Perception of illusory contours enhanced in motion

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Abstract Investigation on illusory contours is important for understanding the mechanisms underlying the object recognition of human visual system. Numerous researches have shown that illusory contours formed in motion and stereopsis are generated by the unmatched features. Here we conduct three psychophysical experiments to test if Kanizsa illusory contours are also caused by unmatched information. Different types of motion (including horizontal translation, radial expanding and shrinking) are utilized in the experiments. The results show that no matter under what kind of motion, when figures or background move separately illusory contours are perceived stronger, and there is no significant difference between the perceived strength in these two types of motion. However, no such enhancement of perceived strength is found when figures and background move together. It is found that the strengthened unmatched features generate the enhancement effect of illusory contour perception in motion. Thus the results suggest that the process of unmatched information in visual system is a critical step in the formation of illusory contours.

Keywords: illusory contours, enhancement, moving, unmatched, psychophysics.

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Object perception is one of the most important components of visual perception of human beings and mammalian animals. It is a most confusing problem on object perception that how we separate object from background and obtain the picture of the whole object. In many cases one object partly occludes the other one in natural world. When the brightness of the occluding object is the same as or similar to that of the background, though there is no difference between visual stimuli, we can still retrieve their relative depth relationship and segregate object from background. It seems that object edges can be perceived in regions that are physically homogeneous, which are named illusory contours or subjective contours[1—3] (see fig.1).

Since "illusory contours bridge the gap between psychophysics and physiology"[4], researches on illusory contours have been widely carried on in the last decades. It was found that not only brightness, color and texture but also depth and motion will affect the formation of illusory contours. Recently, illusory contours under motion and stereopsis have been deeply investigated. It was suggested that unmatchable information play an important role in the process of object recognition and figure-background segregation[5—15]. Actually, the unmatchable information in these studies is that of unmatched part of visual stimuli (specially, the unmatchable information in motion is the unmatched part of stimuli at different time; while the unmatchable information in stereopsis is the unmatched part of binocular images). These facts suggest the process of unmatched information as an important component in visual system.

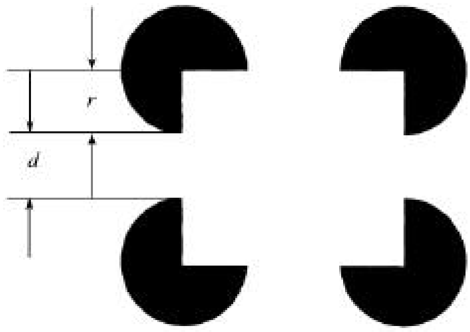


Fig. 1. Kanizsa square. It seems that there is a white square lying on four black disks, and the square seems "whiter" than the background. "*r*" is the radius of the inducer (also called pacmen in Kanizsa illusory contours), while "*d* " is the gap between inducers.

As stated above, lots of researches[10—18] provide evidence that the illusory contours in motion and stereopsis are generated by unmatchable features. Then one would ask if the more classic illusory contours, such as Kanizsa square and Enrenstein figure, also derive from the existence of unmatched information. To our knowledge, there is no research on this topic yet. We assume Kanizsa square is also formed by unmatched features. Then when these unmatched features are strengthened on purpose, the perception of illusory contours should be enhanced. To test this hypothesis, we manipulated Kanizsa squares that would translate horizontally or expand and shrink radially. The moving types consist of still condition (as control), figure in motion (only), inducers in motion (only) and all in motion (both figure and inducers). Under different type of motion, inducer size (r) and inter-pacmen gap (d) may vary separately or together.

Since the perceived strength illusory contours cannot be measured physically, estimation report is commonly used as the measure method[19]. Kellman & Loukides[18] defined a normal Kanizsa triangle as the standard illusory contour whose perceived strength was termed as 10. Observers reported the perceived strength of stimuli configuration by comparing to the standard figure. This method is certainly not only better than those direct report methods (such as reporting strong, normal or weak), but also more precise than those methods that need observers to draw lines representing the strength. However, there is still one imperfection that the results would be close around 10. Previous studies have proved that illusory contours would be stronger with increasing inducer size and decreasing inter-pacmen gap[20]. So in our experiment, three standard illusory figures are manipulated with different r and d to represent 3 matching strength of illusory contours.

1 Experiment 1: Illusory contours translate horizontally

1.1 Subjects

The subjects (XY, CH, HJ, YQ, LBW and HQ) were six postgraduates from Institute of Biophysics who were naive to the purpose of the experiment. Subjects ranged in age from 20 to 32 years, and all had normal or corrected to normal visual acuity.

1.2 Apparatus and displays

The stimuli were presented binocularly on a high-resolution monitor (Eizo Model FlexScan T57S, Japan). They were generated through a PC compatible computer with the use of a special graphics adapter (Elsa Gloria-XL, Germany) providing a display of 1024 pixels (horizontally)× 768 pixels (vertically) at 100 Hz frame rate (non-interlaced). The pixel size was 0.32 mm× 0.32 mm. The viewing distance between subjects and the monitor was 1 m.

Stimuli were Kanizsa squares, with four inter-pacmen gaps combined with three pacmen sizes. The gaps, *d*, were 20, 60, 100, 140 pixels (under the viewing distance of 1 m, the view angles were 0.36, 1.09, 1.82 and 2.56 degrees respectively); pacmen radii, *r*, were 20, 30, and 50 pixels (the corresponding view angles were 0.36, 0.54 and 0.91 degrees respectively).

