TEMPORAL AND SPATIAL FACTORS IN FIGURAL AFTER-EFFECTS

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Since Köhler and Wallach (16) studied the phenomena of "figural after-effects" on the basis of their electrochemical hypothesis of the brain field, many experimental psychologists have been interested in these phenomena and figural after-effects have become a very important problem in visual perception. Hence it would be worthwhile to analyze the stimulus factors in figural after-effects whether we support the brain field theory or not.

Oyama (22, 23, 25), Ikeda and Obonai (10, 11, 12), and some other investigators (2, 5, 6, 18) have conducted lots of experimental analyses on the temporal and spatial factors of figural after-effects. In the present paper, the author intended to review these experimental results and report his supplementary experiments which were conducted, with a new tachistoscope, in order to check the previous results and tried to obtain some general conclusions regarding the problem of temporal and spatial factors of figural after-effects.

TEMPORAL FACTORS

Concerning the temporal aspects of figural after-effects, Gibson and Radner (4) reported that the after-effect increased with the increase in the duration of inspection-period with the maximum effect at about 45 seconds, and, Bales and Follansbee (1) indicated that the after-effect was greatest immediately after the inspection-period and decreased within 60 seconds. More recently, Hammer (6) obtained practically the same results on these two aspects in her more systematic experiments.

In those studies, the amount of after-effects were measured by the method of adjustment, which required several seconds for one setting and consequently it was the after-effects several seconds after the inspection-period that was measured in those studies. Oyama (22) pointed out this and tried to measure the after-effect immediately after the inspection-periods of varied durations, by the method of complete series. According to his results, one second of inspection was long enough to produce considerable amounts of after-effect, i.e., shrinkage of several percents of the size of test-circle, and longer inspection-period could hardly bring about any increase in the effect. He explained that the decreasing curves of after-effect started from almost the same level regardless of inspection time, but the longer the inspection-period was,
the slower was the rate of decrease, and that the former three studies were dealing with the lower points of the curves, while his own compared the curves at their starting points. He obtained such decreasing curves for various inspection-periods. Ikeda and Obonai performed essentially the same experiment more thoroughly and obtained similar results. Fig. 1 shows their results. The curves represent the disappearance courses of after-effect for inspection-periods of varied durations from 1 to 240 seconds. The curves in Fig. 1 start from almost identical level and the longer the inspection-period is, the slower is the rate of decrease. Oyama, and Ikeda and Obonai proposed a mathematical formula for the disappearance course of after-effect on the basis of their experimental data,

\[ A = A_c e^{-kt} \]

in which \( A \) indicates the amount of after-effect, \( A_c \) is a constant which represents the common starting point, \( k \) is a parameter which represents the rate of decrease and \( t \) is the time elapsed after inspection-period. This formula is essentially the same as that of Mueller (17), who used Hammer's data, except that \( k \) is treated as a parameter which varies as a function of inspection time instead of a constant in Mueller's formula.

In Oyama's and Ikeda and Obonai's experiments, the inspection-cards were replaced by the test-cards through manual operations and accordingly it could not be expected to catch the after-effect immediately, in the strict sense, after inspection. Meanwhile, the use of tachistoscope made it possible to reduce the interval between the inspection and test-periods to exactly zero second, and we conducted another experiment, using the tachistoscope, in order to determine the after-effects measured immediately after and one second after the inspection-period of various durations.

Fig. 1. The Decreasing Courses of After-Effects After Inspection-Periods of Various Durations. After Ikeda and Obonai (10).
EXPERIMENT 1

Apparatus. Takei's three stimuli tachistoscope, which consists of a modified Dodge tachistoscope with a modified Harvard time-controller was used. The distance from the subject's eyes to the stimulus was 79cm. The luminance of the stimulus field 10~15 millilamberts.

