The perception of illusory transparent surfaces in infancy: Early emergence of sensitivity to static pictorial cues

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Most developmental studies consistently show that sensitivity to purely pictorial cues to perceptual organization emerges around 6–7 months of age (e.g., B. I. Bertenthal, J. J. Campos, & M. M. Haith, 1980). Here, we show evidence for an early emergence of visual completion using purely static two-dimensional pictorial information. By using preferential looking technique, we examined whether 3–4 and 5–6 month-olds perceive illusory transparent surface which is induced by a newly developed mixed polarity Kanizsa configuration. Our results suggest that 3–4 and 5–6 month-olds discriminate and prefer the transparent Kanizsa configuration both from its rotated counterpart, and from the non-transparent Kanizsa configuration. Our stimuli and experimental manipulation exclude the possibility that these responses were based on the geometrical properties of the figure or the local contrast difference between the figures. Our finding suggests the sensitivity for surface segmentation based solely on two-dimensional cues in both 3–4 and 5–6 month olds.

Keywords: visual completion, illusory contours, transparency, neon spreading, infant, development


Introduction

Like adults, infants and young children must parse complex and dynamic visual stimulation into a set of bounded forms and objects. The complex relationship between objects in the world and their visible regions and the enormous amount of missing information arising from occlusion, camouflage or poor visibility are the principal challenges in this process. Although the mature visual system seems able to complete the missing information seemingly effortlessly and instantaneously, when and how the developing visual system acquires this ability have been questions of intense scientific and philosophical interest.

Adults seem to be able to effectively segregate and organize the visual scene utilizing a variety of visual cues. However, only certain cues seem to afford effective image segmentation in young infants. In infants younger than 5–6 months, common motion emerges consistently as the most effective cue supporting the perception of partly occluded object unity (Johnson & Aslin, 1996; Kellman & Spelke, 1983; Valenza, Leo, Gava, & Simion, 2006) as well as the perception of surfaces bounded by illusory contours (Curran, Bradick, Atkinson, Wattam-Bell, & Andrew, 1999; Otsuka & Yamaguchi, 2003; Valenza & Bulf, 2007) and transparent surfaces (Johnson & Aslin, 2000).

Studies investigating these different types of visual completion seem to agree that sensitivity to purely...
Pictorial cues to perceptual organization and segregation emerges by 6–7 months of age. However, it is still debated whether younger infants are capable of doing so. Studies to date suggest some asymmetry between the different kinds of visual completion. Although there is some evidence showing early emergence of the perception of illusory contours and transparency based only on pictorial cues (Ghim, 1990; Kavšek, 2002; Otsuka, Kanazawa, & Yamaguchi, 2004, 2006a, 2006b), no such evidence was obtained from studies on completion of occluded surfaces (Craton, 1996; Kellman & Spelke, 1983; Otsuka et al., 2006a). Even for the perception of illusory contours and transparency, evidence is still mixed (Bertenthal, Campos, & Haith, 1980; Csibra, 2001; Csibra, Davis, Spratling, & Johnson, 2000; Kavšek, in press).

Figure 1a illustrates a well-known Kanizsa configuration in which the inducing fragments generate a vivid impression of an occluding surface that is bounded by salient subjective or illusory contours in regions with no physical luminance discontinuities. The rearrangement of the inducing elements eliminates the perception of an occluding square as illustrated in Figure 1b. Previous studies on the perception of illusory contours typically examined the discrimination between such configurations, and the successful discrimination has been taken as the evidence of the perception of illusory contours. With the purely static Kanizsa configurations, only infants older than 6 months of age show the robust and consistent sensitivity to illusory contours (Bertenthal et al., 1980; Otsuka & Yamaguchi, 2003). Although a few studies have reported perception of illusory contours using static stimuli in younger infants, such evidence was obtained only when the gap between the inducing elements was fairly small (Ghim, 1990; Kavšek, 2002; Otsuka et al., 2004).

