Illusory contour figures are perceived as occluding surfaces by 8-month-old infants

Gergely Csibra

Birkbeck College, London, UK

Abstract

Infants have been demonstrated to be able to perceive illusory contours in Kanizsa figures. This study tested whether they also perceive these illusory figures as having the properties of real objects, such as depth and capability of occluding other objects. Eight- and five-month-old infants were presented with scenes that included a Kanizsa square and further depth cues provided by the deletion and accretion pattern of a moving duck. The 8-month-old infants looked significantly longer at the scene when the two types of occlusion cues were inconsistent than when they were consistent with each other, which provides evidence that they interpreted the Kanizsa square as a depth cue. In contrast, 5-month-olds did not show this difference. This finding demonstrates that 8-month-olds perceive the figure formed by the illusory contours as having properties of a real object that can act as an occluder.

Illusory contours are subjective lines that are added to the scene by the visual system and may border modally completed, ‘filled in’ surfaces (Kanizsa, 1979). A well-known example of these contours is provided by the Kanizsa figures in which notched circles induce the perception of a triangle or a square. These illusory figures appear to be closer to the viewer than the inducing elements, and recent studies in adults have demonstrated that they can act as occluders in visual search (Davis & Driver, 1998). In fact, Kanizsa hypothesized that the emergence of the illusory figure itself is a result of amodal completion of the notched elements into full circles thereby assuming an occluding surface.1

Several findings in adults have cast doubt on the theory that illusory contour perception itself is dependent on amodal completion and depth reconstruction (e.g. Purghé & Coren, 1992). In addition, single cell recordings in primates (von der Heydt, Peterhans & Baumgartner, 1984) and neuroimaging methods in humans (Ffytche & Zeki, 1996) suggest the importance of primary visual areas, especially V2, in illusory contour perception while neuropsychological data indicate that amodal completion reflects higher level processes (Corballis, Fendrich, Shapley & Gazzaniga, 1999). Though both modal and amodal completion may involve interpolation of edges and surfaces and this interpolation may rely partly on the same processes (Kellman, Yin & Shipley, 1998), these data suggest that the perception of illusory contours does not necessarily imply 3D reconstruction of the scene.

Studies with infants suggest that, at least from 7 months of age, they can also perceive static illusory figures. Bertenthal, Campos and Haith (1980) demonstrated that 7- but not 5-month-olds show a recovery of attention to a Kanizsa square after they have been habituated to a figure without illusory contours, and vice versa. Kavieč (1999) obtained similar results using another illusory figure, the Ehrenstein circle. Neuropsychological findings (Csibra, Davis, Spratling & Johnson, 2000) suggest that the perception of these figures is associated with the same high-frequency neuronal

1 ‘Modal’ and ‘amodal’ completion are technical terms referring to filling in visible surfaces versus completing partly occluded surfaces, respectively (Kanizsa, 1979). The distinction refers to the fact that ‘modal’ completion appears to alter the visual properties (e.g. brightness) of the completed regions while ‘amodal’ completion does not. However, both processes are considered as perceptual in nature (Davis & Driver, 1997).

Address for correspondence: Gergely Csibra, Centre for Brain and Cognitive Development, School of Psychology, Birkbeck College, Malet Street, London WC1H 7HX, United Kingdom. e-mail: g.csibra@bbk.ac.uk

© Blackwell Publishers Ltd. 2001, 108 Cowley Road, Oxford OX4 1JF, UK and 350 Main Street, Malden, MA 02148, USA.
oscillations in infants as in adults. Using visual preference measures with simultaneously presented stimuli, Ghim (1990) found that even 3- to 4-month-old infants displayed evidence of perceiving illusory figures. None of these studies tell us, however, whether infants’ discrimination between illusory and non-illusory figures involves depth reconstruction and whether infants attribute the properties of real objects to these illusory figures. Condry (2000) found that 7-month-old infants (but not 4-month-olds), having habituated to a Kanizsa square, dishabituate to a notched circle but not to a full circle. This demonstrates that 7-month-olds amodally complete the inducing elements and suggests that they may have perceived the illusory depth-relation between the occluding Kanizsa square and the circles.

The present study attempted to test infants’ ability to reconstruct depth information from, and crediting the properties of real objects to, static illusory figures in a more direct way. Our participants were confronted with a scene which included two kinds of potential depth cues: one provided by the Kanizsa square and the other provided by the deletion and accretion pattern of a moving object. This latter depth cue has been shown to be effective for even young infants (Granrud, Yonas, Smith, Arterberry, Glicksman & Sorknes, 1984; Johnson & Aslin, 1998). The two cues indicated an occluder either at the same or at different spatial positions. If infants extract the depth information provided by the Kanizsa square, they should be able to detect when these two cues are inconsistent with each other and should demonstrate this by enhanced attention to the inconsistent scene.

