

Temporal Development of Illusory Contours Induced by Complete Figures

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Day and Kasperczyk (1983) and Takiura (2010) showed empirically that complete figures induced weak illusory contours, which is contrary to Kanizsa's (1979) assertion that amodal completion of incomplete figures is the critical and necessary factor in the formation of illusory contours. In the present study, four experiments were done to investigate the temporal development of illusory contours with complete figures consisting of four pacmen as well as with incomplete figures consisting of four crosses by the backward masking technique. Clarity of illusory contours was monotonically increased with presentation time of inducing figures to about 3000 ms, beyond which it leveled off and remained constant at its value with steady inducing figures. We concluded that reduction of clarity of illusory contours with complete figures is not due to the disruption of processing of illusory image caused by the detection of completeness of figural elements at early stages of processes that was assumed to be by Takahashi (1993), but due to the reduction of amodal completion of inducing figures caused by perceptual completeness of their elements (Kanizsa, 1979) or due to the presence of a nearby edge parallel to the supporting edge in the figural element which prevents observers from perceiving illusory contours (Albert, 1993).

Key words: completeness, illusory contours, microgenesis

Introduction

In order to claim the criticalness and necessity for perceptual incompleteness of inducing figures for perception of illusory contours², Kanizsa (1979) presented a demonstration that illusory contours failed to be perceived in the area cornered with four crosses of perceptually completed structures. This demonstration, however, did not give us any quantitative data on the perception of illusory contours with complete inducing figures.

With magnitude estimation method, Day and Kasperczyk (1983) found that illusory contours could be perceived in the area cornered with four complete crosses with naive observers. Clarity of illusory contours with figures consisting of complete elements was above the half of the one with figures consisting of incomplete elements (notched disks). Purghé and Katsaras (1991) also reported the induction of weak illusory contours by figural patterns consisting of complete elements with naive observers. Murakami (2002) confirmed Day and Kasperczyk's (1983) result with experienced observers. Murakami also found that lightness

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2. We restrict the term *illusory contours* to refer to the bounding contours and not to entire illusion, which we call *illusory figures*.

enhancement occurred on the surface of illusory figures with inducing figures composed of complete elements using the lightness matching method. These quantitative studies cast doubt on the claim that the perceptual completion of incomplete figures is critical and necessary for perception of illusory figures.

With naive observers, Takiura (2010) found that illusory figures induced by four crosses and by six nonagons, each of which consisted of three triangles, were about 40 % in contour clarity, were about 30 % in enhanced brightness, and were about 20 % in stratified depth of illusory figures induced by four notched octagons and by three notched disks. This result shows that illusory figures induced by complete figures give visual impressions largely different in quality from illusory figures induced by incomplete figures, which suggests that complete figures are different in the manner of induction of illusory figures from incomplete ones. So it might be that different processes underlie the induction of illusory figures between complete figures and incomplete ones.

This idea is difficult to be tested by the experiment with inducing figures steadily presented, since the observer will do his or her task not on the basis of an intermediate image of the stimulus, which is formed during the processing in the visual system, but on the basis of the final percept of the stimulus, that is, the perceptual outcome of the visual system.

The backward masking technique is expected to solve this problem. Presentation of a mask just after the offset of a brief stimulus is thought to interrupt the stream of processes to evoke to the observer a percept of the intermediate image of stimulus formed at the time of interruption of processing in the visual system (Felsten & Wasserman, 1980). Gallatry (1980) introduced the backward masking technique to the study of illusory figure perception, and since then many authors used this technique to investigate the temporal evolution of the image of illusory figures induced by incomplete figures (Imber, Shapley, & Rubin, 2005; Muise, LeBlanc, Blanchard, & de Warnaffe, 1993; Parks, 1994, 1995; Reynolds, 1981; Ringach & Shipley, 1996; Spehar & Clifford, 2003; Takahashi, 1993; Takiura, 2005).

Takahashi (1993) applied the backward masking technique to the study of the temporal development of illusory contours induced by complete figures. With well-trained observers and using the rating method with 11-point scale, he found the induction of illusory contours by quite brief presentations of patterns consisting of four crosses. Illusory contours were maximal at about 30-40 ms in presentation time with about 20-30 % in clarity of those induced by four notched disks steadily presented. Clarity of illusory contours was reduced to almost zero at the longest presentation time tested (70 ms). Clarity of illusory contours with incomplete figures was monotonically increased with presentation time. Takahashi concluded that illusory contours were reduced in clarity with complete inducing figures steadily presented because of the disruption of processing of illusory image caused by the detection of completeness of figural elements at early stages of processes.