Furthermore, it has been argued that infants’ discrimination between configurations containing illusory contours and control configurations that consist of outwardly oriented inducers does not necessarily imply that they are capable of perceiving a stratified visual scene, and a number of potential confounds have been identified. For example, Kellman and Arterberry (1998) have argued that typical control configurations contain salient concave discontinuities positioned close to the external boundary of the pattern, that very young infants might be attracted to (so called “externality effect”). In addition, Kavšek and Yonas (2006), argued that Kanizsa configurations with uniformly colored inducers are characterized by a vivid perception of illusory brightness enhancement of the completed illusory figure and that it is impossible to differentiate whether infants respond to the presence of illusory contours or simply to a brightness enhancement in these configurations. Although the illusory brightness enhancement does not seem to play a causal role in generation of illusory contours as illusory contours are clearly visible in inducing configurations containing inducers of varying contrast polarity, it nevertheless presents a potential confound for infant studies using inducers of a single contrast polarity (Ghim, 1990; Kavšek, 2002; Otsuka & Yamauchi, 2003; Otsuka et al., 2004). While configurations with mixed polarity inducers have been used in some of the developmental studies investigated perception of moving illusory contours (Curran et al., 1999; Kavšek & Yonas, 2006), no studies have used mixed contrast polarity variations within purely static configurations. For example, Kavšek and Yonas (2006) used reversed polarity inducers that were rotated from frame to frame so that an illusory Kanizsa square could appear to move left and right across the screen. In the control condition the inducers were oriented so that no subjective square was generated and only the rotary motion of the individual inducers was present. Although the strong preference for the illusory square was observed it was concluded that the preference was not caused by the presence of the illusory square per se, but a combination of the inward facing inducers with a continuous sequential motion. It is possible that the perception of illusory contours would not have happened without facilitation by a continuous sequential motion (Kavšek & Yonas, 2006). In other words it is unclear whether continuous movement was a necessary condition for the young infants’ ability to extract the subjective square or whether it merely facilitated it.

To study the development of the perception of transparency, previous studies typically used stimuli depicting a semitransparent object overlapping the other (Johnson & Aslin, 2000; Kavšek, in press; Otsuka et al., 2006b). By using habituation or familiarization paradigm, these studies investigated whether infants can parse the stimuli consistent with the transparency interpretation. That is they tested whether infants prefer a mosaic colored figure to a uniform colored figure after habituation to the transparent stimuli. The results from these previous studies are rather mixed as to the condition and age that perception of transparency emerges. Johnson and Aslin (2000) reported that 4-month olds perceived transparency with the chromatic moving stimuli that contained background texture elements which through accretion and

![Figure 1. Typical example of the stimuli used in the previous developmental studies on the perception of illusory contours. (a) A Kanizsa illusory contour configuration. (b) An outwardly oriented control configuration.](https://jov.arvojournals.org/pdfaccess.ashx?url=/data/journals/jov/932852/ on 11/01/2018)
deletion provided additional stimulus support for the spatial layout of the display. They also reported that 8-month-olds but not 4-month-olds perceived transparency when the stimuli were achromatic. More recently, Kavšek (in press) reported that 8-month-olds but not 4-month-olds could perceive transparency in the static stimuli even when chromatic information was available. Together, these two studies indicate that younger infants perceive transparency when motion and color information is available but not when these cues are unavailable. In contrast, in our previous study, we found that even 3–4 months perceive transparency in the static achromatic stimuli (Otsuka et al., 2006b).