There are four stimulus types: still (Still), translation of pacmen (TransI), translation of illusory figures (TransF), and translation of both (TransB) pacmen and contours. The luminance of the white pacmen was 170 cd/m^2, and that of the background 9 cd/m^2. When illusory contour is stationary, the acme of Kanizsa square locates at the center of the inducer, which is termed as the center of background, and the center of the figure is of course that of the Kanizsa square. The translation mentioned here is the horizontal movement of the figure in a range of 4 pixels (the corresponding view angle is 0.073 degree) around the center of Kanizsa square. Fig. 2 illustrates the 3 types of movement at 3 different moments ($T = t_1$, t_2 and t_3, while $t_3>t_2>t_1$). One can judge the moving direction and magnitude by the relative position of the figure to the outer frame (it should be kept in mind that the square frame in fig. 2 is only used to illustrate the stimuli which is not presented in the experimental displays). For example, there is no relative motion between inducers and square frame (which means inducers are stationary) as depicted in fig. 2(a), while the white illusory square shifts to the right relative to the frame (which means illusory figure is moving). Such movement is termed as translation of illusory figure (TransF). Similarly, as illustrated in fig. 2(b), translation of inducers (TransI) is the oscillation of black pacmen above which the Kanizsa square keeps stationary; when both figure and background move (TransB), the inducers make the same oscillation as the figure (depicted in fig. 2(c)).

1.3 Method and procedure

We first familiarized subjects with the illusory contours using video displays (such as fig. 1) in which illusory contours occur in the center of the screen with the pacmen size and gap changed. When we asked subjects what they saw, all of them reported that they perceived a black square placed on four white disks (the presented figures have reversed contrast to fig. 1, whose inducers are white and the background is black). And they all reported the square looks darker than the background, which is in fact a homogeneous area. Then they were told that such figures were illusory figures and those black squares are illusory contours. In addition, we showed subjects the matching figures, and asked them to compare the perceived strength of these illusory contours. They all reported that the right one was the strongest, with the less strongest in the middle, and the weakest was in the left (illustrated in fig. 3). Thus, all 6 subjects fit the criterion of our experiment.

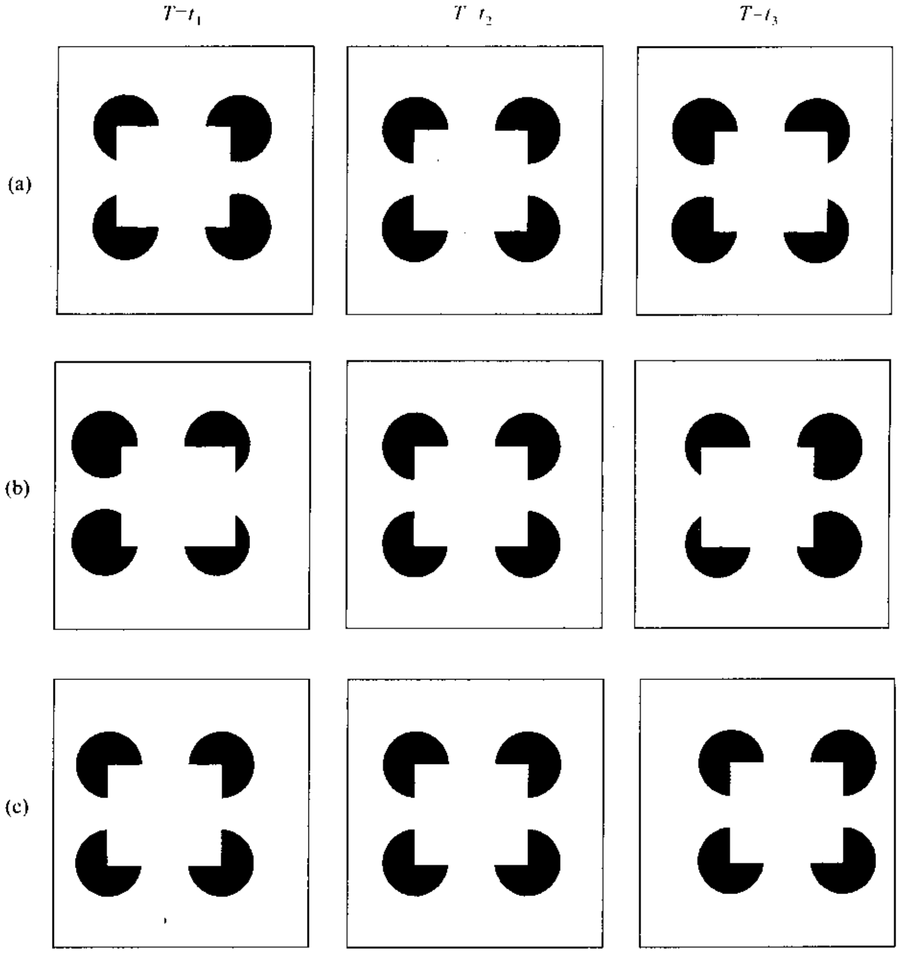
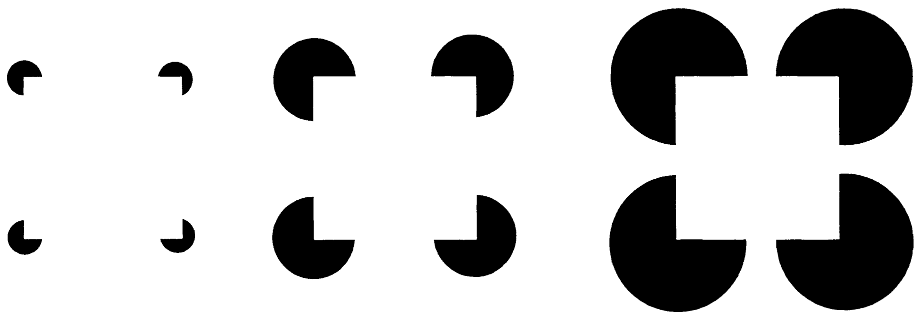


