A Study of Spatial Parameters in Contingent Aftereffects

Tohoku Psychologica Folia
1978, 37(1–4), 116–130

A STUDY OF SPATIAL PARAMETERS IN CONTINGENT AFTEREFFECTS

By
KAYO YASUDA (安田佳世) and YOSHIAKI MAEDA* (前田嘉明)
(*Department of Behaviorology, Osaka University, Osaka*)

Using contingent aftereffects (CAEs), the spatial properties of the stimulus patterns were considered in view of aperiodicity *vs.* periodicity, concentric arrangement *vs.* matrix arrangement and size detection *vs.* spatial frequency detection. A CAE of shapes was also considered. As for the periodicity, paired aperiodic stimuli could produce the CAE and the result were discussed in terms of spatial frequency analysis. As for the configuration, concentric arrangement produced CAEs, whereas matrix arrangement did not. This was discussed from the viewpoint of energy of the patterns and a figural appearance of the quasi-gratings. The interaction between the size and spatial frequency was not clear in the present study. The data obtained here suggest that CAEs are gated by information of paired patterns, and the CAEs would, in turn, become a useful tool for new classification of figures in view of spatial dimension.

Presented a red vertical grating and a green horizontal grating alternately, most observers reported that the achromatic verticals appeared greenish and the horizontals pinkish. This is the first reported color aftereffect contingent on orientation, known as the McCollough effect. Since McCollough found the above-mentioned contingent aftereffect (CAE), a lot of further works have been presented. Especially in the early works, attention was paid to the spatial parameter of the used stimuli, and it was founded that other patterns but gratings could produce CAEs. That is, the aftereffect also occurred contingent on chevrons, dots, checkerboads and a pair of concentric circles and radial lines. (White & Riggs, 1974; Mackay & Mackay, 1975; Green *et al.*, 1976; May *et al.*, 1978; Cavill & Robinson, 1976; Skowbo *et al.*, 1975). CAEs, however, cannot occur on shape dimension, such as a triangle and a circle, and it has been considered that there are constraints of CAE patterns. These aftereffects were only contingent on dimensions of the orientation, spatial frequency and edge which are assumed to have the corresponding feature detectors. Therefore, it has been considered that such feature detectors are involved in CAEs.

Any patterns previously used as CAE stimuli were geometrically periodic patterns. There was no example that a contour of a single figure was used. In some visual phenomena, such as complementary images (Mackay, 1961), lattice effects and cloudy disappearances of a stationary grating at prolonged observation (Wade, 1977),

* Visiting professor of psychology at Tohoku University for the 1977 school year.

etc., similer stimuli to CAE patterns were used. It has been known that one of the critical parameters of such effects is the number of the lines constructing the patterns, which was empirically ascertained 4 to 10. Yasuda (1975, 1978) referred to the relation between the number of the lines constructing the patterns and the intensity of the CAE, using a partial figure of concentric circles and radial lines. And a further research was done to examine the relation between the number of the lines and the intensity of the effect systimatically, using the standard CAE of vertical-horizontal grating. This showed weak occurrence of the aftereffect even when the number of the lines was decreased and became a single bar (Yasuda, 1975, unpublished). That is, some *S*s reported the CAE extended uniformly over the grating with a pair of the single bars. These data suggest that the aperiodic figure is also an effective stimulus producing CAEs. On the contrary, a stimulus that had not been considered as a CAE stimulus produced a CAE when the figure had been reconstructed to the periodic pattern.

What do aperiodic stimuli and periodic stimuli mean ? Through some experiments using the procedure of CAE, we hope to give an opportunity to consider about the periodicity of simple geometric figures and the hierarchy or complexity of the figures.

General Method

Apparatus and stimulus: Adaptation and test patterns were projected onto a white screen by a 750W tangsten lamp projector. The patterned field subtended $10.5° \times 15.6°$ at the viewing distance of 2 m. The adaptation patterns were projected through either a red filter (Kodak Wratten Filter No. 26) or a green filter (No. 55). The achromatic test patterns comprized of two adaptation patterns with the same area except in Exp. I. In Exp. I, a fixation point was used.

Procedure: *S*s were tested individually. Before adaptation, each *S* was shown the achromatic test patterns, and was required to report whether color and/or brightness differences were viewed in particular parts of the test patterns. If there were any, he was asked what differences were visible and where they were. Then, the adaptation trial was introduced. *S* viewed the chromatic adaptation patterns alternately for 6 sec with 3 sec dark interval between the patterns. The total adaptation period was 5 min. After the disappearance of the negative afterimage of the adaptation pattern in the last presentation (20 to 120 sec), *S* was shown the test patterns again, and was required to answer the same questions as before. In Exp. IV, forced choice color naming was used.

