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Reaction Times to Kanizsa Illusion: Effects of the Contrast and Illumination Level

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It has been pointed out that the 3 perceptual attributes are associated with the Kanizsa illusion: illusory contour, brightness (or darkness) enhancement, and depth stratification. Two experiments were conducted to examine the temporal sequence of generation of these attributes by RT measurement. The RT was the shortest to the illusory contour and was the longest to the depth stratification, which suggests that the illusory contour was perceived first, then the brightness enhancement followed by the depth stratification. With decreasing the contrast or illumination of the stimulus, the RT was increased with such the temporal sequence of the perception of 3 attributes kept unchanged. The sequence of the perception of the attributes, however, did not predict the result of the measurement of the steady Kanizsa illusion in which 3 attributes were almost the same in illusion strength or the illusory contour tended to be weaker than the other attributes.

Key words: Kanizsa illusions, illusory contours, brightness enhancement, depth stratification, reaction times

Introduction

Many studies have been carried out on the perception of the illusory figure (for reviews see Lesher, 1995; Spillmann & Dresp, 1995). Most of them have been devoted to investigating the properties of the illusory contour, which is defined as the contour perceived in the area of physical homogeneity. The illusory figure, especially the Kanizsa illusion, is, however, more complex entity than the illusory contour that is only one attribute of this perceptual phenomenon (Kanizsa, 1979; Lesher, 1995; Meyer & Petry, 1987).

With the stimuli inducing the Kanizsa illusion, which are typically three or four notched black disks facing inwards, and with appropriate stimulus parameters such as luminance, size, support ratio or so, the triangle or square space in the display center not only looks delineated by the perceptually-completed contours between the inducing elements as well as the physical edges of the notches of the inducing elements but also looks brighter and nearer to the observer than the background often without any effort. The illusory figure is in fact not the illusion only of the contours, but the illusion of the organized figure to which the completed contour belongs. So it is necessary for the properties of the Kanizsa illusion to be investigated on the various phenomenal attributes as the brightness enhancement and the depth stratification as well as the illusory contour.

There are only a few studies in which the relationship among three attributes of the Kanizsa illusion was investigated, and the results obtained in such the studies were not inconsistent with one another. With the spatio-temporal integration paradigm in which inducing elements were

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successively presented one by one with variable time intervals, Unuma and Tozawa (1994) asked participants to estimate the magnitude of each attribute of the Kanizsa illusion. Results of causal analysis indicated that there was a strong relationship between the illusory contour and the depth stratification but no relationship between the brightness enhancement and the depth stratification. The relationship between the illusory contour and the brightness enhancement was different among participants.

Watanabe and Oyama (1988) investigated the effects of inter-element distance and luminance of the inducing figure on the magnitude of each attribute of the Kanizsa illusion by the magnitude estimation technique. With the causal analysis they claimed that the output of the processes responsible for the illusory contour influenced the processes responsible for the brightness enhancement and the depth stratification but not vice versa. Their results were in accordance with Kanizsa's (1979) speculation that the brightness enhancement and the depth stratification are the consequences of the formation of the surface delineated by the illusory contour, but were not supported by the results of Unuma and Tozawa (1994), where there were large individual differences in the relationship between the illusory contour and the brightness enhancement.

In the study of Halpern (1981), quite complex results were obtained. She measured the magnitude of each attribute of the Kanizsa illusion with separate psychophysical techniques to avoid the artifactual correlation between the measures. The data were analyzed by the multiple regression analysis with the illusory contour strength used as dependent measure. The interrelationships among the illusory contour strength, the brightness enhancement and the depth stratification were not simple and highly dependent on the stimulus configuration.

In all of these studies, inducing figures were steadily presented or were presented with durations longer than 1 s. In the experiment of Unuma and Tozawa (1994), the minimal presentation period of the inducing figure was 1,585 ms within which all the inducing elements were successively presented. In these studies, the final outputs of the visual system responsible for the Kanizsa illusion seem to have been investigated. The processes for the Kanizsa illusion may have the intermediate representations of the illusory figure before the completion of its final percept. The illusory contour, the brightness enhancement, and the depth stratification have been supposed to be given rise to through the separate subsystems in the visual system interacting with one another (e.g., Gove, Grossberg, & Mingolla, 1995; Grossberg, 1994; Seghier & Vuilleumier, 2006). The incomplete percepts generated from the integrated outputs from the intermediate processing stages in such the subsystems may bring information about the relationships among these attributes before the processes reach their static state.