Methods

Participants

Sixteen 8-month-old (11 male and 5 female, age range: 231–258 days, mean: 246.4 days) and sixteen 5-month-old (8 male and 8 female, age range: 139–167 days, mean: 154.5 days) infants were participants in the study. They were all healthy infants, born in term and were recruited in the Greater London area. An additional 13 babies (8 and 5 8- and 5-month-olds, respectively) were tested but were excluded from analyses because of fussiness or not paying attention to the stimuli (4 and 4), experimenter error (2 and 1), or failing to complete the familiarization phase (see below) within 6 trials (two 8-month-olds).

Apparatus

The infants sat in their parent’s lap facing a 21 in. computer monitor at 90 cm distance. The experimental room was dimmed and the monitor was surrounded by black curtain. The lens of an infrared video camera peeped through the curtain 10 cm below the monitor. Two loudspeakers were placed at either side of the monitor to deliver the sounds accompanying the visual stimuli. All the equipment was operated from the adjacent control room.

Stimuli

Each trial consisted of 6 ‘pacman’ figures (three-quarter wedge of a circle) of black colour and white frame and a colourful moving duck (Figure 1). The pacmen had a diameter of 7.3 cm (including 0.3 cm width of white frame) and the duck was 7 cm long and 3.2 cm high and they were presented on a grey background. The duck was moving along the horizontal midline of the monitor at 15.9 cm/sec speed. At the beginning of each trial, it started by entering at the left edge, and subsequently as

Figure 1 Stimulus events in the familiarization and test phases of the experiment. Solid arrows indicate visible, dotted arrows indicate implied motion.
soon as it left the screen, it returned heading in the opposite direction. While moving back and forth, it emitted a ‘quack’ sound at random intervals of 2–5 seconds. Each ‘quack’ lasted about half a second and was accompanied by the opening of the duck’s beak when it was visible.

The six pacmen were arranged in two rows, separated by 3.3 cm gaps from each other in both directions. In the familiarization phase, the ‘mouths’ of the pacmen were oriented away from the middle line (upward in the upper, downward in the lower row), while in the test phases they were oriented towards each other. The right and left pacmen within a row always had the same orientation, while the middle one was its right/left mirror image. The two possible combinations of orientations were alternating during the familiarization phase. In the test phase, the pacmen formed an illusory Kanizsa square of 10.6 cm by 10.6 cm (6.75° of visual angle) either on the left (inconsistent test), or on the right side (consistent test).

In the familiarization phase the duck’s motion was uninterrupted. In contrast, in the test events the duck disappeared between the middle of the screen and the invisible vertical line linking the centres of the two pacmen on the right. Its deletion and accretion pattern was consistent with the presence of an invisible opaque occluder at this position. Note that in the consistent test event this position was the same as indicated by the illusory Kanizsa figure while in the inconsistent test event it was another position. While behind the invisible occluder, the duck disappeared wholly for about 225 msec.

Procedure

The infants’ attention was drawn to the computer monitor by spiralling figures and various short sounds (a bell, a chime, a whistle, etc.). These sounds were also used during the experiment to recapture the babies’ attention. The presentation of the stimuli was computer-controlled so that the experimenter only had to indicate, by keeping a key pressed, whether the infant looked at the monitor or not. When the infant looked first at the screen, a familiarization trial started. A trial was ended whenever the infant looked away from the monitor for at least 2 seconds or when the trial lasted for 2 minutes. If the total looking time during the familiarization trial was shorter than 1 minute, another familiarization trial was presented as soon as the infant looked at the screen again. The familiarization phase ended at the end of the trial that completed a total of at least 1 minute looking time. Two 8-month-old participants who did not complete the familiarization phase within 6 trials (i.e. whose average looking time per trial was below 10 seconds) were excluded from further analyses.

The familiarization phase was immediately followed by the two test trials (consistent and inconsistent). The order of the two test trials was counterbalanced across infants and the experimenter was not aware of which test trial was presented first. Each test trial was presented only once, i.e. until the infant looked away for at least 2 seconds. The infant’s face was video recorded during the whole session together with the timing signals sent by the experimental control computer to the video recorder through a video titler device.

Coding

The looking times were recorded on-line on the basis of the experimenter’s key presses that signalled whether the infants looked at the monitor or not. The looking times during test trials were measured again off-line by a secondary coder from the video recordings. The average level of absolute difference between the two measurements was 0.91 sec and the correlation between the two measurements was 0.998. The analyses of the results were based on the on-line measurements, which were log-transformed to better approximate normal distributions.

Results

The infants completed the familiarization phase in an average of 2.81 and 2.06 trials in the 8- and 5-month-old groups, respectively. This difference is not significant. The total looking time during familiarization, however, differed significantly between the age groups: it was 79.7 sec for the 8-month-olds and 98.4 sec for the 5-month-olds (F[30] = 2.056, p < 0.05).