Fig. 2. Moving stimuli used in Experiment 1. t_1, t_2 and t_3 represent different time. (a) Translation of figure, TransF; (b) translation of inducers, TransI; (c) translation of both figure and inducers, TransB. The actual displays have reversed contrast than in fig. 2. To have better idea of the displays, one can observe fig. 2(a) and fig. 2(b) by cross fusion and uncross fusion respectively, by which the white illusory square is seen lying on 4 black disks (stereo devices are not used in actual experiment). See context for details.

In the experiment, stimuli were displayed in the center of the screen, while the matching figures were located at the bottom from left to right. As stated above, we defined the perceived strength of these matching illusory contours (as illustrated in fig. 3) as 0 (left most, with $d=80$ pixels and $r=10$ pixels), 4 (middle, $d=50$ pixels and $r=25$ pixels) and 9 (right most, $d=10$ pixels and $r=50$ pixels). They were so constructed that the radii of the inducers and the gaps between inducers are different from those of the stimuli. This is done to prevent subjects from only depending on the clues of the radius and the gaps and therefore the effect of learning could be avoided. During the experiment, subjects were told to compare the stimuli to the matching figures and then report the perceived strength of stimuli. For example, if subject perceived that the illusory contour in the middle was stronger than the matching figure at middle-bottom (the strength is 4) while weaker than the right-bottom one (the strength is 9), he (or she) could press number key "5", "6", "7" or "8" to represent the perceived strength of the illusory contour. If the illusory contour was perceived even stronger than "9", the subject could press number key "10", "11" or "12" at most. Then subject should press the space bar to advance to the next trial. Such method of estimation is actually derived from that used by Kellman[18].



(a) (b) (c)

Fig. 3. Matching figures used in the experiment. It is evident that the perceived strength increases from left to right. The perceived strengths are termed as: (a) 0, indicating no illusory contours; (b) 4, normal strength; (c) 9, very strong, like real contour. See context for details.

Previous study[1] has suggested that the perception of illusory contours will diminish or even vanish when observers fixed their sight. In addition, Bradley[21] suggested that unlimited presentation time of displays will maximize the perceived strength of illusory contours. Thus, in our experiment, presentation time of the figures was unlimited and the fixation was free to make the subjects get the strongest perception. Four stimuli types, combined with three inducer sizes, four inter-pacmen gaps, and five repeating times, comprise of 240 trials for one subject. The presentation order of stimulus displays was randomized, between two of which the screen was keeping blank for 2 s. Thus the possible effect of memory and attention could be eliminated.

1.4 Results

The results of 6 subjects are illustrated in fig. 4. First, it is evident that perceived strength of illusory contours decreases with increasing gap between inducers (as seen in fig. 4(a), $F(3,15) = 94.20$; $P<0.001$). Individual result of each subject represents the same trend: CH($F(3,12) = 76.89$; $P<0.001$); HJ($F(3,12) = 47.09$; $P<0.001$); HQ($F(3,12) = 882.23$; $P<0.001$); LBW($F(3,12)=383.26$; $P<0.001$); XY($F(3,12) = 125.12$; $P<0.001$); YQ($F(3,12) = 933.28$; $P<0.001$).

Second, the perceived strength of illusory contours increases with increasing radius of inducer ($F(2,10) = 103.15$; $P<0.001$, as shown in fig. 4(b)). Again, individual result of 6 subjects has the same trend: CH($F(2,8)=103.32$; $P<0.001$); HJ($F(2,8) = 105.86$; $P<0.001$); HQ($F(2,8) = 362.31$; $P<0.001$); LBW($F(2,8) = 200.39$; $P<0.001$); XY($F(2,8) = 200.39$; $P<0.001$); YQ($F(2,8) = 68.02$; $P<0.001$).