If the development of each attribute of Kanizsa illusion is monotonic, with a brief exposure time of the inducing figure, the order of the magnitude of the three attributes of the Kanizsa illusion with respect to the magnitude of the attributes with infinite exposure time will correspond to the order of their degree of development. In the neurophysiological studies of the Kanizsa illusion, it has been well established that in the visual cortex, mainly in the V1 and V2 at the lower level and in the lateral occipital complex at the higher level, the outputs of the neurons processing the features of the stimuli which trigger the generation of the illusory contour with shorter latencies are inputted into the neurons which form the illusory surface with longer latencies (e.g., Halgren, Mendola, Chong, & Dale, 2003; Murray, Wylie, Higgins, Javitt, Schroeder, & Foxe, 2002; Stanley & Rubin, 2003). So with brief exposure of the inducing figure, the psychophysical evidence may be obtained for the faster development of the illusory contour than of the other attributes of the Kanizsa illusion.

By the method of the magnitude estimation, Takiura (2005, 2006a) investigated the perceptual magnitude of the three attributes of the Kanizsa illusion as a function of the duration of the inducing figure. The maximal duration tested was 1 s. It was shown that the development was significantly faster for the illusory contour than for the brightness enhancement and the depth stratification. The brightness enhancement tended to develop faster than the depth stratification. He concluded that the formation of the illusory contour is faster than the filling-in of the brightness followed by the generation of the stratification of depth in the surface of the illusory figure.

It is known that the magnitude of each attribute of the Kanizsa illusion is strongly affected by both the contrast of the inducing figure (Banton & Levi, 1992; Brussell, Stober, & Bodinger, 1977; Dresp, 1992; Matthews & Welch, 1997; Watanabe & Oyama, 1988) and the illumination level (Bradley & Dumais, 1984; Dumais & Bradley, 1976; Warm, Dember, Padich, Beckner, & Jones, 1987). To our knowledge, however, there have been no reports on the effects of stimulus contrast or illumination level on the speeds of the development of the attributes of the Kanizsa illusion. So, further experiments are needed to examine whether Takiura's (2005, 2006a) conclusion about the temporal sequence among three attributes of the Kanizsa illusion holds under the variable luminance conditions.

In the present study, the effects of the stimulus contrast and the illumination level were examined upon the time needed to perceive the illusory contour, the brightness enhancement [2] or the depth stratification of the Kanizsa illusion. The time needed for perception was assessed by reaction time (RT). We supposed that the attribute of the illusion whose speed of development was larger would be detected faster than the other attributes to bring shorter RT.

Experiment 1: Effects of the contrast of the inducing figure on the RT to the attributes of Kanizsa illusion

In this experiment, we examined timing differences in the perception among three attributes of the Kanizsa illusion by measuring RT with variable contrast of the inducing figure.

Method

Participants. Twelve volunteers (nine male and three female, aged between 18 and 23 years) who could perceive the illusory contour, the brightness enhancement and the depth stratification

2 A total of 11 participants in Experiments 1 and 2 reported that they perceived the lightness enhancement (or whiteness enhancement) rather than the brightness enhancement at the free observation of the stimulus or for the question about the perception of the Kanizsa illusion before the experiment. In the present article, however, the lightness was not discriminated from the brightness as an attribute of the Kanizsa illusion and only the former expression was used since all of the participants but two who perceived the lightness enhancement acknowledged the two expressions of lightness enhancement and the brightness enhancement to be interchangeable with each other as to their perception.

of the Kanizsa illusion participated in the experiment. None of them had participated in the experiments on the perception of illusory figure and in the RT measurement, and were aware of the purpose of the experiment. All had normal or corrected-to-normal visual acuity.

Apparatus and stimuli. The experiment was done in a dark room. The stimuli were generated by a personal computer (NEC PC-9821As3) with a frame buffer (Digital Arts HyperFRAME3) and were presented on the screen of a 17-inch CRT monitor (EIZO FlexScan E53F) with a refresh rate of 72 Hz. The stimuli were viewed binocularly at a distance of 57.3 cm.

The inducing figure consisted of four notched black disks of diameter 1.7 deg. These inducing elements were placed in order for the area surrounded by them to form an imaginary square of side 2.8 deg. Support ratio of the stimulus was 0.61.This inducing figure produced clear perception of Kanizsa illusion for all the participants with steady presentation. The luminance of the background was fixed at 26.7 cd/m^2. The inducing figure was 24.3, 15.3 or 1.3 cd/m^2 in luminance, giving 0.09, 0.43 or 0.95 of the Weber contrast, respectively.

Procedure. Before the measurement the participant was adapted to the background luminance for 5 min. At the start of each trial, 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 2 s. Participants were asked to keep themselves from blinking during the time from the warning tone to their responses, and to fix their gaze upon the imaginary crossing of four lines. The time from the offset of the four black lines to the onset of the inducing figure was randomly varied between 1.5 to 3.5 s with s step of 500 ms from trial to trial. Inter-trial interval was as long as about 5 s since the RT tended to increase with repetition of the trial with the inter-trial interval shorter than 2 s under the same stimulus condition in a pilot experiment.