Our motivation was to further explore infant’s ability to perceptually integrate fragmented image features based on purely static pictorial cue. In the present study we use new Kanizsa-type configurations that do not contain confounding influences identified with the previous studies. The main stimulus configuration, illustrated in Figure 2a, is a novel mixed-polarity modification of the configuration that was first devised by Kanizsa (see Figures 2b and 2c). In these configurations, a missing quarter segment of each circular inducer (as in a standard illusory contour configuration) has been replaced by a uniformly colored quarter segment. While the standard Kanizsa configurations generate a vivid percept of an occlusion by an opaque surface, the same configurations with embedded colored sectors can result in a vivid perception of a transparent, faintly colored, “misty” surface that is bounded by illusory contours (Kanizsa, 1955; Varin, 1971; Ware, 1980). These types of stimuli have also been known as the neon color spreading configurations or neon-Kanizsa configurations, directly linking the phenomena of illusory contours, neon spreading and perceptual transparency (Nakayama, Shimojo, & Ramachandran, 1990). While the original demonstrations of neon spreading consist of inducing segments that are all of the same color/luminance and contrast polarity, we use mixed polarity inducers to ensure that perception of illusory transparent surface is not confounded with perception of induced brightness. The induced brightness in neon-Kanizsa configurations is evident by comparing the central gray regions in Figures 2b and 2c which appear darker and lighter respectively. In fact, according to the influential models both illusory brightness (in illusory contours) and color spreading (in neon color spreading displays) hinge on the very same neurophysiological structure, i.e., the feature contour system: they are both thought to depend upon the like-contrast polarity relationships between the inducers (Grossberg & Mingolla, 1985; Grossberg & Yazdanbakhsh, 2005; Nakayama et al., 1990). The most important feature of the novel mixed polarity Kanizsa configuration lies in its ability to dissociate a vivid perception of an illusory transparent surface from that of a uniform color spreading. These configurations have also been used to probe the mechanisms underlying different forms of perceptual completion that are closely matched in the structure of local features (Spehar, 2003; Spehar & Halim, 2008).

The novel mixed-polarity configuration is qualitatively similar to the single polarity neon-Kanizsa configuration regarding local luminance relationships at the level of each inducer. In both types, the luminance of the gray quadrant lies in between the luminance of the background and the circular pacman inducer. These are T-junctions in which the regions lying on both sides of the stem have the same contrast polarity relationship with the region corresponding to the top of T-junction (Figure 3a). Although T-junctions typically indicate occlusion by an opaque surface, the interpretation of opaque versus transparent occlusion is strongly affected by the distribution of constituent luminances. Specifically, when the luminance on one side of the stem of a T-junction lies between the luminances of the other two regions (the region on the top and on the other side of the stem), it is possible for the region of intermediate luminance to be perceived as a transparent or modally completed surface in front of the other two regions. Watanabe and Cavanagh (1993) labeled these junctions “implicit X-junctions” as they have the...
same contrast polarity relationship as configurations that are consistent with occlusion by a transparent region, “transparent X-junctions” (as indicated in Figure 3b). When these luminance and contrast polarity relationships are violated such that the regions lying on both sides of the stem of T-junction do not have the same contrast polarity relationship with the region corresponding to the top of T-junction, then the neon color spreading is absent (as illustrated in Figure 3c).

The novel mixed polarity Kanizsa configurations allow for the effects of induced brightness neon spreading to be dissociated from the illusory, and in this case transparent, boundary effects. As such, although our stimuli share both figural and perceptual properties with configurations used previously to study development of transparency and illusory contours, they have novel characteristics that differentiate them in important ways from previous configurations.

Firstly, previous studies on transparency in infants have typically used configurations where the perceptually grouped regions are adjacent to each other so that no contour completion was required to perceive transparency (Johnson & Aslin, 2000; Kavšek, in press; Otsuka et al., 2006b). In our configuration, however, the perceptually transparent surface is only partially supported by the physical contours and partially by perceptually interpolated illusory contours. Furthermore, all previous studies investigating infants’ perception of transparency contained explicit X-junctions, consistent with the presence of a transparent overlay. As outlined above, our stimuli do not contain any explicit X-junctions. Geometrically they contain T-junctions that, due to specific luminance relationships, are consistent with the perception of a transparent surface (implicit X-junctions). Last but not least, no studies of illusory contour completion in young infants have so far used a purely static variant of mixed polarity Kanizsa configurations. In two experiments we present conclusive evidence for the sensitivity to the presence of illusory transparent contours in purely static two-dimensional configurations in both 3–4 month and 5–6 month old infants.