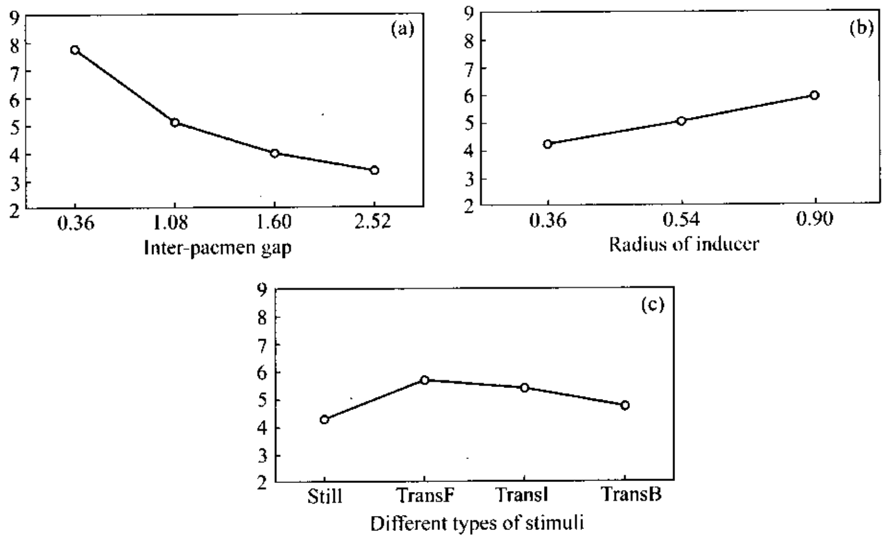


Fig. 4. Averaged results from 6 subjects in Experiment 1. (a) The effect of inter-pacmen gaps on perceived strength; (b) effect of inducer size; (c) perceived strength under different types of stimuli. See context for details.

These results show that under all types of stimuli (Still, TransB, TransI and TransF), the perceived strength will increase with increasing pacmen size and decreasing inter-pacmen gap. It not only provides further evidence for previous studies[22,23], but also proves that our experimental method of magnitude estimation is reliable.

In addition, fig. 4(c) shows that perceived strengths of illusory contours vary under different types of stimuli ($F(3,15) = 15.05$; $P<0.001$), which are also represented in individual results of 6 subjects: CH($F(3,12) = 107.42$; $P<0.001$); HJ($F(3,12) = 5.01$; $P<0.045$); HQ($F(3,12) = 26.16$; $P<0.001$); LBW($F(3,12) = 329.03$; $P<0.001$); XY($F(3,12) = 60.34$; $P<0.001$); YQ($F(3,12) = 31.03$; $P<0.001$). With the same pacmen size and inter-pacmen gap, the perceived strength under TransI ($F(1,5) = 24.28$; $P<0.005$) and TransF ($F(1,5) = 47.59$; $P<0.001$) was much stronger than that under Still. While no significant difference was found between TransI and TransF ($F(1,5) = 3.72$; $P > 0.1117$). When analyzing individual results, it was found that there was no significant difference between TransI and TransF for 3 subjects: CH($F(1,4) = 0.27$; $P \geqslant 0.628$); HJ($F(1.4) = 0.01$; $P \geqslant 0.913$) and YQ($F(1,4) = 0.0$; $P \geqslant 1.00$). However, the other 3 subjects perceived that illusory contours under TransI were not as strong as those under TransF: HQ($F(1,4) = 90.04$; $P<0.002$); LBW($F(1,4) = 54.49$; $P<0.002$); XY($F(1,4) = 13.07$; $P<0.023$).

Of more importance, we found that TransB did not enhance the perceived strength of illusory contours. In other words, there is no significant difference between TransB and Still ($F(1, 5) = 6.03$; $P \geqslant 0.057$). Results of 4 subjects (Subject LBW, XY, HJ, HQ, and CH) show that there is no significant difference between TransB and Still ($P > 0.1$). Only two subjects reported that the perceived strength under TransB was stronger than under Still (YQ: ($F(1,4) = 56.66$, $P<0.002$); CH: $F(1,4) = 58.70$, $P<0.002$), but did not reach the level of TransI and TransF ($P<0.001$).

2 Experiment 2: Illusory contours expand and shrink

We have studied illusory contours in translation, while another common type of motion, expanding and shrinking (termed as expansion in convenience) needs further investigation. We assume that the change of illusory contour perception in expand-shrink should be similar to that in translation. The following experiment was conducted to test this assumption.

2.1 Subjects

The six subjects (XY, CH, HJ, YQ, LBW and HQ) were the same as in Experiment 1. Subjects ranged in age from 20 to 32 years, and all had normal or corrected to normal visual acuity. They had no idea of the purpose of the experiment.

2.2 Apparatus and displays

The apparatus was the same as that in Experiment 1.

Stimuli were still Kanizsa squares, and the variable combination of inducer size and inter-pacmen gap kept the same as in Experiment 1. As shown in fig. 5, there are four stimuli types: still (Still), expansion of pacmen (ExpansI), expansion of illusory figures (ExpansF), and expansion of both (ExpansB) pacmen and contours. The luminance of the white pacmen was 170 cd/m^2, and that of the background 9 cd/m^2. When illusory contour is stationary, the acme of Kanizsa square locates at the center of the inducer, which is termed as the center of background, and the center of the figure is of course that of the Kanizsa square. The expansion mentioned here is the radial movement of figure in a range of 4 pixels (the corresponding view angle is 0.073 degree) around the center of Kanizsa square. The expansion of white illusory square over stationary inducers is termed as expansion of illusory figure (ExpansF). Similarly, expansion of inducers (ExpansI) is the oscillation of black pacmen under the stationary Kanizsa square. When both figure and background move (ExpansB), the inducers make the same oscillation as the figure.

2.3 Method and procedure

The method in this experiment is the same as in Experiment 1. By attending the previous experiment, all the 6 subjects have been familiar with illusory contours and the judge method of their perception strength.