The participants were instructed to push the button of the computer mouse as quickly as possible when they perceived one of the attributes of the Kanizsa illusion. Immediately after the button of the computer mouse was pushed the inducing figure disappeared from the screen and the next trial was initiated. A session was divided into three blocks. Separate blocks were assigned to the measurement with each of the three attributes to avoid the participants' mistake of the attribute to which they should respond. In each block, 10 RTs were obtained for each of the three contrasts, which were presented in random order. The order of the block was set at random. The session was repeated twice for each participant.

The participants were also given two additional tasks to examine the relationship between the RT and the strength of the illusion for the stimuli with the steady presentation at each contrast at the time before the first session, between the sessions and after the second session. In both the tasks the conditions were tested in random order:

1. To make the relative magnitude of the three attributes at each contrast clear, the participants were asked to report the perceived magnitude of brightness and depth with respect to the background by assigning a number with reference of the illusory contour strength called 100 at each contrast. This task is the inter-attributes judgment of the magnitude of the illusion at each contrast.

2. To examine the change of the magnitude of the attributes with contrast, the participants were required to report the perceived magnitude of each attribute at the middle and the lowest

contrasts with the reference of the one at the highest contrast called 100. This task is the intra-attribute judgment of the magnitude of the illusion made among the contrasts.

Four sessions for RT measurement were run as practice sessions for each participant on a day before the experiment. Five practice trials were also given before each block.

Results and Discussion

The mean RT under each stimulus condition for each participant was used in the data analysis.

In Figure 1, the mean RTs to the illusory contour (circles), the brightness enhancement (squares) and the depth stratification (triangles) are shown as a function of the contrast of the inducing figure. The RT was longest for the depth stratification and the shortest for the illusory contour for all the contrasts. Decreasing the contrast of the inducing figure yielded longer RT for each attribute. These effects were also confirmed by the results of the two-way ANOVAs (attribute × contrast). That is, there were significant main effects of both attribute, $F\ (2,\ 22) = 23.60$, $p < .01$, and contrast, $F\ (2,\ 22) = 88.04$, $p < .01$. The interaction between attribute and contrast was also significant, $F\ (4,\ 44) = 4.77$, $p < .01$, which indicated the increase of the RT difference with the decrease of the contrast.

These results strongly suggest that the development was the fastest for the illusory contour, the secondary fastest for the brightness enhancement, and the slowest for the depth stratification. This is consistent with the conclusion of Takiura (2005, 2006a) who examined the magnitude of the Kanizsa illusion for variable duration of the inducing figure by the magnitude estimation method.

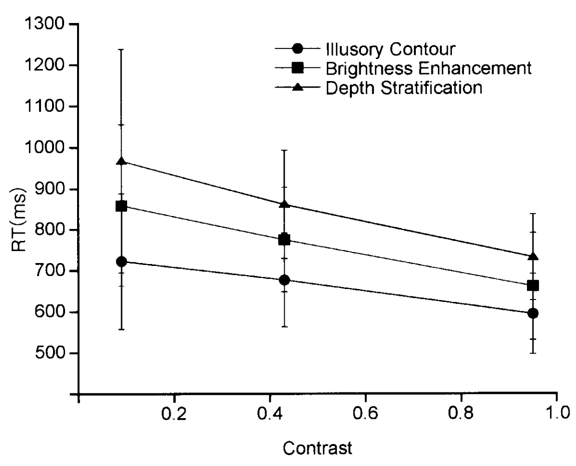

Figure 1. The RT to the illusory contour, the brightness enhancement, and the depth stratification as a function of contrast of the inducing figure.

The dependence of the RT to the illusory contour upon the contrast suggests that the timing of the illusory contour formation is determined by the perceptual clarity of the physical edges of the notch of the inducing elements arranged collinearly. The increment of the RT with the decrease in contrast for the illusory contour seems to be far larger than that for the real figure within the comparable range of contrast (e.g., Burkhardt, Gottesman, & Keenan, 1987). Thus, the increase of the RT to the illusory contour with the decrease in contrast is likely to be caused not only by the delay of the detection of physical edges but also by the delay of judgment on collinearity between them.

The brightness signal might be evoked by the lateral inhibition at the physical edges of the notch of the inducing elements (Frisby & Clatworthy, 1975), which is enhanced at larger contrast (Henning, Millar, & Hill, 2000), and spreads out until it is blocked by the illusory contour already represented in the visual system. The filled-in brightness might give the area delineated by the real and illusory contour the nature of opaque surface. The incompletion of the inducing elements might give the observer the impression that the four complete elements are partly occluded by such the surface, which will lead the illusory figure to be perceived being located in front of the inducing figure and background.

This idea on the formation of the illusory figure is consistent with the results of the present experiment that the brightness enhancement and the depth stratification were second slowest and the slowest in the development, respectively, among the attributes of the Kanizsa illusion and were highly dependent on the inducing figure contrast. The inference that the stratification in depth is triggered the latest seems to be supported by the participants' introspection that they saw the brighter square gradually pushed out from the background toward them.