Stimulus figures. As shown in Fig. 2, the I-figure consisted of a fixation cross and an I-circle, 4cm (2.9° in visual angle) in diameter whose center was located 3.5 cm (2.5° in visual angle) to the right of fixation mark. Each of the T-figures consisted of a fixation cross and a pair of T-circles, one of which was concentric with the I-circle and had constant diameter of 2cm (1.5° in visual angle) and the other one was drawn 3.5cm to the left of fixation cross and with varied diameters by 0.5mm steps from 13mm to 23mm. Stimulus figures consisted of black outline figures drawn on white cardboards. The width of the line was 0.5mm.

Subjects. Five students majoring in psychology served as subjects.

Procedure. The temporal sequence of stimulus presentation was as follows: Darkness→1, 2, 5, 15 or 60 second presentation of I-figure→0 or 1 second interval→0.2 second presentation of T-figure→darkness

For measuring the after-effect, the method of complete series was used. Subjects were instructed to report whether the left T-circle appeared greater than, smaller than or equal to, the right T-circle upon each presentation of T-figure. Two judgments for each T-figure were obtained and PSE was calculated from these judgments in each experiment. Control experiments without I-figure were inserted between every experiment. Average PSE of two control experiments which preceded and followed the experiment was considered as its base point, and the difference between the PSE of the experiment and its base point, was regarded as the amount of after-effect.

Each subject served two experimental sessions, in one of which the interval between the inspection- and test-periods was 0 second and in the other 1 second. In each session, the experiment for each of the five conditions of inspection-time mentioned above were performed. The order of these five experiments was designed with the aid of a Latin-square. At least 3 minute rest was given after each experiment.

Results. Results are illustrated in Fig. 3. The left half of the figure shows the amount of after-effect as a function of inspection time. The solid line represents the amount of after-effect immediately after inspection and the broken line that 1 second after inspection. The solid line tells us that 1 second inspection produces, as in the previously discussed experiments, a considerable amount of after-effect, which is 6% of the size of T-circle, or 5.1' in visual angle, however, longer inspection-period brings about some increase in the
amount of after-effect. The broken line is more like the curves obtained by the method of adjustment. The right half of Fig. 3 shows the initial parts of decreasing courses of after-effect for inspection-periods of various durations. It indicates, generally, that the longer the inspection-period is, the slower is the decrease of after-effect.

Measurements of after-effect immediately after inspection as a function of inspection time were also conducted by Obonai and Suto (20), Fujiwara and Obonai (2) and Suto and Ikeda (29) in addition to the previously mentioned two experiments. According to three (10, 20, 29) out of these five experiments, no significant differences were found between the amount of after-effect of 1 second inspection and that of 15 second or 60 second inspection, but in one experiment (22), the after-effect of 60 second inspection was 73% greater than that of 1 second inspection and it was 209% greater in Fujiwara and Obonai’s one. In the present experiment, the difference is 100%, and this result as well as that of the author’s previous experiment intermediates between the results of the former three experiments and that of the last one. It should be pointed out that in the case of previous manually operated experiments (2, 21) such difference may be attributed to the inevitable lags pertaining to the manual presentation of T-figure, but it cannot be in the case of the present tachistoscopic experiment.

Why does such inconsistency among results of these experiments occur? The question cannot be solved instantly. It calls for further investigations. In author’s opinion, part of the inconsistency may be attributed to the differences in experimental designs, including the practice effect of the subjects in experiments of after-effect.

As general conclusions, we are able to say that only 1 second inspection produces considerable amount of after-effect, the longer inspection period brings no or slight increase of after-effect and the longer the inspection time is, the slower is the rate of decrease in after-effect. In other words, the duration of inspection-period affects the rate of decrease more strongly than it does the amount of after-effect immediately after inspection.*

**Spatial Factors**

According to Köhler and Wallach, the most fundamental principle of figural after-effects is “displacement”. Test-objects or their parts recede from regions in which inspection-objects have been shown, and most particularly from the places where the edges or contours of these objects were located. If a T-object lies entirely within the area of the previously inspected figure, its parts recede from the zone that has been occupied by the contour of this figure, and the T-object shrinks. Conversely, if the T-object surrounds the

* Concerning the temporal factors, Nozawa (19) also conducted an interesting experiment which treated the effect of intermittent presentation of inspection-figures.
area of the I-object, the T-object is enlarged for the same reason.