Four stimuli types, combined with three inducer sizes, four inter-pacmen gaps, and five repeating times, comprise of 240 trials for one subject. The presentation order of stimulus displays was randomized, between two of which the screen was keeping blank for 2 s.

2.4 Results

The results indicate similar trends across all 6 subjects that are illustrated in fig. 6, though there is a little variance of perceived strength.

It is evident that perceived strength of illusory contours decreases with increasing gap between inducers (as seen in fig. 6(a), $F(3,15) = 113.14$; $P<0.001$). The individual result of each subject represents the same trend: CH($F(3,12) = 71.69$; $P<0.001$); HJ($F(3,12) = 426.97$; $P<0.001$);

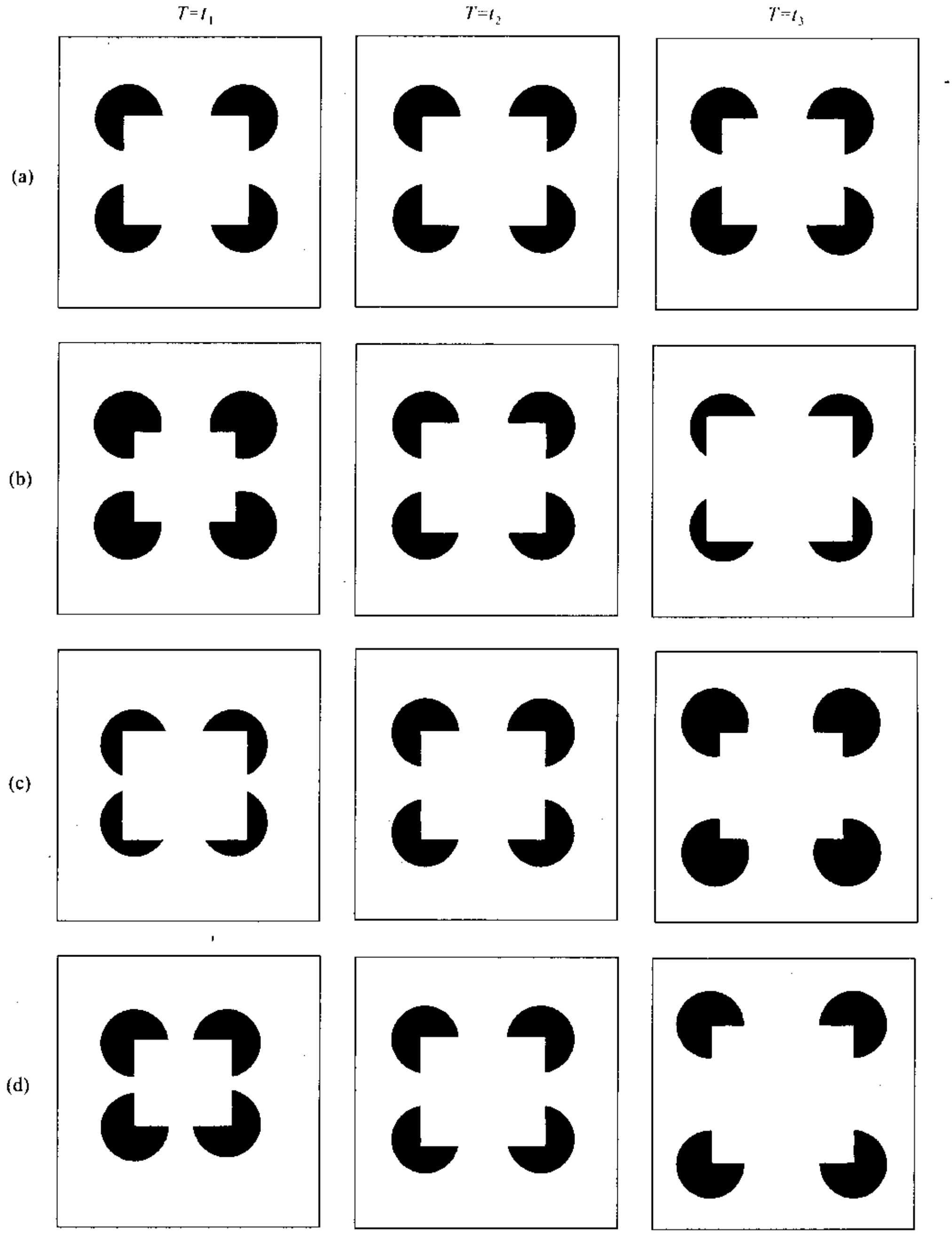


Fig. 5. Stimuli used in Experiment 2. t_1, t_2 and t_3 represent different time. (a) Stationary figures; (b) expansion of figure, ExpansF; (c) expansion of inducers, ExpansI; (d) expansion of both figure and inducers, ExpansB. See context for details.

HQ($F(3,12) = 654.96$; $P<0.001$); LBW($F(3,12) = 1094.75$; $P<0.001$); XY($F(3,12) = 232.92$; $P < 0.001$); YQ($F(3,12) = 1157.94$; $P<0.001$).

At the same time, the perceived strength of illusory contours increases with increasing radius of inducers ($F(2,10) = 57.03$; $P<0.001$, as shown in fig. 6(b)). Again, the individual result of 6 subjects has the same trend: CH($F(2,8)=38.10$; $P<0.001$); HJ($F(2,8)=89.82$; $P<0.001$); HQ($F(2,8)=294.21$; $P<0.001$); LBW($F(2,8)=105.96$; $P<0.001$); XY($F(2,8)=88.67$; $P<0.001$); YQ($F(2,8)=124.24$; $P<0.001$).