The generation and completion of the attributes of the Kanizsa illusion, however, would not be made only in a successive fashion. It might be inappropriate to think that the mechanisms responsible for the brightness enhancement do not operate until the final outputs of the mechanisms responsible for the illusory contour input into them, and that the mechanisms responsible for the depth stratification do not work until the final outputs of the mechanisms responsible for the brightness enhancement input into them.

Takiura (2005, 2006a) found that the magnitude of three attributes of the Kanizsa illusion began to increase at about 20 ms of the duration of the inducing figure. So, the mechanisms responsible for three attributes would operate with partial overlap in time with one another. This inference might be, at least in part, in accordance with the neurophysiological finding that neurons processing the specific features of the stimuli strongly interact with neurons processing other features through both the feedforward and feedback pathways (e.g., Halgren et. al., 2003; Murray et al., 2002; Stanley & Rubin, 2003). It might be also in accordance with the FACADE theory (Gove et al, 1995; Grossberg, 1994) in which the feedback pathways are supposed to connect the subsystem processing the features of the surface (FCS) and the subsystem for the construction of the boundaries (BCS) in the visual system.

For real figure, it has been well established that the RT is increased with the decrease of contrast (e.g., Burkhardt et al., 1987; Jáskowski & Sobieralska, 2004). The RT to the illusory figure was also increased with the decrease of contrast. This may bring the idea that the formation processes of the illusory figure share the neural networks with those of the real figure. The RT was, however, far longer for the illusory figure than for the real figure, suggesting that the underlying mechanisms are partly different between these two kinds of figures. Although the ERP study claimed that there are no neural networks in which the illusory figure is exclusively processed (Pegna, Khateb, Murray, Landis, & Michel, 2002), the EEG and the neuroimaging studies (Hirsch, DeLapaz, Relkin, Victor, Kim, Li, Borden, Rubin, & Shapley, 1995; Larsson, Amunts, Gulyas, Malokovic, Zilles, & Roland, 1999) as well as the psychophysical studies (Imber, Shapley, & Rubin, 2005) reported that the neural networks associated with the illusory figure are different in part from those associated with the real figure. These studies suggest that the specific regions in the brain activated by the illusory figure participate in the grouping operation, surface completion and object recognition.

Results of the additional tasks 1 and 2 are shown in Figure 2a and Figure 2b, respectively. For the magnitude estimates of the strength of each attribute, there were no statistical differences among the time points at which the judgments were made, so that the data were collapsed across this variable for analysis. For comparison, the value of the reference for each task is shown in each Figure.

The mean data of 12 participants of the additional task 1 showed that the magnitude of the illusion was independent both of the contrast and of the attribute, though eight participants judged the brightness enhancement and the depth stratification to be stronger in illusion than the illusory contour. This was also partly supported by the two-way ANOVA, in which levels of contrast were set at two (0.09 or 0.43), $F\ (2,\ 22) = 0.46$, *ns*, and $F\ (1,\ 11) = 3.18$, *ns*, respectively. Result of the additional task 2 showed that the illusion was decreased in magnitude with the decrease of the contrast, and was smaller in decline for the illusory contour than for the other two attributes. These were statistically supported in part by the two-way ANOVAs, in which levels of attribute were set at two (brightness enhancement or depth stratification), $F(1,\ 11) = 63.82, p < .01$, and $F(2,\ 22) = 3.56, p < .01$. Fisher's LSD test revealed that the decrease in the magnitude of the illusion was significantly smaller for illusory contour than for the brightness enhancement and the depth stratification.

The method of the magnitude estimation is the scaling with the ratio scale (Stevens, 1957). So, it is possible to calculate the ratio between the estimates. We calculated the magnitude of the illusion for each attribute at each contrast relative to the one for the illusory contour at the highest contrast.

The result is shown in Figure 2c. The illusion declined with the decrease in the contrast, which was statistically supported by the ANOVA, $F\ (2,\ 22) = 11.73,\ p < .01$. Although the brightness enhancement was a little larger in magnitude than the other two attributes, no statistical differences were found among attributes, $F\ (2,\ 22) = 1.16$, *ns*. The Kanizsa illusion was weakened with decrease in contrast for the three attributes being statistically the same as one another in magnitude at each contrast.

It is clear that the relationship among the three attributes of the Kanizsa illusion with the steady stimulus is not predicted by the RT data shown in Figure 1.