Experiment I

Method

Stimulus: Adaptation patterns were a single vertical bar (length: 7.5°) and a single horizontal bar (length: 8.2°). The bar width of them was 0.4°. One of the test patterns was the cross-shaped figure whose vertical length was 10.5° and horizontal length was 15.6° (bar width: 0.4°). Other test patterns comprised vertical gratings and horizontal gratings with the same area as shown in Fig. 1. The square pattern subtended 10.5°×15.6° and the spatial frequency of the gratings was 1.3 cy/deg. The width of each bar comprizing the gratings was same as the adaptation bars. The disk pattern was 11.3° in diameter and the spatial frequency of the grating was 1.8 cy/deg. The width of each bar was narrower than that of the adaptation bars. All patterns had a fixation point in the middle of each bar or the center of each pattern. In the supplementary experiment, any fixation point was not used.

Subjects: There were 20 students with normal color vision. Ten *S*s saw a green vertical bar and a red horizontal bar during the adaptation period. The remaining *S*s saw a reversed pair of color and contour.

Results and Discussion

The problem of understanding how spatial information of the retinal image is processed and transmitted by the visual system has been previously discussed by many investigators. Current psychophysical and neurophysiological studies have shown two main alternative or even simulutaneously compatible ideas which are called feature analysis model and frequency analysis model. The former is the idea that the visual system detects spatial features of a retinal image by independent neural channels. Each is tuned to a particular set of spatial properties, *e.g.*, the orientation, edge and size. Such channels are called feature detectors and have been neurophysiologically found in the mammalian visual cortex. The latter is the idea, with Fourier theory, that the visual system encodes sinusoidal Fourier components by spatial frequency channels. According to Fourier theory, any spatial distribution of luminance can be expressed as the sum of its sinusoidal components, which are defined by amplitudes and phases. Once an image has been analyzed in its Fourier components, the original light distribution can be reconstructed when both amplitude and phase of each component are given. If neural channels transmit the various sinusoidal components of the retinal image, the visual system would be able to perform Fourier analysis. In the visual cortex of the cats and monkies, such channels selectively sensitive to a narrow band of spatial frequencies have been recently found (Maffei & Fiorentini, 1973). Although there exist spatial frequency detectors in the visual system, it does not mean that they act as a Fourier analyzer and transform the visual stimulus. They might only respond to the size of each element in the visual field or encode the repetition of it, *per se*.

Neurophysiologically data could not indicate whether the visual system operates frequency analysis or encodes a particular set of features. It would be also hard to distinguish by the psychophysical studies used periodic patterns. As Weisstein said, however, the distinction can be theoretically made if aperiodic stimuli are paired with periodic stimuli (Weisstein & Bisaha, 1972). In Fourier terms, a periodic stimulus has a limited number of frequency components (if it is sinusoidal grating, it contains a single frequency component), while a single aperiodic stimulus, such as a dark or light bar, has an infinite number of frequency components. If the visual system performs a frequency coding, the presentation of a single bar of aperiodic stimulus would mean that a broad range of periods has to be registered, and the presentation of a grating of periodic stimulus would mean that one period, or a limited number of periods is registered. If the visual system acts as a feature-coding system, the presentation of a single bar would mean that a particular size is registered, and the presentation of a grating would mean that a particular size is repeatedly registered. Thus the adaptation to a bar produces different aftereffects depending upon whether the visual system performs feature analysis or frequency analysis. If the visual system encodes the frequency components of a bar, the aftereffect extends over the test grating uniformly, because the single bar contains all frequency components of the grating. If the visual system encodes the orientation and size of a single bar, the aftereffect of the bar is limited in a few central bars of the test grating.

The result of the CAE on a single bar was not clear in the present experiment. In the cross-shaped test stimulus, many *S*s reported the color aftereffect contingent on the orientation. In the grating test patterns, however, a half of *S*s did not report any color name. This may be related to the subjective organization of the elements of test patterns determines the appearance of CAEs, as shown by Jenkins & Ross (1977). Thus, when *S*s viewed the test pattern of the concentric squares in the present experiment as a set of L-shaped black line, not as four gratings, two horizontally and two vertically, the number of the color appearance might decrease.

Then, a supplementary experiment was carried out. That is, test patterns were presented with short comments of the organization of them. Fixation points were not used at this time. The results of 5 *S*s are shown in Table 1. The number of the reports of "Neither" decrease from 50% to 15%. And 70% of the reports showed the uniformly tinged colors on the predicted regions of the test gratings. The question raised here is whether or not frequency analysis was applicable in the visual system from the data obtained; 70% of the reports in the supplementary experiment and 34% of the reports in the first experiment. Can other interpretations derive from these data? The following interpretations can be reasonably induced: First, complex cells that respond to a bar or slit of a certain orientation regardless of the portion on the retina may involve the CAE. Second, eye movements may lead to the firing of many simple cells having various receptive fields on the retina especially in the case of the supplementary experiment. Third, information about the color and contour may be stored at higher level of the central system, and the position of a single bar might have been filtered. Fourth, the contrast effect of the negative afterimage elicited by a single bar may be act on the CAE. In this case, the colors of the aftereffect do not uniformly spread over, whereas complementary colors alternately do. According to a subject's report, the line of the grating tinged alternately with complementary colors, green and red, immediately after the presentation of the test grating, and soon tinged colors uniformly extended in the appropriate regions. This report may suggest the effect of

Table 1. Color aftereffects contingent on stimulus patterns.