In the four experiments of the present study the temporal development of illusory contours with complete figures was investigated in detail with the backward masking technique. In Experiments 1 and 2, we replicated the experiment of Takahashi (1993) with

relatively shorter presentation times with the aid of improved methodology. In Experiments 3 and 4, we traced the temporal development of illusory contours at longer presentation times.

Experiment 1. Rating of clarity of illusory contours with shorter presentation times of complete and incomplete figures

In Experiment 1, the measurement made by Takahashi (1993) was replicated to examine whether his result that clarity of illusory contours was changed as an inverted-U function of presentation time of inducing figures was reproduced.

Method

Observers

Thirteen volunteers (11 male and 2 female, aged between 22 and 42 years) participated in the experiment as observers. They were familiar with illusory contours with incomplete figures. Eleven of them had already participated in the experiment on illusory contour perception with incomplete figures. All of them were not aware of the purpose of the experiment. All had normal or corrected-to-normal visual acuity.

Apparatus and stimuli

The stimuli were generated on a personal computer (NEC PC-9821Xa10) and were presented on a 17-inch CRT monitor with a refresh rate of 70 Hz (EIZO FlexScan E53F). The stimuli were viewed binocularly at a distance of 1 m.

Takahashi (1993) gave the description of spatial parameters of inducing figures only about their outer sizes in his article. Since we could not be informed on the other spatial parameters of inducing figures from the author directly, the inducing figures with spatial parameters similar to those estimated from his Figure 1 were used in the present experiment.

The inducing figures used in the present experiment are shown in Figure 1.

The incomplete figures consisted of four notched black disks of diameter 2.0 deg. These

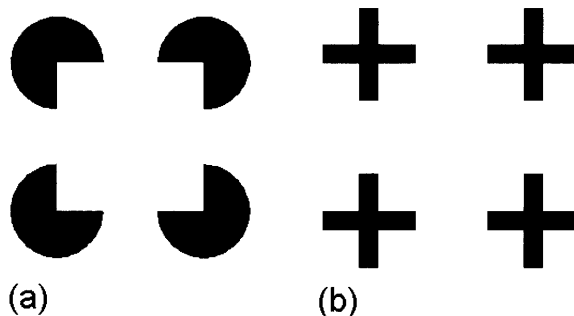


Figure 1. Inducing figures used in the present experiment: (a) the incomplete figure, (b) the complete figure.

elements were placed in order for the area cornered by them to form an imaginary square of side 3.3 deg with support ratio of 0.60. The complete figures consisted of four symmetrical black crosses whose crosspieces were 2.0 deg in length and 0.4 deg in width. The imaginary square area cornered by crosses was 3.3 deg in side so that the support ratio was 0.49. The luminance of the background was 29.5 cd/m^2 and the luminance of the inducing figure was 6.3 cd/m^2 .

Procedure

Measurement was made in an illuminated booth (40 lx). At the start of each trial, a beep tone was presented as a warning signal. One hundred milliseconds after the offset of the beep tone, four black lines of 0.05 deg wide by 1.9 deg long in each size were presented above, below, at the right and the left to the inducing figure for 2000 ms. Observers were asked to keep themselves from blinking during the time from the presentation of beep tone to the offset of the inducing figure and to fix their gaze upon the imaginary crossing of four lines. Immediately after the offset of the inducing figure, the random dot mask of 6.7 deg by 6.7 deg was presented for 500 ms. A side of a square dot was 0.05 deg and the dot density was 0.5 for the mask. Inter-trial interval was about 1000 ms. These were common to Experiments 2 to 4.

Clarity of illusory contours was rated on an 11-point scale, 0 (no illusory contours) to 10 (illusory contours of the same clarity as illusory contours with incomplete figures steadily presented). The observer was asked to rate with ignoring the difference in presentation time of inducing figures. Presentation times of inducing figures were 14.3 to 300 ms.