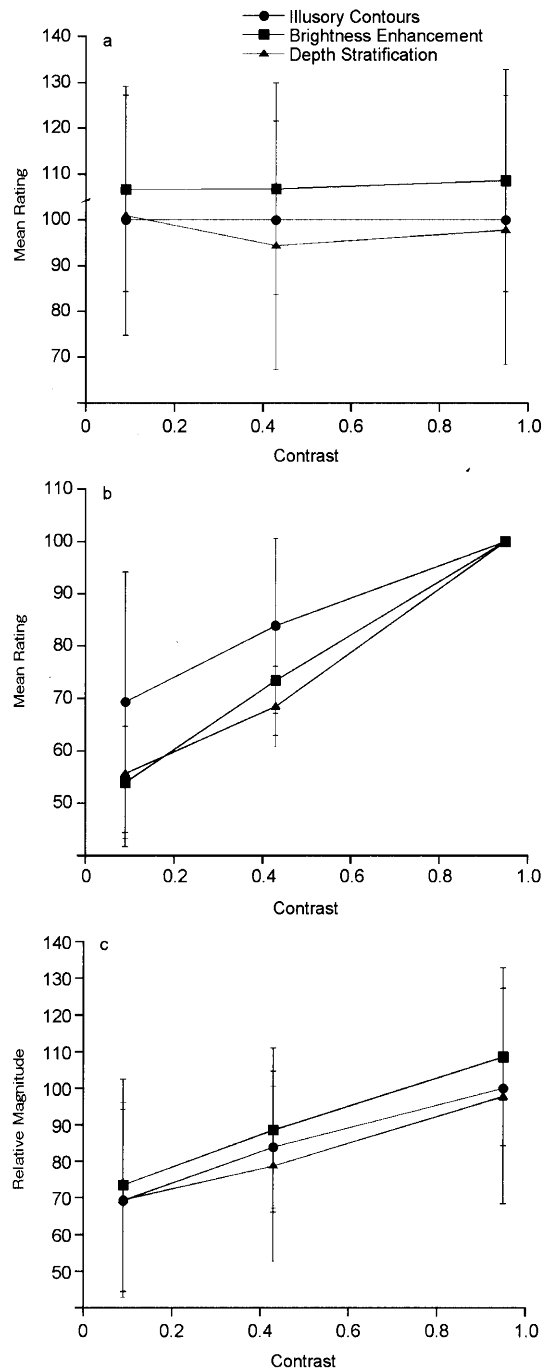

Figure 2a. Results of the inter-attributes judgment of the magnitude of the illusion at each contrast.
Figure 2b. Results of the intra-attribute judgment of the magnitude of the illusion made among the contrasts.
Figure 2c. Magnitude of the illusion for each attribute as a function of the contrast relative to the one for the illusory contour at the highest contrast.

As the present experiment, previous studies on the effects of contrast upon the Kanizsa illusion reported the decrease both of the strength of the illusory contour (Banton & Levi, 1992; Brussell et al., 1977; Matthews & Welch, 1997) and of the brightness or darkness in the area delineated by the illusory contour (Banton & Levi, 1992; Dresp, 1992; Matthews & Welch, 1997). The independence of the brightness from the contrast was reported by Watanabe and Oyama (1988) in which the inducing elements separation was as large as 4.1 deg or more and by Banton and Levi (1992) in which the support ratio was as small as 0.06 or 0.20. Under such stimulus conditions the illusion in itself seems to be quite weak. Watanabe and Oyama (1988) reported the effects of the contrast on the illusory contour and the depth stratification in opposite direction to our result. We have no explanation for this difference.

Experiment 2. Effects of illumination on the RT to the attributes of Kanizsa illusion

In this study, we examined timing differences in the perception among three attributes of the Kanizsa illusion by measuring the RT with variable illumination of the stimulus field.

Method

Participants. A new group of 12 volunteers (all male, aged between 18 and 44 years) who could perceive the illusory contour, the brightness enhancement and the depth stratification of the Kanizsa illusion participated in the experiment. None of them had experienced the psychophysical measurement and were aware of the purpose of the experiment. All had normal or corrected-to-normal visual acuity.

Apparatus and stimuli. The system for stimulus presentation and the values of the spatial parameters of the stimulus were the same as those in Experiment 1. The stimuli were viewed with the participants' right eyes at a distance of 57.3 cm.

The illumination of the stimulus field was attenuated by the setting neutral density filters with the transmittance of 1 or 10 % (Special Optics, Cedar Grove, NJ) in front of the participant's right eye. With no filter the luminance of the background and of the inducing figures were 26.7 and 1.3 cd/m^2, respectively. A lightproof tube whose inside was painted with Chinese ink was set between the CRT monitor and participant's eye to keep the light of the ambient illumination by the monitor from entering the eyes.

Procedure. The sequence of the stimulus presentation in a trial was the same as that in Experiment 1. Measurements with different illumination were done in separate session. When the illumination level was changed, the participants were re-adapted to the new luminance of the background for 5 min. The sessions were given in random order for each participant.

A session was divided into three blocks. Separate blocks were assigned to the measurement with each of the three attributes of the illusion. In each block, 20 RTs were consecutively gathered. The order of the block was set at random.