Experiment	Adaptation stimulus	Test stimulus	Frequency of response				
			CAE	No-CAE	Total	χ^2	p
Exp. I N=20	Single	Cross (1–1)	31	9	40	12.1	.001
	bar	Grating (1–2)	28	28	56	9.66	.01
		(1–3)	Central Uni-formly bar				
			9 19		28	3.57	
Exp. I′ N=5	Single	Cross (1–1)	9	1	10	6.40	.05
	bar	Grating (1–2)	17	3	20	12.04	.001
		(1–3)	Central Uni-formly bar				
			3 14		17	7.12	.01
Exp. II N=10	Concentric triangles	Compound pattern (2–2)	17	0	17	17.00	.001
Exp. III N=10	Concentric triangles and Concentric circles	Compound pattern (3–1)	15	4	19	6.37	.05
Exp. IV N=10	Matrix of dots	Compound dots (4–1)	20	0	20	20.00	.001
		(4–2)	16	6	20	7.20	.01
		(4–3)	14	4	20	3.20	

* The data were coded as follows: When either color of the aftereffect appeared, it was counted once. When both colors appeared, it was counted twice. "CAE" is pooled these two appearances. When neither color of the aftereffect appeared, it was counted twice, and registered in the column "No-CAE."

the color contrast.

Thus, there are at least four interpretations to explain the data. This suggests that the paradigm pairing a bar and a grating in order to know the coding or analyzing process in the visual system needs to be re-considered.

Experiment II

If a single bar can produce the CAE uniformly extended over the grating with the same orientation of the bar, can paired regular triangles arranged upright and 180° rotated yield a CAE? Both triangles' contour comprizes the same orientations; right oblieque, left oblieque and horizontal. Therefore if the aftereffect of a single bar can extend over the whole visual field, paired triangles should not produce the CAE, because the adaptation procedure is an alternate presentation of complementary colors. Based upon this assumption, a preliminary experiment was carried out.

After alternately viewing a red (or green) upright triangle and green (or red) inverted triangle (side length: 8.6°, width: 0.4°), two *S*s reported the occurrence of the CAE of the test patterns 2–1 and 2–2. On the test pattern 2–2, colors uniformly extended in the predicted parts, although they were very faint (*cf.* Exp. I). The CAE of paired triangles occurred inspite of the complementary color adaptation to the side lines with the same orientation. Therefore, this aftereffect may be considered not to be exclusively contingent on the orientation of each line. White & Riggs (1974) attributed the CAE on oppositely pointed chevron-shape to the color adaptation of higher-order hypercomplex cells that optimaly respond to "corner" type stimuli. In the present experiment, it may be valid to consider that such detectors were involved in the occurrence of the CAE. But if they were involved in this case, the clearest CAE should occur in the test pattern 2–3, because this pattern is comprized edges of two triangles. However, we could not get the CAE in this pattern. The fact that CAEs were not obtained on the pattern 2–3 but on the test pattern 2–2 seems to support that this aftereffect was contingent not on edge but on line orientation. Such idea, however, contradicts already-mentioned assumption. To clarify the contradiction, the scanning experiment was performed. That is, if this CAE occurred on orientation dimension, when *S*s view the stimulus, scanning it continuously, the effect should be weakened. For, in such a condition, *S*s are presented the same orientation lines with complementary colors. To examine the effect of the scanning, a supplementary experiment was carried out. *S*s were asked to move their fixation continuously and horizontally over the adaptation patterns, so that the side lines of two triangles fell on the same retinal regions. Under this condition, the CAE still appeared. Thus, it seems to be hard to consider that the color aftereffect produced here was contingent on the line orientation.

Then, is there only one way to consider that the CAE of paired single triangles was contingent on the shape of them ? Or, was the eye-movement of the *S*s insufficient to cancell the CAE ? To give an answer, a further experiment was designed.

Adaptation patterns and test patterns are shown in Fig. 1 (A–2–2, 2–1, 2–2). The line width was 0.4° and the spatial frequency was 1.4 cy/deg. Ten *S*s were used in this experiment. The apparatus and procedure were the same as the foregoing experiments.

The CAE of paired concentric triangles occurred as shown in Table 1. This CAE seemed to be obtained as easily as a standard McCollough-effect, *i.e.*, the CAE of the grating orientation. But, it was difficulut to occur in the test pattern 2–3 compared with 2–2. Test pattern 2–3 was hard to be regarded as a compound stimulus of two concentric triangles, and it appeared as a concentric star-shaped stimulus. This appearance may be related to the decrease in the number of the color report. However, there is another important difference in appearance between two test patterns. Test pattern 2–2 comprized the side line of the triangles, while test pattern 2–3 comprized the edge of the triangles. The former could easily produce the CAE and the latter could not. Therefore, the color aftereffect of paired concentric triangles seems to be contingent on the orientation of the composing lines.