The second important principle of Köhler and Wallach's theory is "distance paradox". The amount to which T-objects are displaced depends on their distance from the I-object. For instance, if the I-object is a straight line, a T-line which coincides with the I-line will not be displaced. It will also not be displaced if it is shown very far apart from the I-line. In a wide range of the intermediate positions the T-line will recede from the I-line, and at a certain distance within this range its displacement will be maximal. The fact that, up to such an optimal distance, the farther the T-line is from I-line, the larger is the displacement, is called "distance paradox." If we locate an outline circle as a T-object within another outline circle adopted as an I-object, the T-circle will be expected to shrink according to the "displacement" principle. And the T-circle will grow when it surrounds the I-circle. Such a shrinkage or growth would become maximal at a certain spatial separation between the outlines of the I- and the T-circle, according to the "distance paradox" principle.

Size of I-circle.

It seems worthwhile to measure the amount of growth and shrinkage of the T-circle by varying the size of the I-circle from smaller to larger size than the former. Oyama (23), Ikeda (9), and Obonai (12) and Kogiso (15) conducted experiments designed to test the above case and obtained the results which are illustrated in Fig. 4. With respect to this figure, the following discussions may be pertinent:

I) The T-circle grows when it is larger than the I-circle and shrinks when it is smaller. This fact exactly agree with the "displacement" principle.

II) If the size of T-circle is equal to that of I-circle and coincides with it, the "displacement" principle predicts that neither growth nor shrinkage occurs. On the contrary, Fig. 4 indicates that it shrinks under such conditions. Köhler and Wallach already recognized this and presented an additional hypothesis to meet the facts. However, Hebb (7) and Smith (2) objected that the additional hypothesis was an ad hoc one.

III) The amount of shrinkage, in general, is greater than the amount of growth. This is also underviable from the simple "displacement" principle.

IV) There are, as the "distance paradox" principle predicts, the optimal point of growth and that of shrinkage where the amount of growth or shrinkage becomes maximal. In almost all curves in Fig. 4, the maximal growth occurs when I-circle is one-half of T-circle in diameter, and maximal shrinkage is obtained when it is twice as

*Köhler and Wallach's "displacement" theory was also criticized by Yoshida (30) and Kogiso (14) who measured the displacements of T-dots surrounding I-figures.
Fig. 4 *After-Effect as a Function of the Size Ratio of I-circle to T-circle*. After Oyama (22), Ikeda (9), Ikeda and Obonai (12), and Kogiso (15).

<table>
<thead>
<tr>
<th>Observation</th>
<th>Diameter of T-circle</th>
<th>Inspection Time</th>
<th>Method of Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oyama 1</td>
<td>3 m</td>
<td>2 cm</td>
<td>15 sec.</td>
</tr>
<tr>
<td>Oyama 2</td>
<td>3 m</td>
<td>4 cm</td>
<td>15 sec.</td>
</tr>
<tr>
<td>Oyama 3</td>
<td>3 m</td>
<td>4 cm</td>
<td>15 sec.</td>
</tr>
<tr>
<td>Ikeda</td>
<td>3 m</td>
<td>3 cm</td>
<td>120 sec.</td>
</tr>
<tr>
<td>Ikeda &amp; Obonai</td>
<td>1 m</td>
<td>3 cm</td>
<td>0.5 sec.</td>
</tr>
<tr>
<td>Kogiso</td>
<td>1.15 m</td>
<td>5 cm</td>
<td>15 sec.</td>
</tr>
</tbody>
</table>