The participants were also given the following additional tasks similar to those in Experiment 1 at the time before the first session once and after the third session twice:

1. To make the relative magnitude of the three attributes of the illusion at each illumination level clear, the participants were asked to report the perceived magnitude of enhanced brightness and depth with respect to the background by assigning a number with reference of the illusory contour strength called 100 at each illumination level.
2. To examine the change of the magnitude of the attributes with illumination, the participants were required to report the perceived magnitude of each attribute at each illumination level with the reference of the one at the highest illumination level called 100 presented to the participant's left eyes to keep the adaptation level of the right eye from damaging. The reference was not steadily presented but was presented whenever the participants wanted to see it in the experiment. The target was disappeared during the presentation of the reference. In both the tasks the conditions were tested in random order.

Three sessions that were the same ones as in the experiment were given twice as practice sessions to each participant on the days before the measurement. Five practice trials were also given before each block.

Results and Discussion

The mean RT is shown in Figure 3 as a function of the background luminance. In this experiment, the illumination level of the display was varied with the contrast kept constant. So, the illumination level was indicated as the background luminance in Figure 3.

The RTs were longest for the depth stratification and were shortest for the illusory contour at all the illumination levels. Decreasing the illumination level yielded longer RTs to each attribute. These results strongly suggest that the speed of development was decreased with the decreasing of the illumination level with its order among the attributes kept unchanged.

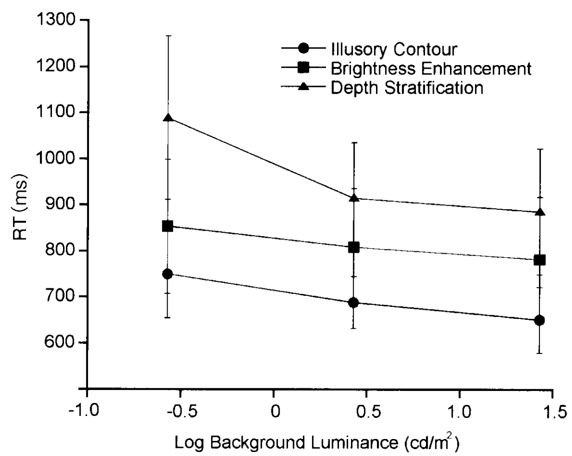

Figure 3. The RT to each of the attribute as a function of the illumination level indicated as the background luminance.

These effects were also confirmed by the results of the two-way ANOVA (attribute × illumination level). That is, there were significant main effects of both attribute, $F(2, 22) = 49.37$, $p < .01$, and illumination level, $F(2, 22) = 19.56$, $p < .01$. The interaction between attribute and illumination level was also significant, $F(4, 44) = 6.66$, $p < .01$. Multiple comparisons using Fisher's LSD test revealed that there were significant differences in the RT between all the illumination levels for the illusory contour, between the highest and the lowest illumination levels for the brightness enhancement, and between the highest and the lowest as well as between middle and the lowest illumination levels for the depth stratification. Fisher's LSD test also detected the statistically significant differences between all the attributes at each illumination level.

It is known that the RT is increased when the illumination level of the real figure is decreased with its contrast kept constant (Burkhardt et al., 1987). The present experiment showed that this also holds for the illusory figure. In the illusory figure, the physical edges of the notch of the inducing elements are decreased in clarity at lower illumination level. This might delay the construction of the illusory contour by making the detection of the collinearity between the physical edges as well as the physical edges themselves difficult, and might delay the filling-in of brightness by weakening the lateral inhibition. The stratification of the depth might also be delayed due to the delay of the formation of the surface with the illusory contour and filled-in brightness.

The stimulus at the highest illumination level was the same as that at 0.95 of contrast in Experiment 1. The RT to this stimulus was, however, longer in Experiment 1 than in Experiment 2. Differences in the RT were shown at the center column in Table 1. To examine whether these differences in RT were due to the difference in the viewing condition in Experiments 1 and 2, the RTs were compared between under binocular vision and under monocular vision for the same observers. A new group of 10 naive volunteers (eight male and two female, aged between 33 and 45 years) participated in the supplementary experiment. Measurements were done at 0.95 of contrast. Thirty RTs were gathered for each attribute for each participant. In the supplementary experiment, the RT was similar for the illusory contour, but was about 40-50 ms longer for the brightness enhancement, and was about 60-90 ms longer for the depth stratification than in Experiments 1 and 2 compared under the same viewing condition. The RT was significantly shorter with binocular vision than with monocular vision, $F(1, 9) = 27.89$, $p < .01$, and was the longest for the depth stratification, the second longest for the brightness enhancement and the shortest for the illusory contour, $F(2, 18) = 23.06$, $p < .01$. Differences in the RT in the supplementary experiment were shown at the right column in Table 1.