In each session, the incomplete figure was presented steadily as reference before the measurement. Trials with incomplete figures and those with complete figure were given in random order. Presentation times were tested in random order for each type of inducing figure. In one session, four ratings were made for each combination of the type of inducing figure with presentation time. The session was repeated twice for each observer.

The observer was also asked to rate the clarity of illusory contours with the complete figure steadily presented once at the time before the first session and after the second session with reference of the illusory contour clarity with the incomplete figure steadily presented called 10. For this task, the complete figure and the incomplete figure were presented with the horizontal distance between the centers of both the figures at 10.6 deg. The location, left or right, of the figures was determined at random.

Results

Figure 2 shows the mean rated points of clarity of illusory contours as a function of presentation time of inducing figures.

A two-way ANOVA revealed that there were significant main effects of type of inducing figure, $F(1, 12) = 79.35$, $p < .01$, and of presentation time, $F(7, 84) = 96.49$, $p < .01$, respectively. The interaction between type of inducing figure and presentation time

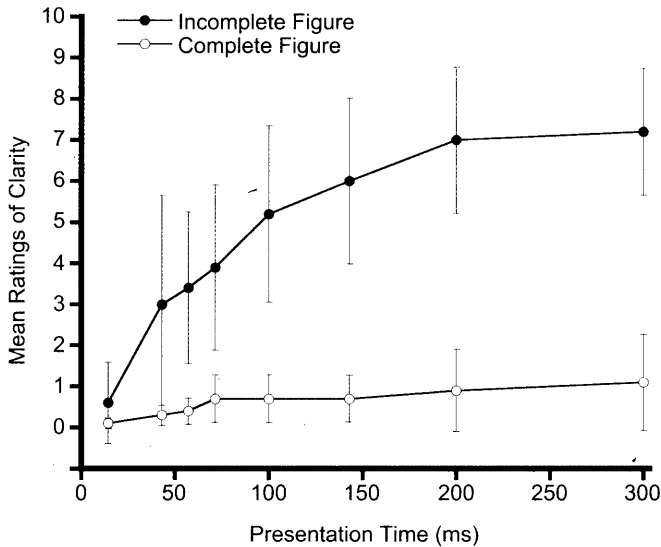


Figure 2. Mean rated points of clarity of illusory contours as a function of presentation time of inducing figures.

was also significant, $F(7, 84) = 51.89, p < .01$. Clarity of illusory contours was increased with presentation time both of incomplete figures and of complete figures. Clarity of illusory contours was higher with incomplete figures than with complete figures at all the presentation times.

The result that clarity of illusory contours was increased with presentation time of incomplete figures was in agreement with previous studies (Parks, 1994; Ringach, & Shipley, 1996; Spehar, & Clifford, 2003; Takahashi, 1993; Takiura, 2005). Clarity of illusory contours with complete figures was not developed in inverted-U fashion as reported by Takahashi (1993) but was developed in roughly a monotonically increasing manner with presentation time. Illusory contours induced by complete figures were as low as about one-seventh of illusory contours induced by incomplete figures in clarity at the longest presentation time tested (300 ms).

A two-tailed t -test detected no statistical difference in clarity of illusory contours with complete figures steadily presented between the time points (before and after the experiment) at which the ratings were made, $t(12) = 2.11, ns$. The mean rate of clarity of illusory contours with complete figures steadily presented between the time points was 2.3.

Discussion

The result with complete figures was different between the present experiment and Takahashi (1993). The stimulus configuration was similar and stimulus luminance and contrast were not largely different in the two studies.

The tachistoscope lamps used in the experiment of Takahashi (1993) were able to be lower in output at several dozen milliseconds and be of relatively long off periods (Bolander, 1979; Mollon & Polden, 1978), whereas the CRT used in the present experiment was free from these undesirable timing properties (García-Pérez & Peli, 2001; Vergilino-Perez & Findley, 2003). It seems, however, that such the timing properties of tachistoscope lamps do not enhance illusory contour clarity at the middle range of presentation time or inhibit it at the longer presentation times. So, the discrepancy of result with complete figures between the present experiment and Takahashi's experiment does not seem to have been caused by the differences in stimulus condition and apparatus.