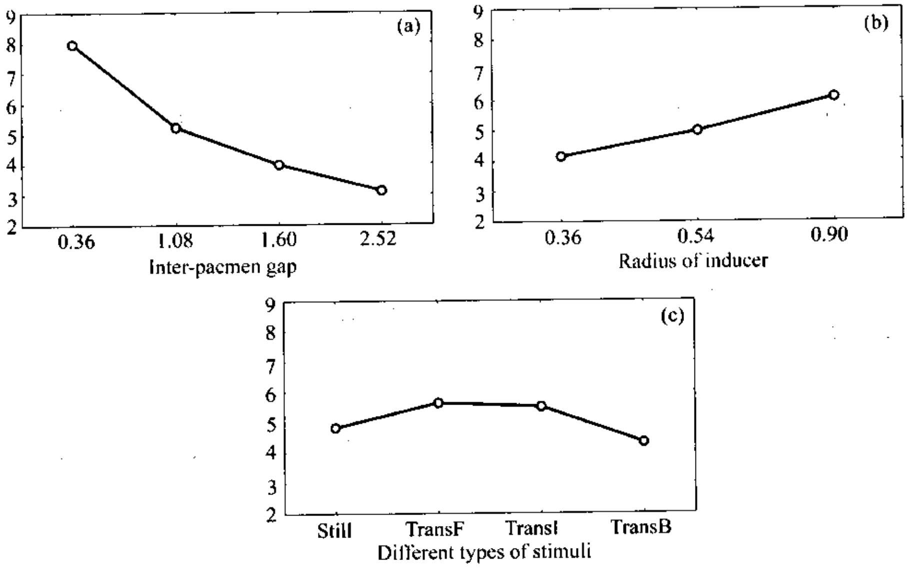


Fig. 6. Averaged results of 6 subjects in Experiment 2. (a) Effect of inter-pacmen gap; (b) effect of inducer size; (c) perceived strength under different types of stimuli. See context for details.

These results show that under all types of stimuli (Still, ExpansB, ExpansI and ExpansF), the perceived strength will increase with increasing pacmen size and decreasing inter-pacmen gap. Again it not only provides further evidence for previous studies[22,23], but also proves our experimental method to be reliable.

In addition, fig. 6(c) shows that perceived strengths of illusory contours vary under different types of stimuli ($F(3,15) = 5.54$; $P<0.01$). With the same pacmen size and inter-pacmen gap, the perceived strength under ExpansI ($F(1,5)=11.56$; $P<0.020$) and ExpansF ($F(1,5)=19.65$; $P<0.007$) was much stronger than that under Still. While no significant difference was found between ExpansI and ExpansF ($F(1,5)=0.41$; $P\geqslant0.548$). When analyzing individual results, it was found that there was no significant difference between ExpansI and ExpansF for 4 subjects: CH($F(1,4)=2.78$; $P\geqslant0.170$); HJ($F(1.4)=1.05$; $P\geqslant0.362$); XY($F(1,4)=0.03$; $P<0.867$) and YQ($F(1,4)=1.53$; $P\geqslant0.283$). However, the other 2 subjects perceived that illusory contours under ExpansI were not as strong as those under ExpansF: HQ($F(1,4)=9.09$; $P<0.039$); LBW($F(1,4)=55.51$; $P<0.002$).

Of more importance, we found that ExpansB did not enhance the perceived strength of illusory contours. In other words, there is no significant difference between ExpansB and Still ($F(1,5)=1.86$; $P\geqslant0.2313$). The result of 1 subject (Subject CH: $F(1,4)=6.69$; $P\geqslant0.061$) does not show any significant difference between ExpansB and Still. Only 3 subjects reported that the perceived strength under ExpansB was stronger than under Still (Subject HJ: $F(1,4)=78.22$, $P<0.001$; LBW:

$F(1,4) = 57.02$, $P<0.002$, and YQ: ($F(1,4) = 135.28$, $P<0.001$), but did not reach the level of ExpansI and ExpansF. The rest 2 subjects (HQ: $F(1,4) = 26.72$, $P<0.006$; XY: $F(1,4) = 7.92$, $P<0.48$) seemed to perceive weaker illusory contours in ExpansB than in Still.

3 Experiment 3: The possible effect of mask figures on moving illusory contours

Most recent research shows that fixing sight on color spreading figures will result in not only local aftereffect corresponding to inducers but also global aftereffect of illusory figures[24]. Although there is no fixation point in the two experiments above, the 2-s blank interval may be not able to eliminate the possible effect of memory and aftereffect. In cognitive science studies, mask figures are often used to diminish the effect of memory and aftereffect[25]. Thus in this experiment, we investigate the possible effect of mask figures, which are interpolated in the intervals between stimuli, on perception of illusory contours.

3.1 Subjects

To avoid the effect of memory, four new graduates (DST, TQ, YF and LJ) attended the experiment as naive subjects. Subjects ranged in age from 20 to 26 years, and all had normal or corrected to normal visual acuity.