**Experiment 1**

The first experiment investigated whether 3–4 and 5–6 month-old infants could detect the illusory transparent surface in novel mixed polarity Kanizsa configuration. We compared infants’ preference for the illusory transparent Kanizsa configuration to a configuration that consisted of identical but outwardly rotated elements (Figure 4 top). Although these two configurations differ only in the orientation of the inducing elements, they differ drastically in the type of percepts they afford. The perceptual properties associated with the illusory transparent Kanizsa configuration are consistent with the stimulus properties known to favor spontaneous preference of infants: a large pattern over a small one, a three-dimensional pattern over a two-dimensional one, and figures that contain a larger number of contours (Slater, 1995). The percept of an illusory transparent surface in Kanizsa configuration with inwardly oriented inducers entails the perception of a semi-transparent surface that is larger than the individual circular inducing elements, that is positioned in front of the inducing elements, and bounded by illusory contours, perceptual properties that fit very well with the stimulus properties that induce spontaneous preference of infants.

However, the illusory transparent and the comparison, outwardly facing, configurations differ not only in terms of the perceived illusory transparent surface. While the overall symmetry was kept constant, there were some geometrical differences in the spatial position of the embedded grey segments. Thus, it is possible that when the gray segments are embedded in an inward facing configuration, it might be the greater spatial proximity of these quadrants to each other that governs infants’ visual preference. To control for the possibility that infants simply respond to the geometrical properties of the inward and outward facing configurations we introduced a non-transparent Kanizsa configuration side by side with the respective outward facing configurations as a control condition (as depicted in Figure 4 bottom).

The non-transparent configuration was created by simply switching the black and white regions of the
illusory transparent configuration. Thus, non-transparent and illusory transparency configurations are identical in terms of local geometrical structure, containing segments of equal size and relative position. Both configurations also contain a significant number of very similar contrast polarity variations across the four inducers. The only difference is in the relative luminance relationship of the quadrants to the adjacent regions. However, these slight variations in luminance relationship have profound consequence for the type of perceptual completion supported in the two configurations. As discussed earlier, the gray quarter segments in the illusory transparency configuration are of intermediated luminance relative to the two other local regions (implicit X-junctions) and thus compatible with the perceptual completion of the four quadrants, in the form of a transparent layer in front of the black and white inducers. In the non-transparent Kanizsa configuration, the corresponding quadrants are not of intermediate luminance relative to the locally adjacent regions and are thus incompatible with the perception of illusory transparent contours.

Note that the transparent and non-transparent configurations are composed of exactly same component elements with a different pairing between the quarter segments and the three-quarter circles. Although the four gray quarter segments in the transparent and those in the non-transparent configuration look as if they are colored differently, in fact, it is not the case. Figure 5 demonstrates that the transparent and non-transparent configurations are identical when the three-quarter circles (pacmen) are removed (Figure 5).

By using novel and unique test and control stimuli, we examined whether 3–4 and 5–6 month old infants are able to link spatially separate implicit X-junctions into a semi transparent surface bounded by illusory contours.

Methods

Participants

Twelve 3- to 4-month-old infants (5 male, 7 female, mean age = 98 days, ranging from 75 to 133 days), and twelve 5- to 6-month-old infants (6 male, 6 female,
mean age = 161 days, ranging from 135 to 182 days), participated in Experiment 1. An additional 4 infant were tested for Experiment 1, but were excluded from the analysis due to a side bias greater than 90% (1), and short looking time (less than 10 seconds) in one of the two conditions (3).

Apparatus

All stimuli were depicted on a mid-gray (18.5 cd/m²) background. All of the four configuration were composed of the same component elements: two dark-gray (9.4 cd/m²) and two light-gray (36.7 cd/m²) quarter segments, and two black (0.5 cd/m²) and two white (95.4 cd/m²) three-quarter circles. The transparent and non-transparent Kanizsa configurations were created by pairing between these quadrant and the three-quarter circles in the different ways (see Figure 5).

The transparent Kanizsa configuration was composed of two black inducers with dark-gray quadrant and two white inducers with light-gray quadrant. The non-transparent Kanizsa configuration was composed of two black inducers with light gray quadrants and two white circles with dark gray quadrants. Locally matched comparison configurations were created by rotating each element of the transparent and non-transparent figure by 180 degrees.