Individual differences of the observer seem to be the most plausible cause of the discrepancy of result between the present experiment and Takahashi (1993). A total of 13 observers participated in the present experiment. Clarity of illusory contours was increased with five observers and was almost unchanged with four observers with presentation time of complete figures. With the other four observers, clarity of illusory contours was changed in an inverted-U fashion with presentation time of complete figures. The maximum of clarity, however, appeared at longer presentation times than 30-40 ms, at which the maximum appeared in Takahashi's experiment. In the present experiment it appeared at 71.4-100 ms with three observers, and at 150 ms and at 200 ms with the other two observers, respectively.

The observers of Takahashi (1993) were well trained for doing the experimental task so that their perception and rating should be highly reliable. They were, however, as few as four. So, the result obtained by Takahashi should be strongly influenced by individual differences in perception. It is probable that in Takahashi's experiment the change in clarity of illusory contours in an inverted-U fashion with presentation time of complete figures was shown with most of the observers, whereas in the present experiment such the change in clarity was shown with only 30 % of the observers.

Experiment 2. Change of clarity of illusory contours with presentation time of complete and incomplete figures investigated by the temporal forced-choice technique

In Experiment 1, we found that clarity of illusory contours was changed not as an inverted-U function but as a monotonically increasing function of presentation time of complete figures. In Experiment 2, this result was confirmed by the measurement with the temporal forced-choice technique that is probably more sensitive than rating for detecting the variation of clarity of illusory contours.

Method

Observers

A new group of 13 volunteers (9 male and 4 female, aged between 20 and 39 years) participated in the experiment as observers. They were familiar with illusory contours with incomplete figures. Nine of them had already participated in the experiment on illusory

contour perception with incomplete figures. All of them were not aware of the purpose of the experiment. All had normal or corrected-to-normal visual acuity.

Apparatus and stimuli

The apparatus and the stimulus configuration were the same as in Experiment 1.

Procedure

Since the forced-choice is based on discrimination between the stimuli, it is probably more sensitive than the rating for detecting the difference of clarity between illusory contours. In the present experiment the technique that Bowen and Pokorny (1978) devised to study the temporal brightness enhancement with real figures was used with modification from spatial forced-choice with haploscopic view to temporal forced-choice with binocular view.

In each trial two inducing figures were presented successively at temporal interval of 2000 ms. They were the same in figural type (incomplete or complete) but different in presentation time. The shorter inducing figure had presentation time values from 14.3 to 200 ms, and the longer one had larger value than the shorter one by 28.6 ms. Such the relatively small increment in presentation time with the longer inducing figure was set because of the rapid change in clarity of illusory contours with complete figures reported by Takahashi (1993). Takahashi reported that the increase and the following decrease in clarity of illusory contours induced by complete figures occurred in the range of presentation time as short as 50 ms or so.

The shorter presentation times were tested in random order. The order between the shorter inducing figure and the longer one was set at random on each trial. Trials with incomplete figures and those with complete figures were given in random order.

The task of the observer was to judge which of the two figures presented successively induced clearer illusory contours. The observer was asked to make his or her judgment with ignoring the difference in presentation time between the two figures.

In one session, five judgments were made for each combination of the type of inducing figure with the shorter presentation time. The session was repeated twice for each observer.

The clarity of illusory contours with the complete figure steadily presented was measured by the same manner as in Experiment 1.

Results

The results expected to be given by the temporal forced-choice in the present experiment are as follows. In the region where clarity of illusory contours is increased with presentation time of inducing figures, clarity of illusory contours with longer figure should be judged higher at the percentage between 50 and 100 % according as the discriminability of clarity between the shorter figure and the longer figure. In the region where clarity of illusory contours is almost invariant with presentation time of inducing figures, clarity of illusory contour with the longer figure should be judged higher on 50 % or nearly so of all trials. And in the region

where clarity of illusory contours is decreased with presentation time of inducing figures, the percentage of trials with judgment of higher clarity with the longer figure should be on 0 to 50 % of all trials according as the discriminability of clarity of illusory contours between the shorter figure and the longer one.

If clarity of illusory contours is increased at first and then decreased with presentation time of complete figures as seen in the result of Takahashi (1993), the percentage of trials with judgment of higher clarity of illusory contours with longer complete figure should be 50 % or above at and about both the ends of the range of presentation time tested and be below 50 % at the middle presentation times.

Figure 3 shows the percentage of trials on which clarity of illusory contours with the longer of the two inducing figures was judged higher as a function of presentation time of the shorter inducing figure.