Adding a word, during the adaptation to the concentric triangles, some *S*s reported the complementary afterimages (*CAI*s). After viewing upright triangles, an afterimage of inversed triangles appeared, and after viewing inversed triangles, an afterimage of upright triangles appeared. All the patterns which have produced CAEs of the orientation, from grating to radial patterns, yield *CAI*s. If *CAI*s reflect the neural connection of orientation detectors (suggested by Mackay using another word), the CAEs containing the *CAI*s are considered to be contingent on the orientation. The CAE of concentric triangles seems to be contingent on the orientation.

The last experiment of triangles was related to stimulus configurations. A triangle was repeated not in concentrical arrangement but in matrix arrangement. Yasuda (1975), using a small triangle matrix pattern, already showed that such a configuration could not produce the CAE. In her experiment, however, the length of the side line in each element was 0.7°. Thus, it might be too short to produce the CAE. To examine the line length of a triangle, the viewing conditions were changed in the following experiment, shown in Table 2.

Table 2. Size variations of each triangle in matrix arrangement.

Side line length (cm)	Viewing distance (cf)	Visual angle (deg)
2.4	200	0.70
6.5	200	1.86
11.0	350	1.80
11.0	200	3.15
16.5	200	4.72

The result shows that the CAE in such a configuration could not occur in all visual angles. The side line of the largest triangle used in this experiment should be long enough to produce the CAE, in the light of previous experiments. Furthermore, many triangles of the various retinal regions produced the CAE as was shown in the above-mentioned scanning experiment. In this matrix configuration, however, we could not obtain the CAE.

Then, two questions are still left here. One of them is whether the color aftereffect contingent on shape exists. The other is whether matrix arrangement can produce CAEs. As for the first question, Exp. III was designed and to the second question, Exp. IV was carried out.

Experiment III

CAEs on shape dimension have been considered not to occur, even though shapes are so simple as a circle or a triangle. This restriction of CAE stimuli was one of the bases on which detector models in CAE are constructed. Detector models, adopted by McCollough (1965), Fidell (1970) and White & Riggs (1974), posited CAE as the color adaptation to feature detectors which process a particular color and contour. However, some findings, such as long persistence of the effects, spontaneous recovery in darkness (Mackay & Mackay, 1977) and no change in threshold of chromatic gratings during the occurrence of the CAE (Timney *et al.*, 1974), have not supported the theory of the adaptation to a color-coded single cell. Thus, instead of detector models, multiple-unit models has been presented. This is the idea that CAEs are the results of color adaptations *in conjunction with* contour information (Murch, 1972), assuming that the color and contour are processed at different parts in the visual system. In the sence that color and contour are associated together, such a conjunction hypothesis finally leads to a theory of associative learning or conditioning. If CAEs are pure associative leaning or conditioning, any pattern must be able to be associated with colors. A CAE, however, has been considered not to occur in a pair of a circle and a triangle, as was above mentioned. Yet, empirical data have not been published. Thus, the purpose of this Exp. III is to examine whether the aftereffects are contingent on shape dimension.