Differences in the RT between the two viewing conditions in the supplementary experiment were roughly the same as those between Experiments 1 and 2 for the illusory contour and brightness enhancement. For the depth stratification, however, difference was considerably larger for Experiments 1 and 2. The *SD*s were similar for all the experiments at 0.95 of contrast for each attribute. So, the RT differences with the same stimulus observed between Experiments 1 and 2 can be thought to be mainly due to the difference in the viewing condition, that is, binocular vision or monocular vision, but in part due to the individual differences among participants,

Table 1 Differences in the RT between with binocular viewing and with monocular viewing.

	RT Difference Between Experiments 1 and 2 (ms)	RT Difference Between Binocular and Monocular Conditions in Supplementary Experiment (ms)
Illusory Contour	73.0	56.4
Brightness Enhancement	97.6	104.8
Depth Stratification	137.5	75.1

especially for the depth stratification. The processes responsible for the depth stratification seem to be triggered last among the three attributes as discussed above, so it is likely that the accumulated individual differences of the timing in the early processing of the illusory figure are added to the individual timing difference of the processing of depth itself. It is possible to suppose that the formation of the illusory figure is faster in the binocular pathway than in the monocular one. Such the binocular dominance of perception seems to be common to the real and illusory figures, since the RT to the real figure is also shorter with binocular vision than with monocular vision (Minucci & Connors, 1964; Teichner & Krebs, 1972).

Results of the additional tasks 1 and 2 are shown in Figure 4a and Figure 4b, respectively. Since there were no statistical differences among the time points at which the judgments were made, the data were collapsed across this variable for analysis. For comparison, the value of the reference for each task is shown in each Figure.

In the additional task 1 the brightness enhancement and the depth stratification were stronger at the lowest illumination level, which was statistically supported by the two-way ANOVA, $F(2, 22) = 19.06$, $p < .01$, and by Fisher's LSD test. The depth stratification was stronger than the brightness enhancement only at the lowest illumination level, $F(1, 11) = 6.76$, $p < .05$.

The stimulus at highest illumination level in the Experiment 2 was the same as that with the contrast 0.95 in Experiment 1, but the mean estimate for the depth stratification was somewhat higher in the Experiment 2. This discrepancy was likely to be due to the individual differences of the participants. In Experiment 1 eight participants judged the brightness enhancement stronger than the depth stratification and four vice versa, whereas in Experiment 2 four participants judged the brightness enhancement stronger than the depth stratification and six vice versa. Takiura (2006b) found that there are large individual differences in the rating of the magnitude of the three attributes of the Kanizsa illusion.

Result of the additional task 2 showed that with the decrease of the illumination level the clarity of the illusory contour was decreased, $F(2, 22) = 75.40$, $p < .01$, and the magnitude of the brightness enhancement and the depth stratification was increased, $F(2, 22) = 7.02$, $p < .01$ and $F(2, 22) = 11.37$, $p < .01$, respectively. No difference of the estimate was found between the brightness enhancement and the depth stratification.