A two-way ANOVA revealed that there was no significant main effect of type of inducing figure, $F(1, 12) = .95, ns$, which means that clarity of illusory contours is changed in the same manner with presentation time both of incomplete figures and of complete figures. The main effect of presentation time was significant, $F(6, 72) = 7.88, p < .01$. This indicates that both the graphs declined with presentation time of the shorter inducing figure. The interaction between type of inducing figure and presentation time was not significant, $F(6, 72) = .89, ns$.

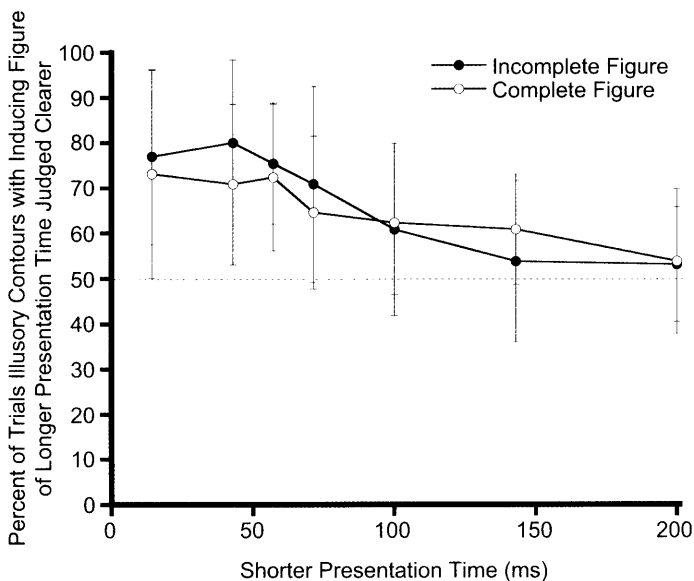


Figure 3. Percentage of trials on which clarity of illusory contours with the longer of the two inducing figures was judged higher as a function of presentation time of the shorter inducing figure.

The percentage of trials on which clarity of illusory contours with the longer of the two inducing figures was judged higher was above 50 % at all the presentation times of the shorter inducing figure tested.

A two-tailed *t*-test detected no statistical difference in clarity of illusory contours with the complete figure steadily presented between the time points at which the ratings were made, $t(12) = 1.15$, *ns*. The mean rate of clarity of illusory contours with the complete figure steadily presented between the time points was 2.4, which was not statistically different from the one in Experiment 1 by a two-tailed *t*-test, $t(24) = .14$, *ns*.

Discussion

The percentage of trials on which clarity of illusory contours with the longer of the two inducing figures was judged higher was always above 50 %, indicating that the shorter was not judged higher in clarity than the longer of the two inducing figures. So clarity of illusory contours should not have been changed in an inverted-U fashion with presentation time not only of incomplete figures but also of complete figures. This is in agreement with the result of Experiment 1, though the method used in the present experiment gave no evidence of monotonically increasing change in clarity of illusory figures with presentation time of complete figures.

The decline of the graphs in Figure 3 with presentation time of the shorter inducing figure indicates the decrease in discriminability of clarity between the shorter and the longer of the two inducing figures with presentation time of the shorter inducing figure. This suggests that clarity of illusory contours is deceleratingly changed with presentation time. In Figure 2, such the change, the increase, in clarity of illusory contours assessed by the rating method was clearly noticed with incomplete figures. It was not, however, so clear with complete figures probably because the scale used in Experiment 1 was too rough to make the observer rate the clarity of a faint illusory percept minutely.

Experiment 3. Magnitude estimation of clarity of illusory contours with long presentation time of complete and incomplete figures

In Experiments 1 and 2 we investigated the temporal development of illusory contours with presentation time of inducing figures at and below 300 ms. We found that clarity of illusory contours was increased monotonically with presentation time both of incomplete figures and of complete figures. In the present experiment we extended the presentation time tested to 1000 ms and used magnitude estimation technique to measure the clarity of illusory contours.

Method

Observers

A new group of 23 volunteers (9 male and 14 female, aged between 19 and 27 years) participated in the experiment as observers. They were familiar with illusory contours with incomplete figures. Two of them had already participated in the experiment on illusory contour perception with incomplete figures. All of them were not aware of the purpose of the experiment. All had normal or corrected-to-normal visual acuity.