METHOD

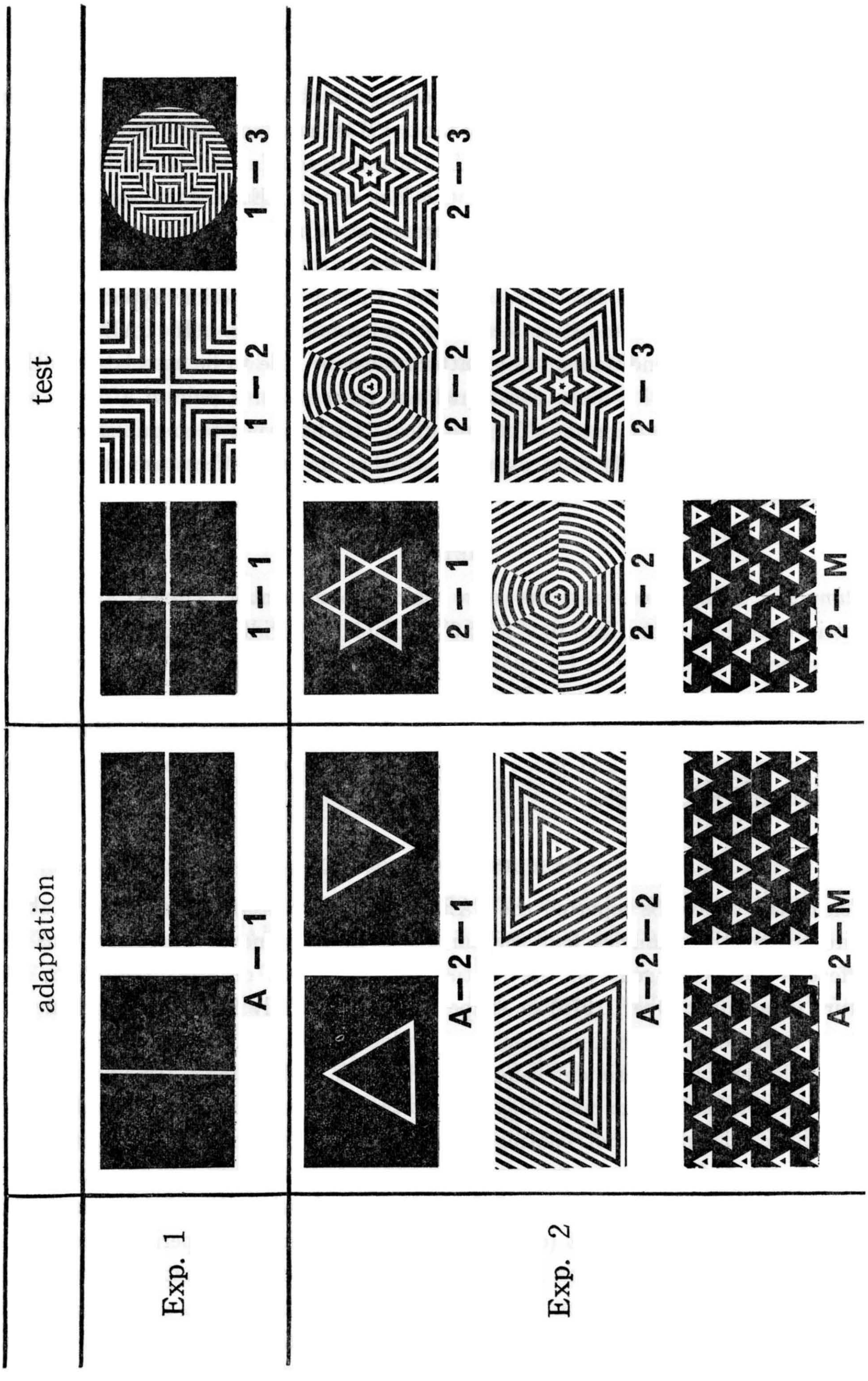
Stimulus: Adaptation patterns were thirteen concentric circles and thirteen concentric triangles, subtended $10.5° \times 15.6°$. Black line width of them was $0.4°$ and spatial frequency of them was 1.4 cy/deg. Test patterns comprized these two adaptation patterns with the same area (Fig. 1, A–3, 3–1, 2, 3, 4).

Subjects: Twelve naive students with normal color vision were used. Half of them were presented red circles and green triangles, and the rest of them were presented green circles and red triangles.

RESULTS AND DISCUSSION

Ten of the twelve *S*s reported the CAE on the test pattern 3–1 and 3–2 (Table 1). The circles and the triangles had the same spatial frequency. Therefore, this color aftereffect is not contingent on the spatial frequency but on the orientation, edge, curvature (Crassini & Over, 1975) or shape dimension. Only from this experiment, it is difficult to indicate which dimension was involved in this CAE. However, according to the supplementary experiment using a single circle and a single triangle, the CAE could not be obtained. This may suggest that the color aftereffect of concentric circles and concentric triangles is not contingent on the shape of them. Moreover, in this experiment, the *CAI* of concentric circles or concentric triangles did not occur at all. If the occurrence of the *CAI* is one of the indicators showing the establishment of the orientation contingent aftereffect (cf. Exp. II), the CAE in this experiment reflects the conjunction of the color and edge (or curvature) of the stimulus patterns, and is not contingent on the line orientation.

In the matrix arrangements of small disks and small triangles, shown in Fig. 1 (A–3–M, 3–M), any CAE could not occur (6 *S*s). This result, however, does not mean


test
adaptation
Exp. 1
Exp. 2
1 — 1
1 — 2
1 — 3
2 — 1
2 — 2
2 — 3
2 — 2
2 — 3
2 — M
A — 1
A — 2 — 1
A — 2 — 2
A — 2 — M