The circle measured 160 pixels (8.5 deg) in diameter, and the distance between the each adjacent element

Figure 5. Demonstration that the transparent and non-transparent configurations are identical when the three-quarter circles (pacmen) are removed: (Top) Transparent and non-transparent configurations, and (Bottom) transparent and non-transparent configurations without three-quarter circles. Although the four gray quarter segments in the transparent configuration and those in the non-transparent configuration look as if they are colored differently, actually they are identical as seen in the bottom.
centers was 240 pixels (12.85 deg), so that the illusory square was 240 pixels (12.85 deg). The figures were presented side by side on the CRT monitor, side by side. The distance between the outer inducers’ edges of the two figures was 226 pixels (12.09 deg).

Procedure

A preferential-looking paradigm was used to measure each infant’s response. Prior to each trial, a cartoon accompanied by a short sound was presented at the center of the monitor. The experimenter initiated each trial as soon as the infant was attending to the cartoon. In each trial, stimuli were presented for 15 sec. The presentation time of the stimuli was fixed regardless of whether the infants looked or not. Each infant underwent 2 trials for each of the experimental (illusory transparency) and control (non-transparent) condition.

For each condition, the transparent and non-transparent Kanizsa configurations were presented side by side with their corresponding outwardly rotated comparison configuration. We defined the transparent and the non-transparent Kanizsa configuration as the target for the experimental and control condition respectively. The position of the target figure was reversed between the two trials. The position of the target figure in the first trial and the order of presentation of the two conditions were randomly changed across the infants. One observer, unaware of the stimulus identity, measured infants’ looking time for each stimulus based on the video recordings. Only the infant’s looking behavior was visible in the video. Although the observer could not see the stimulus, the timing of the beginning and the end of each trial was evident through the beep sound presented at the beginning and the end of each trial. To compute the inter-observer agreement, a second observer’s measurement of infant’s looking time was obtained from 25% of the total data. Inter-observer agreement was $r = 0.95$ across the two experiments.

Results

Table 1 shows the mean looking time of each age group during the experimental and control conditions. We calculated an individual percentage preference score for each condition with the Kanizsa configuration as the target. The preference scores were calculated by dividing the infants’ looking time for the target during the two test trials by the total looking time over the two test trials, and then multiplying this ratio by 100. Figure 6 shows the mean preference score of each age group in the experimental and control condition. A two-tailed one-sample $t$-test (vs. chance level of 50%) revealed that both 3–4-month-old and 5–6-month-old infants preferred the Kanizsa configuration in the experimental condition (3–4 months: $t(11) = 6.07$, $p < 0.01$, $P_{rep} = 1$, $d = 1.75$; 5–6 months: $t(11) = 4.74$, $p < 0.01$ $P_{rep} = 0.99$, $d = 1.37$), but not in the control condition (3–4 months: $t(11) = 1.36$, $ns$ $P_{rep} = 0.72$, $d = 0.39$; 5–6 months: $t(11) = 1.21$, $ns$, $P_{rep} = 0.72$, $d = 0.35$). A two-way ANOVA of Age (3–4 months / 5–6 months) × Condition (experimental / control) revealed a significant main effect of condition ($F(1, 22) = 22.89$, $p < 0.01$, $P_{rep} = 1$), indicating that the preference for target figure was greater in the experimental condition than in the control condition. No other effect or interaction approached significance.

Discussion

The results of Experiment 1 demonstrate that both 3–4 and 5–6 month old infants prefer the Kanizsa configuration that induces the perception of an illusory transparent surface. Even though the two types of Kanizsa configuration differed only in the luminance relationship between the elements (presence or absence of implicit X-junctions), infants responded very differently to these figures when presented side by side with their respective outwardly facing comparison configurations. The results from the control condition exclude the possibility that the infants’ preference was based on geometrical properties of...
inwardly and outwardly oriented inducing configurations. If infants based their preference simply on the greater spatial proximity of gray quarter segments in inward oriented inducing Kanizsa configurations, then they would prefer an inward oriented configuration regardless of whether the inducing segments are compatible with the perception of illusory transparency (implicit X-junctions) or not. We believe that this pattern of results indicate infants’ sensitivity to distribution of image intensities that goes beyond the sensitivity to the geometrical layout of spatially separated collinear segments contained in the studied configurations. That is, the results of Experiment 1 suggest that even 3–4 months old infants could organize inducing elements in the Kanizsa configuration consistent with the transparent surface overlay only when the distribution of image intensities is compatible with conditions for perceptual transparency (implicit X-junctions).