Apparatus and stimuli

The apparatus and the stimulus configuration were the same as in Experiment 1.

Procedure

Clarity of illusory contours was assessed by the method of magnitude estimation. The observer was asked to do his or her task with ignoring the difference in presentation time of inducing figures. Presentation times of inducing figures were 57.1 to 1000 ms.

In each session, the incomplete inducing figure was presented steadily as reference before the measurement. Clarity of illusory contours with the reference was called 100. Trials with incomplete figures and those with complete figures were given in random order. Presentation times were tested in random order for each type of inducing figure. In one session, four estimates were made for each combination of the type of inducing figure with presentation time. The session was repeated twice for each observer.

Clarity of illusory contours with the complete figure steadily presented was also measured by the method of magnitude estimation. Estimates were made once at the time before the first session and after the second session with reference of the illusory contour clarity with the incomplete figure steadily presented called 100. Stimulus display for this task was the same as in Experiment 1.

Results

Figure 4 shows the mean estimate of clarity of illusory contours as a function of presentation time of inducing figures.

A two-way ANOVA revealed that there were significant main effects of type of inducing figure, $F(1, 22) = 29.68$, $p < .01$, and of presentation time, $F(7, 154) = 89.02$, $p < .01$, respectively. The interaction between type of inducing figure and presentation time was also significant, $F(7, 154) = 19.56$, $p < .01$. Clarity of illusory contours was monotonically increased with presentation time to 1000 ms both of incomplete figures and of complete figures. No overshoot of clarity occurred at shorter presentation times than 1000 ms. Clarity of illusory contours was higher with incomplete figures than with complete figures at all the presentation times. These were in agreement with the result of Experiment 1 with presentation times at

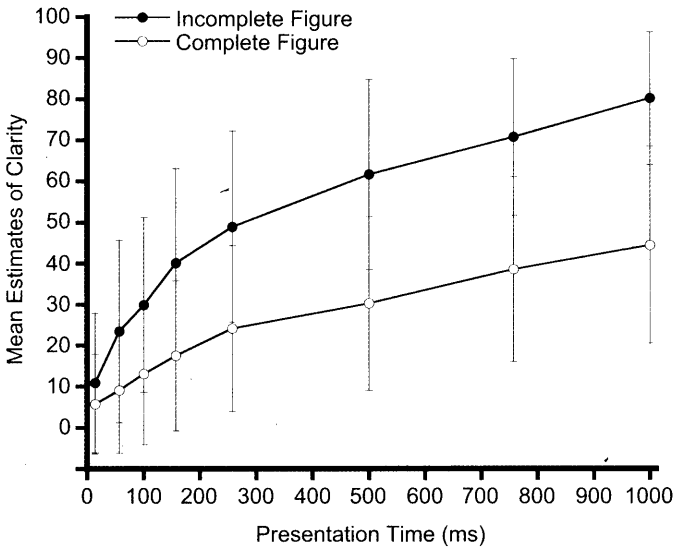


Figure 4. Mean estimates of clarity of illusory contours as a function of presentation time of inducing figures to 1000ms.

and shorter than 300 ms.

A two-tailed *t*-test detected no statistical difference in clarity of illusory contours with the complete figure steadily presented between the time points at which the estimates were made, $t(22) = 1.69$, *ns*. The mean estimate of clarity of illusory contours with the complete figure steadily presented between the time points was 22.7.

Discussion

We concluded from the results of Experiments 1-3 that clarity of illusory contours is not changed in an inverted-U fashion but is increased monotonically with presentation time at least below 1000 ms with complete figures as well as with incomplete figures.

Lower clarity of illusory contours with complete figures is not due to the disruption of processing of illusory image following the detection of completeness of figural elements at early stages of processes that was assumed to be by Takahashi (1993). It seems to be caused by the reduction of amodal completion of inducing figures due to the perceptual completeness of figural elements (Kanizsa, 1979) or by the presence of a nearby edge parallel to the supporting edge in the element which prevents observers from perceiving illusory contours (Albert, 1993).

Experiment 4. Clarity of illusory contours with very long presentation time of complete and incomplete figures

From Figure 4, it seems that longer presentation time than 1000 ms is need for clarity of

illusory contours to reach a steady level which is maintained at longer presentation times both with incomplete figures and with complete figures. In the present experiment, the change of clarity of illusory contours with presentation time of inducing figures longer than 1000 ms was investigated.