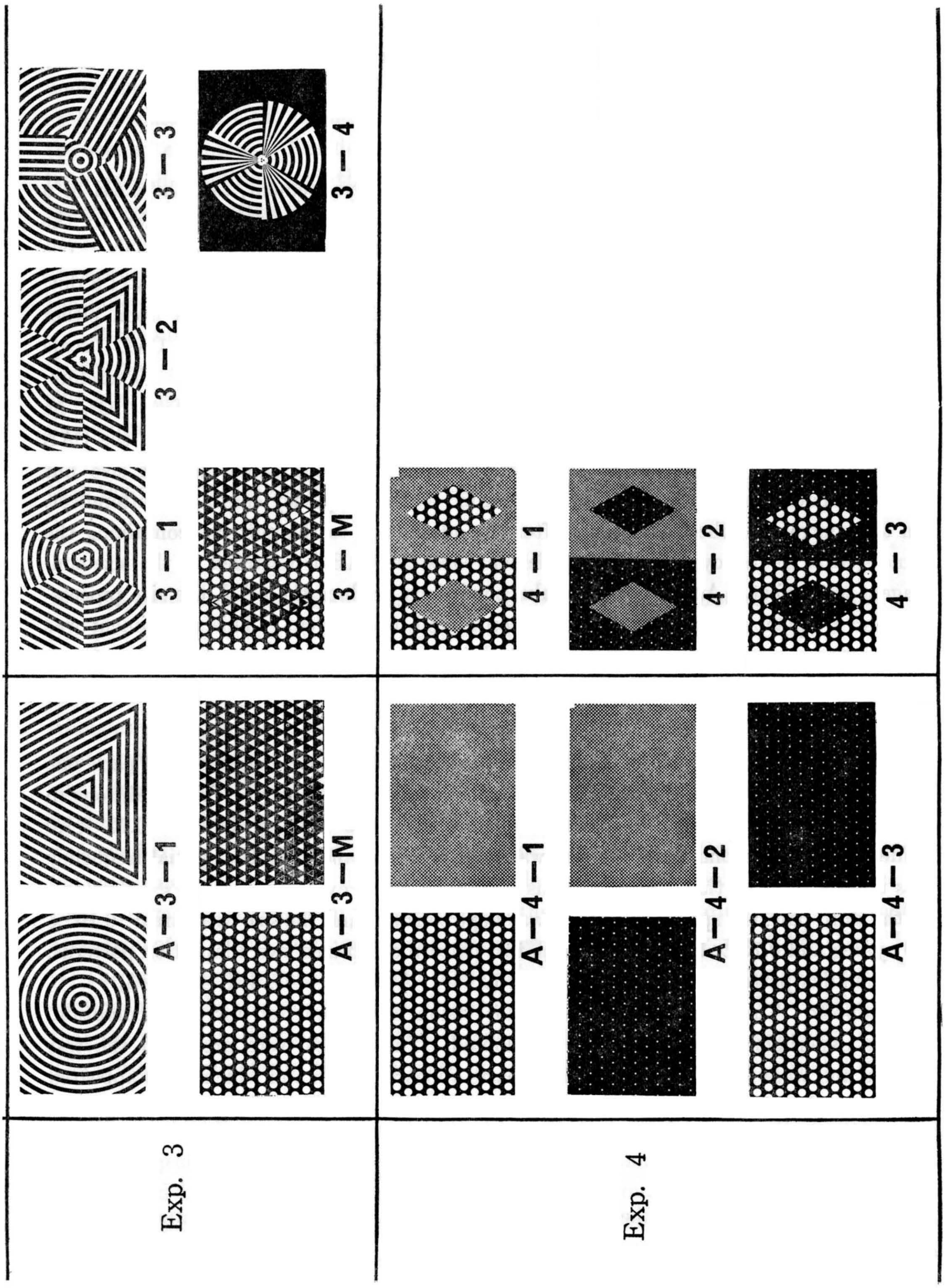


Fig. 1. Adaptation patterns and test patterns used in Exp. 1–4.

that these matrix arrangements never produce CAEs. A pair of the small disks which arrange matrix configurations could produce the CAE (Mackay & Mackay, 1975; Yasuda, 1975). In the next experiment, the results are shown.

Experiment IV

Mackay (1975) demonstrated the CAE of matrix arrangement, *i.e.*, the CAE of a pair of hexagonal dot patterns differing in magnification. He did not refer to the stimulus patterns themselves, because he aimed at the dichoptic induction of CAEs. The patterns used in his experiment differ in the element size and spatial frequency (1.8 dot/deg and 4.6 dot/deg). Thus, it was not clear whether his CAE depends upon either the difference in the element size or spatial frequency. He called the CAE "scale dependent chromatic aftereffect," and used the words "large" and "small." Therefore, he may have considered the CAE as the size contingent color aftereffect. Or, he regarded that the size processing was equal to the frequency processing.* If the CAE occurs after the adaptation to the patterns containing the same element size but different spatial frequency, the CAE is regarded as the frequency contingent aftereffect. On the contrary, if the CAE occurs after the adaptation to the patterns containing the same spatial frequency but different element size, the CAE is regarded as the size contingent aftereffect. And if both stimulus conditions produce the CAE, the size processing and frequency processing do not be considered independent. This experiment was designed to examine the size and/or spatial frequency processing.

Method

Stimulus: Three pairs of adaptation patterns were used. In the firts pair, one element is different from the other in the size and spatial frequency. Two conditions in terms of size (in diameter) $\times$ spatial frequency were $0.19° \times 3.1$ cy/deg and $0.72° \times 1.0$ cy/deg. In the second pair, the size was kept constant and only the spatial frequency was manipulated so that the conditions were $0.19° \times 3.1$ cy/deg and $0.19° \times 1.0$ cy/deg. In the third pair, the spatial frequency was kept constant and the size was varied; $0.19° \times 1.0$ cy/deg and $0.72° \times 1.0$ cy/deg. Each test pattern comprized two adaptation patterns. The stimulus patterns are shown in Fig 1 (A-4-1, A-4-2, A-4-3, 4-1, 4-2, 4-3).