3.2 Apparatus and displays

The apparatuses are the same as those in the previous experiment. To compare to and test previous results, the stimuli in Experiment 1 were used again. Four stimuli types, combined with three inducer sizes, four inter-pacmen gaps, and five repeating times, comprise of 240 trials for one subject. The presentation order of stimulus displays was randomized, between two of which blank screen and mask figures (shown in fig. 7(a)) were displayed for 50 ms and 2 s continuously. The mask figures are 4 white discs, whose radius and inter-disc gap are the same as the preceding displayed stimulus figure. Other experimental factors keep the same as those in Experiment 1.

3.3 Method and procedure

Four stimuli types (Still, TransF, TransI and TransB), combined with three inducer sizes, four inter-pacmen gaps, and five repeating times, comprise of 240 trials, that were shown to subjects randomly.

3.4 Results

The results of 4 subjects are illustrated in fig. 7(b), which shows similar trend across 4 subjects. It is evident that perceived strength of illusory contours decreases with increasing gap between inducers ($F(3,51) = 277.28$; $P < 0.001$). At the same time, the perceived strength of illusory contours increases with increasing radius of inducer ($F(2,34) = 286.79$; $P<0.001$). Again, these results show that under all types of stimuli (Still, TransB, TransI and TransF), the perceived strength will increase with increasing pacmen size and decreasing inter-pacmen gap.

In addition, perceived strengths of illusory contours vary under different types of stimuli

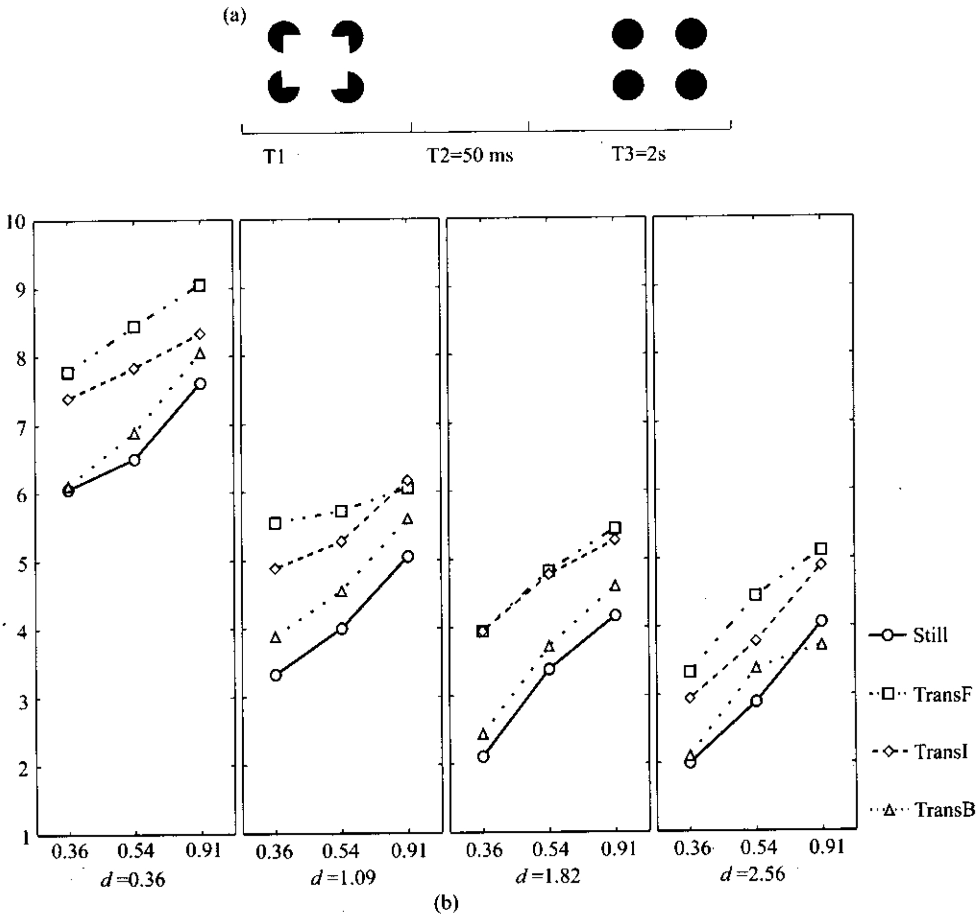


Fig. 7. (a) Display intervals order in Experiment 3. The screen changes to blank for T2=50 ms after the stimulus representing time T1, and then mask figures are displayed for T3=2 s. After the response, the next stimulus will be shown. The time intervals are not drawn in scale by line segments. The actual displays in the experiment have reversed contrast. (b) Averaged results under all 48 conditions from 4 subjects in Experiment 3, which are similar to those in Experiment 1. See context for details.

($F(3,51) = 56.20$; $P<0.001$). With the same pacmen size and inter-pacmen gap, the perceived strength under TransI ($F(1,19) = 130.20$; $P<0.001$) and TransF ($F(1,19) = 55.19$; $P<0.001$) was much stronger than that under Still. illusory contours under TransI were not as strong as those under TransF ($F(1,19) = 8.99$; $P<0.007$). It was found that although the perceived strength under TransB was stronger than under Still ($F(1,17) = 10.60$, $P<0.004$), it did not reach the level of TransI ($F(1,17) = 33.90$, $P<0.001$) and TransF ($F(1,17) = 66.91$, $P<0.001$).