Method

Observers

A new group of 13 volunteers (9 male and 4 female, aged between 21 and 27 years) participated in the experiment as observers. They were naive about illusory contours and were shown incomplete and complete figures that produce illusory contours first in the present experiment. None of them had already participated in the experiment on pattern perception. All of them were not aware of the purpose of the experiment. All had normal or corrected-to-normal visual acuity.

Apparatus and stimuli

The apparatus and the stimulus configuration were the same as in Experiment 1.

Procedure

The procedure was the same as in Experiment 3. Presentation times of inducing figures were 100 to 5000 ms.

Results

Figure 5 shows the result. A two-way ANOVA revealed that there were significant main effects of type of inducing figure, $F(1, 12) = 67.96$, $p < .01$, and of presentation time, $F(4, 48) = 37.66$, $p < .01$, respectively. The interaction between type of inducing figure and presentation time was also significant, $F(4, 48) = 10.38$, $p < .01$. Clarity of illusory contours was monotonically increased with presentation time to 5000 ms both with incomplete figures and with complete figures. Clarity was higher with incomplete figures than with complete figures at all the presentation times. These were in agreement with the results in Experiments 1 and 3 with presentation times at and shorter than 1000 ms.

Clarity of illusory contours was increased with presentation time to about 3000 ms at which point it leveled off and remained constant with both incomplete figures and complete figures at its value with steady figures.

A two-tailed t -test detected no statistical difference in clarity of illusory contours with the complete figure steadily presented between the time points at which the estimates were made, $t(12) = 1.94$, ns . The mean estimate of clarity of illusory contours with complete figures steadily presented between the time points was 27.7, which was not statistically different from the one in Experiment 3 by a two-tailed t -test, $t(34) = .61$, ns . As the case with incomplete

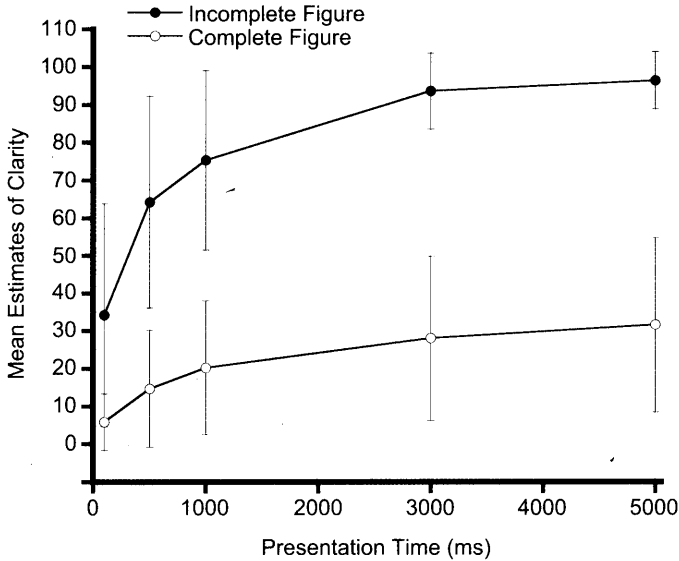


Figure 5. Mean estimates of clarity of illusory contours as a function of presentation time of inducing figures to 5000ms.

figures, the maximal clarity (about 30 in estimate) of illusory contours with complete figures was quite similar to the clarity of complete figures steadily presented.

Discussion

Illusory contours completed to develop at presentation time of about 3000 ms. At this presentation time, complete figures as well as incomplete figures induced illusory contours of almost the same clarity as illusory contours induced by these figures steadily presented. The maximal clarity of illusory contours with complete figures in the present experiment was lower than those reported by Day and Kasperczyk (1983) and by Takiura (2010) with naive observers. The reason for this difference between the results may be attributed not only to individual differences in observer but also to the differences in stimulus configurations. Day and Kasperczyk showed that the additional elements such as short lines or diamonds between the crosses, which were not included in the complete figures in the present experiment, increased clarity of illusory contours. The cross patterns in the inducing figures had larger ratio of the width to the length of the crosspiece (about 0.33) in Day and Kasperczyk's and Takiura's experiments than those in the present experiment (0.20), which is more favorable to illusory contour formation (Purghé, 1989).