Fig. 5 *After-Effect as a Function of the Size Ratio of I-circle to T-circle.*

*The method of transposition is a new psychophysical method devised by Oyama (24)*

large as the T-circle. The rules hold irrespectively of the size of T-circle. It means that the optimal condition of displacement, or the limit of "distance paradox", is not determined by the absolute distance between the outlines of I- and T-circles, but it depends upon the relative size ratio of I-circle to T-
circle. The similar facts were discovered by Ogasawara (21) with the simultaneous assimilation-contrast illusion of concentric circles in which the maximal attraction-effect occurred when size-ratio of two circles was 2:3 or 3:2. In this illusion, the direction of "displacement" and the numerical values of the ratio at which the maximal effects were obtained were different from those of the figural after-effects. Inspite of these difference, the fact that the principle of ratio-relation applies adequately to both phenomena suggests strongly their fundamental similarity.

The next experiment was planned to check these results by our tachistoscopic method.

**EXPERIMENT 2**

*Conditions.* The diameters of I-circle were 0.25, 0.5, 0.75, 1, 1.25, 1.5, 2, 2.5 and 3 cm respectively in Series-A, and 0.5, 1, 3, 4, 5 and 6 cm respectively in series-B. The diameter of the right-hand T-circle was 1 cm in Series-A, and 2 cm in Series-B. All other conditions were same as in Experiment 1.

*Procedure.* The temporal sequence of stimulus presentation was follows:

White paper→1 second presentation of I-figure→0.2 second presentation of T-figure→white paper.

There was always no interval between the presentations of I-figure and T-figure. Each of five subjects served in two experimental sessions for each of the two series. In one of these sessions, I-figures smaller than or equal to T-figures were used, and in an other session, larger I-figures were used. At least one minute of rest was given after each experiment. All other procedures were same as in Experiment 1.

*Results.* As shown in Fig. 5, results of two series of experiment 2 confirmed the previous results, I—IV. Compared with the curves in Fig. 4, the present curves are somewhat different in that the amount of shrinkage is, in general, smaller and the relative size of the optimal I-circle for shrinkage of T-circle is slightly larger.

Other than the experiments whose results were shown in Fig. 4, Oyama (23) conducted similar experiments with the T-circle of 4 cm in diameter by the method of limits, and with the T-circle of 2 cm in diameter by the method of complete series. Ikeda (9) also performed an experiment with inspection-period of 15 seconds. All these experiments brought about practically the same results so that I—IV should be regarded as a well-established ones. These conclusions were also found valid in another experiment in which two dots were used as I-figure and T-figure, and in which the growth and shrinkage of apparent distance between two T-dots was measured (25).

**Size of T-circle.**

The author's previous research also indicated that the amount of after-effect increased in proportion to the increase in the size of T-circle and that the relative amounts (%) of after-effect remained constant provided that the relative size of I-circle to T-circle was constant. This rule also held in Ogasawara's study of the illusion of the concentric-circles. However, the results of the two series in the Experiment 2 were not necessarily considered to be supporting this rule. Therefore, in
order to examine this point, another experiment was designed.

**EXPERIMENT 3**

*Conditions and Procedure.* The diameters of I-circle and T-circle in four conditions were as follows:

<table>
<thead>
<tr>
<th>Condition</th>
<th>I-circle</th>
<th>T-circle</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.5 cm</td>
<td>1 cm</td>
</tr>
<tr>
<td>B</td>
<td>3 cm</td>
<td>2 cm</td>
</tr>
<tr>
<td>C</td>
<td>4.5 cm</td>
<td>3 cm</td>
</tr>
<tr>
<td>D</td>
<td>6 cm</td>
<td>4 cm</td>
</tr>
</tbody>
</table>

Under these four conditions, the relative size ratio of I-circle to T-circle was kept constant, 3:2, while absolute sizes of I- and T-circles were varied.

There were four subjects, each of whom participated in one experimental session. All other conditions and procedures were the same as in Experiment 2.