Subjects: Thirty *S*s with normal color vision were used, ten for each condition. In this experiment, forced-choice was adopted. That is, *S*s were presented the test pattern and were forced to choose which parts appeared green and which parts appeared red, even when he could not see any colors on the test patterns.

Results and Discussion

In the first condition, there was no discrepancy between the prediction and the

* The concept of *frequency* processing in this experiment is different from that of processing by spatial *frequency* analysis mentioned in Exp. I.

result as was expected from Mackay's data. When this color report was contingent on the spatial frequency, the CAE should have occurred under the second condition and not under the third condition. In the case that this report was contingent on the size of each element, the CAE should have occurred under the third condition and not under the second condition. The data, however, showed the occurrence of the CAE under both second condition and third condition. Moreover, under all conditions, some *S*s spontaneously reported the color aftereffect. Therefore, this color aftereffect seemd to occur contingent on both the spatial frequency and size. However, the correct answer percentage, the number of the spontaneous reports and subjective assurance of the judgements increased in order of $1>2>3$.

Blakemore *et al.* (1969) considered the frequency detector as the size detector, and Glezer *et al.* (1973) actually found that the same cortical neuron responded to both two slits and one slit equal in area. It is true that consideration is needed whether their finding in one dimensional spatial frequency applies the present data of two dimensional spatial frequency. However, these results may suggest inadequancy of the consideration that the size and spatial frequency are independent from each other.

General Disucssion

The results obtained here were as follows: (1) The CAE uniformly extensible over the test grating occurred by the adaptation to paired single bars (Exp. I). These results were considered in view of feature analysis and frequency analysis, and resulted in re-examination of the paradigm *per se*. (2) Concentric triangles and inversed triangles produced the *CAI* and the CAE. They seemd to be contingent on each line orientation. Paired single triangles also produced the CAE, but it was not clear on what dimension they were contingent. The matrix arrangement of small triangles could produce no CAE (Exp. II). (3) The CAE of concentric circles and concentric triangles was yielded, and interpreted in terms of color adaptation in conjunction with edge (or curvature) information. Paired single circle and triangle could not produce the CAE. It was considered from the viewpoint of the CAE on shape dimension. The matrix arrangement of small disks and small triangles could not elicit the CAE (Exp. III). (4) The matrix arrangement of paired small disks, however, produced the color aftereffect contingent on the size or the spatial frequency. The results of (2), (3) and (4) indicate that the important factor of the CAE is not stimuli *per se* but the coupling of them. The critical parameter of the occurrence of the CAE seems to be the visual dimension involving paired stimuli rather than figures or configuration of them.

Thus, a CAE is considered to be gated by information of paired patterns regardless of the subject's conscious awareness about the information. Such a characteristics, in turn, would be useful to investigate the hierarchy or complexity of stimulus pattern. Some investigations to express the hierarchy or complexity of figures have been done previously, but their results have not been sufficiently obtained for the present. Through reconstruction of many data of the CAE in terms of visual dimension, it may serve as an effective tool for new classification of figures.

In the present study, the adaptation to a pair of single bars produced the CAE uniformly extensible over the test grating. According to Weisstein and Sullivan (1972), this result may support the model of frequency analysis. However, from the reports of the *S*s, other interpretations could be induced in view of energy of the patterns. The repetition of a single element seems to increase energy of the pattern itself and to strengthen the aftereffects. The difference in potential energy of patterns may relate to the intensity of CAEs. Although the repetition of a single element contains both concentric and matrix arrangement, energy of the latter seems to be lower than that of the former, according to the obtained data. Matrix arrangement may be highly redundant compared to concentric arrangement. In this sense, the complexity of the pattern may be increased in matrix arrangement. But if we discuss the difference in the intensity of a CAE only in view of the amount of information, the CAEs of paired concentric circles and triangles could be regarded as the aftereffects contingent on shapes of the stimuli. For, these patterns are considered to produce the CAEs by increasing the energy of the figures through the repetition of a single contour. Would it correct that there are color aftereffects contingent on shapes? For this question, it is suggestive that the paired triangles produced the CAE (Exp. II) but the circle and triangle did not (Exp. III). Moreover, from the viewpoint of the frequency analysis, a concentric pattern is an expression of higher harmonics of a single figure but a matrix pattern does not have such harmonics as an entire unit. In matrix arrangement, each element is independent as a figure. There is a great difference between two arrangements in terms of the complexity of the pattern. The results of CAEs may suggest the hierarchy of the patterns.