The rate of increase in clarity of illusory contours with incomplete figures was larger in Figure 2 than in Figures 4 and 5 in the range of presentation time shorter than 300 ms. Rubín, Nakayama, and Shapley (1997) found the rapid and stimulus-size-specific learning in illusory

contour perception. In the present study, the observers in Experiment 1 had been more experienced in experiments on illusory contour perception with similar stimulus configuration to the present study than those in Experiments 3 and 4, so that they should have perceived clearer illusory contours with brief incomplete figures than the observers in Experiments 3 and 4 did.

General Discussion

In the present study we found that illusory contours developed monotonically with presentation time of incomplete figures as well as of complete figures. Clarity of illusory contours reached a plateau at presentation time of about 3000 ms. Clarity at the plateau was almost the same as the clarity with steady complete figures and was about 25 % of the clarity with steady incomplete figures. Development of illusory contours was parallel over all the presentation times tested. We obtained no evidence for the disruption of processing of illusory image caused by the detection of completeness of inducing elements at early stages of processes that was assumed to be by Takahashi (1993) to explain lower clarity of illusory contours with complete figures.

In Experiments 3 and 4 with the longest presentation times on the order of seconds all of the total of 36 observers showed the increase in clarity of illusory contours with presentation time of incomplete figures. However, they can be classified in three groups as to perception of illusory contours with complete figures. Twenty-six observers showed the increase in clarity of illusory contours with presentation time. They also perceived illusory contours with steady presentation. Six observers perceived little or no illusory contours with tachistoscopic as well as steady presentation. The rest of four observers showed the increase in clarity of illusory contours with presentation time but perceived little or no illusory contours with steady presentation.

The backward masking technique is believed to interrupt the stream of processes to evoke to the observer a percept of the intermediate image of stimulus formed at the time of interruption of processing in the visual system (Felsten & Wasserman, 1980). So from the results from the first and the second groups, whose members amounted to 89 % of the total observers in Experiments 3 and 4, we can see that the final percept of illusory contours results from the monotonic evolution of internal representation of illusory contours in the visual system. The observer who perceives illusory contours with complete figures briefly presented perceives them with complete figures steadily presented. The observer who perceives little or no illusory contours with complete figures briefly presented hardly perceives or does not perceive them with complete figures steadily presented.

The conflicting result from the third group may be due to breaking up and fading away of illusory contours by prolonged fixation of the steady figures. Laurie, Warm, Dember, and Frank (1994) reported that breakup of illusory contours with incomplete figures occurred after about 15 s of observation on the average. It is probable that quite faint illusory contours

induced by complete figures are broken up much faster. If the observers in the third group tended to gaze the stimulus with steady presentation, estimated clarity of illusory contours should have been very low.

Kanizsa (1979) claimed that figural incompleteness of inducing elements is a necessary condition for generation of illusory contours. Rock and Anson (1979) showed that figural incompleteness of inducing elements as well as alignment of physically present edges between inducing elements are necessary for the formation of illusory contours. Illusory contours are, however, perceivable with figural patterns consisting of complete elements, though they are fairly weak. It is clear that figural incompleteness is insufficient for generation of illusory contours.

The models on illusory contour perception based on the alignment cues (e.g., Grossberg, 1994; Grossberg & Mingolla, 1985) fails to predict perception of illusory contours induced by complete figures. Such the models explain perceptual completion of collinearly aligned contours of paired inducing elements with no consideration whether the inducing element is incomplete or complete. So they do not predict that illusory contours are far weaker with complete figures than with incomplete figures.

Recently Kogo, Strecha, van Gool, and Wagemans (2010) proposed a model on illusory contour perception based on the local occlusion cues. This model explains the formation of illusory contours by determination of the occluding surface, which looks to be closer to the observer, and the occluded surface, which looks to be more distant from the observer, based on L- and T-junctions at the border between these surfaces. This model takes into consideration whether the inducing element is incomplete or complete. It predicts, however, little or no generation of illusory contours with complete figures, which is incompatible with our empirical data.

These models also fail to predict Albert's (1993) observation that illusory contours were easily perceived with complete figures with removing the parallelism of the edge from the inducing elements (crosses). These models need to be modified to predict the experimental results on illusory contour perception with complete figures.

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