Fig. 6 AFTER-EFFECT AS A FUNCTION OF THE SIZE OF T-CIRCLE. I-CIRCLE IS ALWAYS AS LARGE AS 1.5 × T-CIRCLE.

**Results.** The results are plotted in Fig. 6, in which the abscissae represent diameters of T-circle while the ordinates represent relative amounts of after-effect. If the above mentioned rule hold, a flat curve should be expected. However, it does not in these results. The curve of Fig. 6 is a descending curve, especially the value decreases between 1 and 2 cm of the abscissae. Perhaps this abrupt drop may partly be due to incidental experimental error.

Fig. 7 AFTER-EFFECT AS A FUNCTION OF THE DISTANCE BETWEEN THE CENTERS OF I- AND T-CIRCLE.

It would be a reasonable conclusion derived from these data that after-effect increases when the size of T-circle increases, but the rate of increase is not always proportional to T-circle. This conclusion also is supported by the experiment of two-dots figures (25).

**Eccentric Presentation of I- and T-Circle.**

It was reported that considerable amount of after-effect was found when I-circle was presented eccentrically to T-circle and the after-effect slightly decreased as the distance between the centers of I- and T-circle increased (23). This is an interesting fact related to the "localization" of after-effect which was found by some early investigators (3, 16). In order to re-examine this problem, the following experiment was performed.

**EXPERIMENT 4**

*Conditions and Procedure.* The diameters of I-circles were kept constant, each 3 cm in length, but the location of their center with respect to the fixation mark was...
varied, while the diameter of the right-hand T-circle was 2 cm and its center was always located 3.5 cm to the right of the fixation mark. The distances between the fixation cross and center of I-circle were 3.5, 4.5, 5.5, 6.5, and 7.5 cm respectively. Consequently the distances between the centers of I- and T-circles were 0, 1, 3 and 4 cm respectively. There were five subjects, each of whom served in one session. All other conditions and procedures were same as in Experiment 3.

Results. As shown in Fig. 7, the results confirmed the previous results. It was noteworthy that there was after-effect even when spatial overlapping of I- and T-circles was lacking.

Width of Outline of I-Circle.

It was reported that, when the width of the outline of I-circle was varied, the after-effect slightly increased as the width increased. In order to check this, Experiment 5 was conducted.

EXPERIMENT 5.

Conditions and Procedure. The diameter of I-circle was kept constant, 3 cm in length, and its center was always located 3.5 cm to the right of the fixation cross, but the width of the outline of I-circle was varied. Its widths were 1/8, 1/4, 1/2, 1 and 2 mm respectively. The diameter of the right-hand T-circle was 2 cm and the width of its outline was 1/2 mm. It was concentric with the I-circle. All other conditions and procedures were the same as in Experiment 4.

Results. The average value of five subjects is illustrated in Fig. 8. It confirms the previous results, except the value at the width of 2 cm, in which after-effect drops abruptly in spite of expected increase. This discontinuous value may be attributed to some secondary influence of paling, the second symptom of figural after-effects, which appears more markedly as the width of I-circle increases, or it may be attributed to some other experimental errors.

Graham (5) and Kogiso (15) also analyzed the effect of width of I-figure, and the former obtained almost flat curve, while the latter a slightly ascending curve. Thus, we should like to conclude that the increase of width of I-figure has no effect or, if any, weak positive effect.

Retinal Size vs. Apparent Size.

In a previous paper (23), the author reported two experiments which were planned to examine: Which was the determining factor of after-effect, the retinal size or the apparent size of I-circle? In these experiments, I-figures were presented at a distance, which was one-half of the distance at which T-figures were presented, and the size of I-circle was varied while that of T-circle was kept constant. In such a situation, if the retinal size is the determining variable, T-circle will grow when its retinal size is larger than that of I-circle and it will shrink when it is equal to or smaller than that of I-circle, and the maximal growth and shrinkage will be obtained when the ratios between the retinal sizes of the two circles are 1 : 2 and 2 : 1 respective-
ly. On the contrary, if the apparent size is the determining variable, the growth and shrinkage of T-circle and the optimal points for them will be determined by the ratio between the apparent sizes of the two circles. The results showed the retinal size to be the determining variable, except in the case of the optimal point of shrinking effect in one of the experiments. In order to check these results, another experiment was conducted in which I-figures were presented at a distance twice as far as the distance at which T-figures were presented.