The looking times during the test phase are depicted on Figure 2. Their logarithmic conversions were entered into a three-way ANOVA in which the event type (consistent vs inconsistent) served as a within-subject factor and age group (8- vs 5-month-olds) and order of test trials served as between-subject factors. This analysis yielded a significant interaction of event type and order of presentation (F[1, 28] = 8.713, p < 0.01) and a significant three-way interaction (F[1, 28] = 5.632, p < 0.05). Because of the three-way interaction, separate two-way ANOVAs were performed within the two age groups. In the 8-month-old group, this analysis resulted only in a significant main effect of event type (F[1, 14] = 5.972, p < 0.05) due to the longer looking time during the inconsistent test event. In the 5-month-old group, the two-way ANOVA showed only a
significant interaction between event type and order of presentation \((F[1, 14] = 9.311, p < 0.01)\) indicating that the infants in this group tended to look longer at the first test event, irrespective of its content. This is a common finding in preferential looking studies (e.g. Baillargeon, 1986; Csibra, Biró, Koós & Brockbank, 1999).

The above effects were confirmed by non-parametric analyses as well. Wilcoxon tests indicated that only 8-month-olds looked significantly longer at the inconsistent than at the consistent test event \((z = 2.223, p < 0.05)\) and that only 5-month-olds looked significantly longer at the first than at the second test event \((z = 2.792, p < 0.01)\). Figure 2 suggests that, though there was not a general preference for either event type in the 5-month-old group, there might have been a difference in looking time to the first test event whether it was consistent or inconsistent. However, neither parametric \((\chi[14] = 0.946)\) nor non-parametric (Mann-Whitney \(z = 1.260)\) tests confirmed this hypothesis.

**Discussion**

The main question this study addressed was whether infants’ perception of illusory contours results in attribution of the properties of real objects, including the capacity to act as an occluder, to the illusory figure bordered by those contours. The results suggest that the 8-month-old infants did indeed perceive the Kanizsa square as an object separated in depth from the inducing elements (pacmen) and being capable of occluding another object. Had they not seen the position of the Kanizsa square as a depth cue, they would not have been able to notice the difference between the consistent and inconsistent test events. Note that (1) there was a Kanizsa square present in both test displays, (2) the duck’s movement was exactly the same in both events, and (3) the spatial position of its deletion and accretion always coincided with an edge interpolatable between two pacmen. Moreover, the longer looking time for the inconsistent test event indicates that they not only detected the difference, but also found the inconsistent test event more interesting. This was probably due to the fact that the infants noticed that the inconsistent test event could not be seen as a coherent event in three dimensions if the Kanizsa square is taken as a foreground object and the adjacent area as its background. In fact, infant looking times mirrored the adult observers’ subjective experience that the inconsistent test event was difficult to interpret coherently because the background and the foreground kept swapping back and forth, like a Rubin vase.

The 5-month-olds’ apparent failure to discriminate between the test events indicates that they did not detect inconsistencies between the conflicting depth cues. Several studies suggest that even 2-month-old babies can reconstruct invisible occluders on the basis of the deletion and accretion patterns of other objects (Johnson & Aslin, 1992). These results imply that the 5-month-olds in the current study did not see the Kanizsa square as a potential occluder and did not interpret it as being closer to them than the adjacent areas. Note that this does not necessarily imply that the 5-month-olds were unable to see the square formed by the illusory contours. They might have perceived the ‘good form’ created by perfect line alignments without assigning a relative distance to the surface bounded by this line. Indeed, electrophysiological findings (Csibra et al., 2000) indicate that 6-month-olds can discriminate between a Kanizsa square and a control stimulus without the illusory figure but assembled of the same pacmen. However, these infants did not show the gamma-band oscillatory bursts that are correlated to the processing of Kanizsa squares in adults and 8-month-olds.

The present finding also shows that motion in itself is not sufficient to facilitate illusory form perception in young infants. Object motion is well known to provide the earliest source of information on object unity during development (Johnson & Aslin, 1996). Kavšek and Yonas (in preparation) demonstrated that even 4-month-old infants perceive Kanizsa squares when these undergo an apparent motion. Motion helped their participants to extract the illusory form from a display, which they preferred over a similar apparent motion.
display without the illusory square. Kavšek and Yonas speculated that motion might have attracted the infants' attention, increasing the probability of deeper processing of the stimuli. The present finding suggests that when the moving stimulus is not the to-be-perceived figure itself, motion does not necessarily facilitate illusory form detection, however attention catching it is.

Finally, the results of the present study are consistent with previous research on the development of depth perception and amodal completion. Infants start to rely on static pictorial depth cues between 5 and 7 months of age (Arterberry, Bensen & Yonas, 1991) and do not complete static occluded objects until 7 months of age whether they are occluded by real (Craton, 1996) or illusory figures (Condy, 2000). The present study demonstrates that as soon as, but not before, they interpret 2D pictures as 3D objects using static cue of distance, they also perceive an illusory figure as a real object capable of occluding other objects.

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References


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