Concerning the result that a CAE with concentric pattern occurs easily and with a matrix pattern does not, another explanation can be postulated. That is, the concentric repetition of a single figure produces quasi-gratings with different orientations. If the color aftereffect contingent on the orientation easily occurs, the CAE of concentric circles or concentric triangles can be regarded as the orientation contingent aftereffect of such quasi-gratings. Furthermore, regarding to the difference between two arrangement it is needed to consider that the length of the lines of which the matrix figure is consisted. In the matrix patterns of the present experiment, the lines of each element are shorter than those of some lines in concentric patterns. If orientation detectors involve the detection of the lines of CAE stimuli, it would be doubtlessly easy to detect the lines when they are long.

The problem left here are as follows: (1) The critical value of line length was not explicitely obtained. Namely, how long line is need to elicit the CAE should be measured in relation to the sensitivity to the line length. (2) In the experiment of the alternate presentation of a single triangle and a inversed triangle, in spite of the procedure that the same orientation detector was adapted to complementary colors, the CAE was obtained extending over the test grating. This may be considered as a retinalregion-specific CAE. In this case, an appropriate method is the observation of eye movement under a forced-scanning condition. If it is purported to demonstrate another interpretation based upon the edge orientation, variation in angles should be required. (3) It was not explicitly obtained that the role of the spatial frequency detector is the detection of the repetition of elements or the detection of the size or both. A more systematic change in dot arrangement should be employed in attempt to shed light on such propositions. (4) From a lot of data of CAEs including the results shown here hierarchic classification is to be conducted in further works.

References

Blakemore, C. & Campbell, F.W. **1969** On the existence of neurones in the human visual system selectivity sensitive to the orientation and size of retinal image. *J. Physiol.*, **203**, 237–260.

Cavill, J. & Robinson, J.O. **1976** A color aftereffect contingent on complex pattern features. *Percept. & Psychophys.*, **19**, 454–459.

Crassini, B. & Over, R. **1975** Curvature-specific color aftereffects. *Percept. & Psychophys.*, **17**, 398–404.

Fidell, L.K.S. **1970** Orientation specificity in chromatic adaptation of human "edge detectors." *Percept. & Psychophys.*, **8**, 235–238.

Glezer, v.d., Ivanoff, V.A., & Tsherbach, T.A. **1973** Investigation of complex and hyper-complex receptive fields of visual cortex of the cat as spatial frequency filters. *Vision Res.*, **13**, 1875–1904.

Green, M., Corwin, T., & Zemon, V. **1976** A comparison of fourier analysis and feature analysis in pattern-specific color aftereffect. *Science*, **192**, 147–148.

Hubel, D.H. & Wiesel, T.N. **1968** Receptive fields and functional architecture of monkey striate cortex. *J. Physiol.*, **195**, 215–243.

Jenkins, B. & Ross, J. **1977** McCollough effect depends upon perceived organization. *Perception*, **6**, 399–400.

Mackay, D.M. **1961** Interactive processes in visual perception. in W.A. Rosenblith (ed.) *Sensory communication*. New York, Wiley, 339–355.

Mackay, D.M. & Mackay, V. **1975** Dichoptic induction of McCollough-type effects. *Quart. J. Exp. Psychol.*, **27**, 225–233.

Mackay, D.M. & Mackay, V. **1977** Retention of the McCollough effect in darkness: storage or enhanced read-out ? *Vision Res.*, **17**, 313–315.

Maffei, L. & Fiorentini, A. **1973** The visual cortex as spatial frequency analyzer. *Vision Res.*, **13**, 1255–1267.

May, J.G., Agamy, G., & Matteson, H.H. **1978** The range of spatial frequency contingent color aftereffects. *Vision Res.*, **18**, 917–920.

Murch, G.M. **1972** Binocular relationships in a size and color orientation specific aftereffect. *J. Exp. Psychol.*, **93**, 30–34.

Skowbo, D., Timney, B.N., Gentry, T.A. & Morant, R.B. **1975** McCollough effects: Experimental findings and theoretical accounts. *Psychol. Bulletin*, **82**, 497–510.

Sullivan, G.D., Georgeson, M.A., & Oatley, K. **1972** Channels for spatial frequency selective and the detection of single bars by the human visual cortex. *Vission Res.*, **12**, 383–394.

Timney, B.N., Gentry, T.A., Skowbo, D. & Morant, R.B. **1974** Chromatic grating thresholds and the McCollough effect. *Vision Res.*, **14**, 1033–1035.

Wade, N.J. **1977** Distortions and disappearances of geometrical patterns. *Perception.*, **6**, 407–433.

Weisstein, N. & Bisaha, J. **1972** Grating mask bars and bars mask gratings: Visual frequency response to aperiodic stimuli. *Science*, **176**, 1047–1049.

White, K.D. & Riggs, L.A. **1974** Angle-contingent colour aftereffects. *Vision Res.*, **14**, 1147–1154.

Yasuda, K. **1975** A study of the information processing of the color and shape using McCollough-type aftereffects. M.A. thesis, Dept. of Psychol., Osaka Univ., Japan.

Yasuda, k. **1978** Color aftereffects contingent on Mackay complementary regular patterns. *Jap. Psychol. Res.*, **20**, 115–123.

(Received November, 30 1978)