**EXPERIMENT 6**

**Conditions and Procedure.** By means of additional attachment to the tachistoscope, an I-figures were presented at the distance of 158 cm while T-figures were presented at the distance of 79 cm as in the preceding experiments. The diameters of I-circles were 1, 2, 3, 4, 5, 6, 8, and 10 cm respectively. Its center was located 7 cm to the right of fixation cross. The diameter of the right-hand T-circle was 2 cm in length and its center was located 3.5 cm to that right of fixation cross. Thus its retinal image was concentric with that of I-circle. There were four subjects, each of whom served in two sessions. All other conditions and procedures were the same as in Experiment 1.

The results are illustrated in Fig. 9. When the retinal size of I-circle was greater than that of T-circle, the experimental results met the prediction based upon the retinal-size hypothesis. The shrinkage occurred under all these conditions and the assumed maximum could be approximated from the plotted results at the point where the size ratio was 2:1, though the actual experimental value for that point was somewhat smaller, presumably due to some incidental errors. When the retinal size was smaller than that of T-circle, the growth, contrary to the expectation based on the retinal-size hypothesis, did not necessarily occur under all conditions and its maximum was not obtained when the size ratio was 1:2. We hesitate to attribute all these discrepancies to experimental errors.

While some investigators (8, 26) supported the retinal-size hypothesis, Sutherland (28), based on his experimental data, recently discussed that both the retinal size and the apparent size were determining factors for the figural after-effects. From the results of our experiments and those of other investigators, we cannot conclude univocally which is the determining factor, the retinal size or the apparent size. We may rightly say, however, that figural after-effects are not determined by the apparent size alone.

**CONCLUSIONS**

From the results of our previous and present experiments and that of other investigators we can conclude as follows:

1) Only 1 second inspection of certain figures produces considerable amount of figural after-effects and longer inspection period brings no or, if any, slight increase in the after-effect.
2) After-effect is greatest immediately after the inspection-period and decreases exponentially with the increase of time elapsed after inspection. The longer the inspection time is, the slower is the rate of decrease.

3) When the size of T-circle is larger than that of I-circle, it grows, and when it is equal to or smaller than that of I-circle, it shrinks.

4) The amount of shrinkage, in general, is greater than the amount of growth.

5) The maximal growth occurs when the size ratio of I-circle to T-circle is 1:2, and the maximal shrinkage is obtained when the size ratio is 2:1. This rule holds irrespectively of the absolute size of T-circle.

6) After-effect increases when the size of T-circle increases, but the rate of increase is not always proportional to T-circle.

7) Considerable amount of after-effect is found when I-circle is presented eccentrically to T-circle. The after-effect slightly decreases as the distance between the centers of I- and T-circles increases, but it occurs even without any spatial overlapping of I- and T-circles.

8) When the width of the outline of I-circle increases, the after-effect does not increase or, if any, the increase is slight.

9) It is certain that the retinal size of I-circle is, at least, a determining variable for after-effect, but it is possible that the apparent size also is a simultaneous determining factor.

10) Köhler and Wallach's "displacement" and "distance paradox" theories do not always satisfactorily explain the experimental facts.

REFERENCES


8) Hochberg, J. and Bitterman, M. E.: Figural after-effects as a function of the retinal size of inspection figure. *Amer. J. Psychol.*, 1951, 64, 94—102.


28) Sutherland, N.S.: Figural after-effects, retinal size and apparent size. *Quart. J.exp. Psychol.*, 1954, 6, 35—44.