. According to the study on memory texture, there is a texture appropriate for each object—some textures can be divided into *white noise* or *1/f noise*. We hypothesized that adding noise to a blurred image causes the subject to recall the texture of that object from memory; simultaneously, the subject perceives sharpness. We will test the hypothesis by adding white noise and 1/f noise to a variety of objects to identify if noise that better improves sharpness matches with the noise of memory texture. Because previous studies did not discuss the individual differences, we will discuss the relationship between the individual differences in the perception of image sharpness and those in memory texture.

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