These results are in accordance to those in Experiment 1, which indicates the reliable finding of difference between all types of stimuli. However, aftereffect could not interpret the enhancement of illusory contours in motion since it dose not have essential effect on the results.

4 Discussion

Our results indicate the significant difference between the perceived strength in ExpansI

(TransI) and that in Still, which was also found between ExpansF (TransF) and Still. In other words, illusory contours in ExpansI and ExpansF (TransI and TransF) are perceived much stronger than in Still. It may be assumed that such difference is caused by the motion-induced change of size-gap ratio (r/d). But the expansion (or translation) of the inducers or figures neither increases size (r) nor decreases gap (d), the latter of which is even increased when inducers and figures leave their center position. Therefore, such enhancement of perceived strength is not due to the change of inter-pacmen gap. It is more important that there is no significant difference between ExpansI and ExpansF (not between TransI and TransF either), which is different from the previous study[26]. Consequently, we assume that there is no so-called "Background Superior Effect", at least for Kanizsa illusory contours. Bruno and Gerbino studied moving line segment figures, which produce illusory contours similar to Ehrenstein figure. The different results from these two types of illusory contours may indicate different possible underlying mechanisms, which need further investigation using both psychophysical and neurophysiological methods.

As stated above, the more important finding is that when inducers and figures move together the perception was not enhanced at all, or not enhanced that much as in ExpansI and ExpansF (TransI and TransF). This result implies that the enhancement of perceived illusory contours strength was not just due to kinetic information, since one type of motion (TransB and ExpansB) did not enhance the perceived strength or not that much. The significantly different configuration between TransB and TransF or TransI (ExpansB and ExpansF or ExpansI) is the unmatched information in time domain. That is, TransF and TransI (or ExpansF and ExpansI) impressed subjects as if the square was translating (or expanding) over the inducers (or the inducers were translating under a white square). However TransB (or ExpansB) just provides the motion information. Therefore, it is the unmatched feature "induced" from motion information that accounts for the enhancement of perceived illusory contours strength, rather than motion information itself. Then it is natural to assume the critical role of unmatched information in the perception of moving illusory contours.

Since illusory contours are perceived when our stimuli figures are still, unmatched features generate between illusory contours. For example, in TransF of Experiment 2 (as shown in fig. 8), illusory contours in motion produce unmatched features (no matter whether they are horizontal or vertical) which in turn produce "extra" illusory contours, thus the perceived strength is enhanced. However, since unmatched features were not produced in TransB, no enhancement was observed. In addition, it can be seen from fig. 8 that there is no difference between the unmatched information in figure motion and those in background motion, which results in no BSE effect.

Although the perception of illusory contours may be mediated by conscious processes and attention, they cannot explain why we see illusory contours nor by which mechanisms these perception are generated. There is even more evidence that illusory contours can be perceived without involvement of higher level cortex. Illusory contours could pop out at trusted subjects which indicates that illusory contours are processed preattentively. The stimuli figures in our ex-

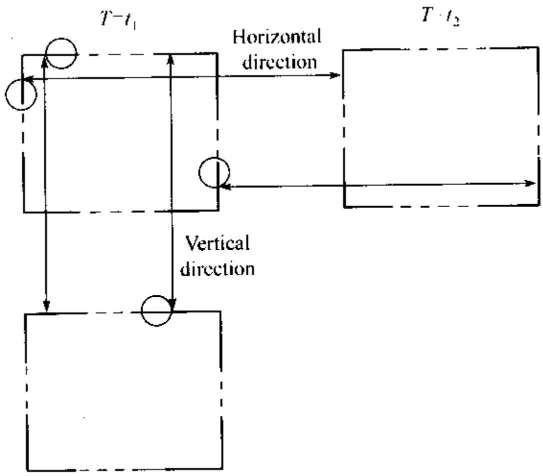


Fig. 8. Unmatched features between illusory contours at different time. Illusory contours are represented by dashed line, while solid line indicates real edges, and inside the circles are unmatched parts. See context for details.

periment would not generate ambiguous perception, which suggests that the enhancement of perceived strength found in our results is not due to the effect of attention.

Neurophysiological studies found that, in area V2 of the primate cortex of monkey[27] and area 17, 18 of cat[28,29] one third of the orientation-selective neurons respond to illusory contours as they do to real edges and contours[30]. These findings indicate a possible basis of binocular neural orientation selective mechanisms for illusory contours perception. Illusory contours will vanish in the case of equal-brightness[31], suggesting that illusory contours may form in the magnocellular system. It is in accordance to this finding that moving illusory contours are stronger in our experiment, because motion information is processed in magnocellular system. Sheth et al.[32] investigated the neural response to orientation illusory contours in area V1 and V2 of cat and suggested that the illusory contours were first perceived in V1 and processed in higher level cortex area. Nakayama and Shimojo[33] suggested that the perception of illusory contours may be explained by bottom-up processing and inferring process at the primate level, whose base is the image sampling in the moving procedure. Recently, one of the fMRI researches[34] found adaptation in LOC (Lateral Occipital Complex) when perceived shape was identical but contours differed, but not when contours were identical but perceived shape differed. These data suggest that the LOC represents not simple image features, but rather higher-level shape information. Thus, the formation of illusory contours not only includes the process in primate cortex but also involves the feedback from higher cortex.

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