However, there are two reasons to remain cautious about this interpretation. Firstly, the comparison between configurations affording the perception of illusory transparency and those that do not is only indirect and via comparison with their outwardly facing counterpart configurations. Secondly, the illusory transparent and non-transparent configurations (and their respective outwardly facing counterparts) differed in a potentially important way. Namely, the embedded gray quadrants in the non-transparent configurations are not of intermediate luminance relative to the overall gray background and thus share a higher local contrast with their respective neighboring regions. Thus, one could argue that it was this local contrast difference that had caused differential looking behavior in two conditions and that infants simply failed to differentiate between inward and outward facing configurations at higher contrast levels. Although we consider this an unlikely possibility, in Experiment 2, we directly compared the illusory transparency and non-transparent configurations to test for this possibility.

**Experiment 2**

In this experiment, we directly compared infants’ preference between the inward oriented Kanizsa configurations that were either consistent with a perception of a transparent overlay (as illustrated in Figure 7 top left), or inconsistent with such a percept (as illustrated in Figure 7 top right). In the current experiment, the four stimuli used in Experiment 1 were paired up differently. If the difference in luminance contrast between the two configurations was causing the pattern of results observed in Experiment 1 and infants simply responded to differences in geometrical layout, that, for some reason, was more apparent at lower contrast levels, then by directly comparing two inward oriented and two outward oriented configurations, the preferential looking observed for the illusory transparent configuration should be eliminated. Moreover, as many previous studies have found preference for high contrast patterns in young infants (Slater, 1995), one would expect a preference for the higher contrast, non-transparent, configuration with both inward and outward facing inducers.

**Method**

**Participants**

Twelve 3- to 4-month-old infants (4 male, 8 female, mean age = 112 days, ranging from 86 to 132 days), and twelve 5- to 6-month-old infants (6 male, 6 female, mean age = 167 days, ranging from 137 to 192 days) participated in Experiment 2. An additional 2 infant were tested for Experiment 2, but were excluded from the analysis due to a side bias greater than 90% (1), and short looking time (less than 10 seconds) in one of the two conditions (1).

**Apparatus and stimuli**

Apparatus were the same as those used in Experiment 1. Stimuli were the same as those used in Experiment 1, but the four figures were paired up differently from Experiment 1 (Figure 7).

**Procedure**

Procedure was the same as in Experiment 1, except for the following. For the experimental condition, the transparent and non-transparent Kanizsa configurations were presented side by side. For the control condition, the two locally matched rotated comparison configurations were shown side by side. We defined the transparent Kanizsa configuration and its locally matched counterpart configuration as the target for the experimental and control condition, respectively.

**Results**

Table 2 shows the mean looking times of each age group during experimental and control condition. We calculated an individual preference score in the same way as for Experiment 1. Figure 8 shows the mean preference score of each age group in the experimental and control condition. A two tailed one-sample t-test (vs. chance level of 50%) revealed that both 3–4 and 5–6 month-old significantly preferred the Kanizsa configuration that appears side by side. For the control condition, the two locally matched rotated comparison configurations were shown side by side. We defined the transparent Kanizsa configuration and its locally matched counterpart configuration as the target for the experimental and control condition, respectively.

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$p < 0.01, P_{rep} = 1$), indicating that the preference for the target figure was greater in the experimental condition than in the control condition. No other effect or interaction approached significance.

**Discussion**

These results demonstrate that infants prefer the Kanizsa configuration that induces perception of transparency to the Kanizsa configuration without illusory transparency, even though these figures are identical in their geometrical properties. However, infants showed no preference between the outwardly rotated control configurations that are locally matched to illusory transparency and non-transparent configurations. The results with the outward oriented inducers eliminate the possibility that the infants’ preference was based on local contrast differences, or the local intensity distribution within the elements. The results of Experiment 2 along with that of Experiment 1, strongly suggest that infants could organize the illusory transparent Kanizsa configuration consistent with the perception of an illusory transparent surface.