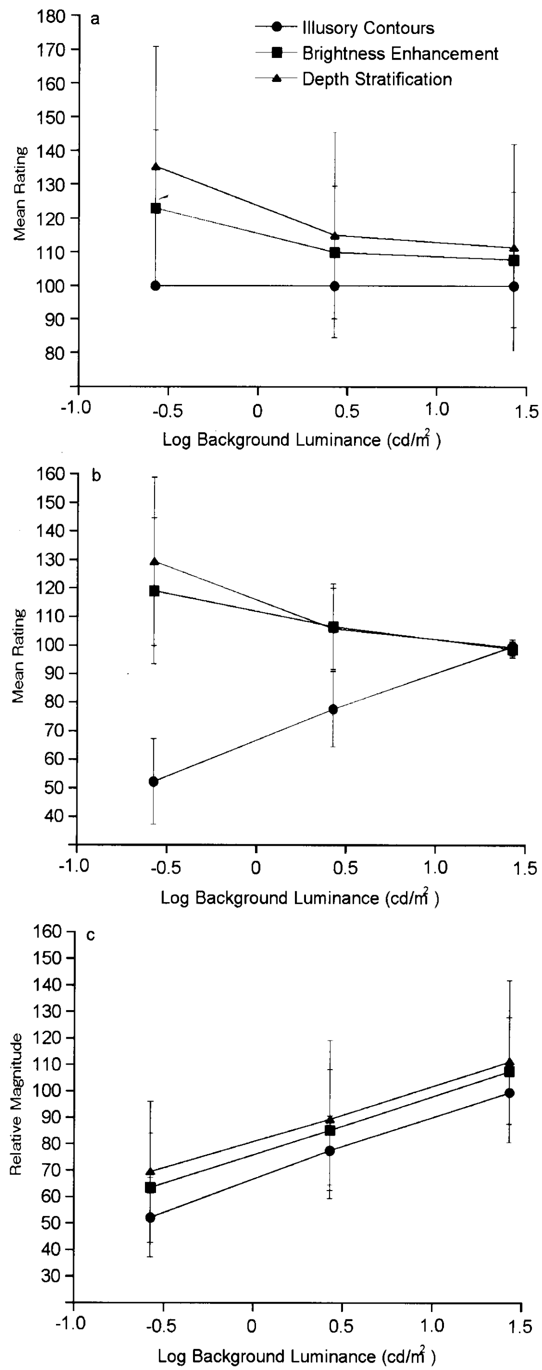

Figure 4a. Results of the inter-attributes judgment of the magnitude of the illusion at each illumination level indicated as the background luminance. *Figure 4b.* Results of the intra-attribute judgment of the magnitude of the illusion made among the illumination level. *Figure 4c.* Magnitude of the illusion for each attribute as a function of the illumination level relative to the one for the illusory contour at the highest illumination level.

The magnitude of the illusion for each attribute relative to the one for the illusory contour at the highest illumination level is shown in Figure 4c as a function of the illumination level. The illusion declined with the decrease in the illumination level, which was statistically supported, $F\ (2,\ 22) = 38.42,\ p < .01$. The main effect of attribute was only marginally significant, $F\ (2,\ 22) = 3.04,\ p < .10$, No interaction of the effect was detected between illumination level and attribute, $F\ (4,\ 44) = 1.02$, *ns*. The Kanizsa illusion was weakened with the decrease of the illumination level, and the depth stratification tended to be the most salient and the brightness enhancement tended to be the second most salient among the attribute of the illusion at any illumination level.

It is clear that there are no relationships between the perceptual strength of the three attributes of the Kanizsa illusions with the steady stimulus and the RT data shown in Figure 3.

The result that the depth stratification was increased in magnitude with the decrease of the illumination level had been obtained by Bradley and Dumais (1984), too. Parks and Marks (1985) reported the comparative data with the Ehrenstein illusion. They also found that the brightness enhancement became stronger as the illumination level was decreased. Warm et al. (1987) showed that the clarity of the illusory contour was decreased with the decrease of the illumination, which agrees with our result. Dumais and Bradley (1976) obtained the converse data, but their result was likely to be a judgment artifact with the dimly illuminated real figure as a reference (Warm et al, 1987). Parks and Marks (1983) reported that in the Ehrenstein illusion the clarity of the illusory contour was increased in strength with the decrease of the illumination, which suggests that the mechanisms responsible for the illusory contour are different between the Kanizsa illusion and the Ehrenstein illusion.

General Discussion

Takiura (2005, 2006a) investigated the changes of the magnitude estimates of the three attributes of the Kanizsa illusion with the duration of the inducing figure. He found that the speed of development was significantly higher for the illusory contour than the brightness enhancement and the depth stratification. The brightness enhancement tended to develop faster than the depth stratification. The results of the two experiments reported here suggest that the temporal sequence of the fast forming of the illusory contour and the following late producing of the brightness enhancement and the depth stratification is insusceptible of the change of both contrast and illumination level. This is similar to the inference of Watanabe and Oyama (1988), though their result and ours were quite different in the effects of contrast. We conclude that the formation of illusory contour precedes the generation of the brightness filling-in and depth stratification in the surface of the illusory figure, which holds irrespective of the contrast and illumination level.

It was impossible to predict the relationship among the attributes of the Kanizsa illusion with the steady stimulus from the RT data. Based on the result of the RT measurement, the illusory contour is expected to be strongest in illusion among the three attributes with steady stimulus because of the shortest RT to the illusory contour suggesting the fastest development. In fact, however, there was no difference in magnitude among the attributes or, at best, slight tendency toward the higher magnitude for the other attributes than the illusory contour for the steady Kanizsa illusion. This fact suggests that the representation of the Kanizsa illusion in the neural networks is quite different at the dynamic state in the course of the development from at the static state after its completion.

In the present experiments we obtained mean RT of about 600 ms for the perception of the illusory contour at the highest contrast with binocular viewing. The RT to the real figure has been reported to be about 200-250 ms with the high contrast stimulus presented on the background at moderate luminance (Burkhardt et al., 1987; Vicars & Lit, 1975). Lee and Nguyen (2001) found that the first neuronal responses to the illusory contour occurred as early as at about 65-120 ms in V1 and V2 of the rhesus monkey where the illusory contour are processed on a local scale, though such responses might already be influenced by the feedback signal from the late processing stages (Foxe & Simpson, 2002; Murray et al., 2002) at which the grouping mechanisms operate to represent the global shape and to yield the figure-ground segregation..The maximal neuronal responses at the late and global processing stages have been reported to reach their peaks at about 150-200 ms (Murray et al., 2002; Pegna et al., 2002). So we might be possible to speculate that the RT to the illusory figure mainly reflected latencies of the neuronal responses at late and global processing stages rather than those at early and local processing stages.

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