**General discussion**

We found that 3–4 and 5–6 month-old infants prefer the Kanizsa configuration that induces the perception of an
The results from two experiments exclude the possibility that infants simply responded to the geometrical properties of the figures or to the local contrast differences in intensity distribution within the elements in tested configurations. Thus, the preference of 3–4 and 5–6 months-old infants are consistent with their perception of an illusory transparent surface in a purely static pictorial display.

Although Kellman and Arterberry (1998) argued that infants discrimination of illusory contours can be based on the fact that outwardly facing control configurations contain concave discontinuity positioned close to the external boundary of the pattern, the same does not apply to our findings. In the experimental condition of Experiment 1, infants showed preference for illusory transparent Kanizsa configuration compared to the outwardly oriented control configuration. If infants discriminated between these configurations solely based on the “externality effect,” they should have showed the same pattern in the non-transparent Kanizsa configuration. However, infants did not do so in the control condition. Furthermore, in Experiment 2, infants showed preference for the transparent Kanizsa configuration to the non-transparent Kanizsa configuration even thought the inducing elements were oriented inward in both configurations.

Infants’ discrimination between the illusory and non-illusory figure could not have been based on the perceived brightness difference between the figures (Kavšek & Yonas, 2006). As we have already discussed in the introduction, the illusory brightness enhancement is eliminated by using mixed polarity inducers. Furthermore, while configurations with mixed polarity inducers have been used in some of the developmental studies investigated perception of moving illusory contours (Curran et al., 1999; Kavšek & Yonas, 2006), no previous studies have used mixed contrast polarity variations within purely static configurations.

Apart form the perception of illusory contours, previous studies on the development of perceptual transparency typically used figures where the perceptually grouped regions are adjacent to each other so that no contour interpolation is required to perceive transparency and where X-junction cues that indicate the presence of transparent overlay exist (Johnson & Aslin, 2000; Kavšek, in press; Otsuka et al., 2006b). For example, Otsuka et al. (2006b) showed that 3–4 months are able to parse a partly overlapping circle and square according to transparency interpretation when the luminance intensity relationship along the X-junction meets the condition for transparency, but not when it violates the condition for transparency. However, the findings from previous studies are mixed with respect to the conditions and age where infants start to perceive transparency. While Otsuka et al. (2006b) suggest that even 3–4 months perceive transparency in the static achromatic display, other two studies reported that infants failed to perceive transparency when the figure was depicted only with achromatic information (Johnson & Aslin, 2000) or when the figure was static (Kavšek, in press). The finding of the present study support that of Otsuka et al. (2006b) in showing that even 3–4 months perceive transparency in the static achromatic display, but we further extended the finding to show that young infants are able to perceive transparency even when explicit X-junction cues are not available and the perceptually transparent surface was only partly supported by physical contours. Our results and Otsuka et al. (2006a, 2006b) suggest that the distribution of achromatic luminance intensities play an important role in perceptual organization in infants as well as in adults (e.g. Watanabe & Cavanagh, 1992).

In conclusion, the stimulus manipulation and procedures used in the present study exclude the potential confounds described above, and provide evidence that young infants are able to bridge the gap between the elements and perceptually complete missing structure in the image based on static pictorial cues alone. Previous studies have shown that sensitivities to several Gestalt principles for perceptual organization in the static domain such as lightness similarity, shape similarity, and good continuation emerge at around 3–4 months of age (e.g., Quinn & Bhatt, 2005a, 2005b, 2006; Quinn, Brown, & Streppa, 1997), although not all of these principles are equally operational (Quinn & Bhatt, 2006; Quinn, Bhatt, Brush, Grimes, & Sharpnack, 2002). Furthermore, recent studies have demonstrated that infants as young as 4-months of age are sensitive to purely static two-dimensional image cues that structurally define a
globally coherent object and enable a successful discrimination between possible and impossible objects (Bertin & Bhatt, 2006; Shuwairi, Albert, & Johnson, 2007). Together with these recent studies, the present study suggests the emergence of the sensitivity for static pictorial cues to perceptual organization and segregation in early infancy.

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