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Preference for Impossible Figures in 4-month-old Infants

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Abstract

Can infants use interposition and line junction cues to infer three-dimensional (3D) structure? Previous work (Shuwairi et al., 2007) has shown that in a task that required 4-month-olds to discriminate between static 2D pictures of possible and impossible cubes, infants exhibited a spontaneous preference for displays of the impossible cube, but left open the question of whether they did so on the basis of purely local “critical regions”, or whether infants were able to employ more global clues. Here, infants were presented with possible and impossible cubes in which the strictly local cues that could have derived from exterior binding contours were deleted. Results showed that infants were still able to discriminate possible from impossible cubes, suggesting longer looking infants are sensitive to global properties and the capacity to integrate pictorial information to perceive aspects of global 3D shape may develop earlier than previously demonstrated using reaching tasks.

Keywords

visual development; pictorial depth cues; cue integration; impossible objects; 3D coherence; object perception in infancy

The ability to extract information about the three-dimensional structure of objects is a remarkable achievement of the visual system, and understanding how coherent three-dimensional object perception develops in early infancy has been a central topic of developmental research (Johnson, 2003; Piaget, 1954; Spelke, 1998). An important aspect of object perception that has been less well studied is the capacity of young infants to integrate local and global depth relations that lend to the perception of three-dimensional shape. This work investigates the development of spatial processing and object knowledge, and also relates to work on perceptual completion in early infancy.

Early in postnatal life, infants demonstrate a number of perceptual aptitudes that lend to perceiving objects in three dimensions, and facilitate the ability to distinguish between depictions of globally coherent and incoherent objects. Within the first few months, infants perceive completion of surfaces moving behind a static occluder (Johnson, 2004; Kellman & Spelke, 1983), organize local geometric elements into global patterns based on spatial arrangements (Quinn, 2003; Quinn, Slater, Brown, Hayes, 2001; Turati, Simion, & Zanon, 2003), and discriminate between possible and impossible occlusion events involving real, solid objects (Baillargeon, 1987; Baillargeon & Wang, 2002), suggesting that young infants respond

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appropriately to several cues needed to represent aspects of spatial orientation and object structure.

Adult studies of object recognition suggest that representing shape in three dimensions arises from the ability to extract critical information regarding the local spatial configuration of edges, junctions, binding contours and surface characteristics (Biederman, 1987; Biederman & Ju, 1988; Enns, 1992; Marr & Nishihara, 1978). These perceptual computations occur rapidly to capture the available pictorial and isometric cues from local features and parts present in a given 2D view of an object, which contains essential information for interpreting the global 3D representation (Cooper, 1990). Interpreting structural impossibility in line drawings of objects results from detecting a perceptual discrepancy in the apparent levels of depth of surfaces and edges (Cowan & Pringle, 1978; Penrose & Penrose, 1958).

Evaluating how these perceptual abilities arise in early infancy will lead to a better understanding of the development of 3D object perception. Previous research has largely focused on infants' use of motion cues for processing shape information (Kellman & Short, 1987; Kellman & Spelke, 1983; Yonas, Arterberry & Granrud, 1987). Some work also indicates that 3-month-olds respond equally to different viewpoints of the same shape varying in slant, suggesting that infants may represent global aspects of shape across certain rotational transformations (Bower, 1966; Caron, Caron & Carlson, 1979).

Additional literature indicates that by 7-months, infants demonstrate sensitivity to pictorial depth cues in static images during tasks of surface completion and shape discrimination (Kavsek, 1999, 2004; Yonas & Arterberry, 1994) and visually guided reaching (Yonas, Elieff, & Arterberry, 2002). Reaching studies demonstrate that 7-month-olds respond appropriately to depth information under monocular conditions and reach for nearer-appearing objects after experimental manipulations of depth cues including linear perspective and texture gradients (Yonas, Granrud, Arterberry, & Hanson, 1986), surface contours (Sen, Yonas, & Knill, 2001), shading (Granrud, Yonas, & Opland, 1985) and cast shadows (Yonas & Granrud, 2006), but that younger infants do not appear responsive to these cues in a reaching paradigm.

Using a looking-time paradigm, Yonas and Arterberry (1994) found that 7.5-month-olds were sensitive to line junctions and edges that specify fundamental characteristics of object structure rather than dispensable surface markings, however younger infants were not included in the task for comparison. More recent work with younger infants has shown that 3-month-olds can detect changes in depth cue information in static 2D multi-element displays depicting 3D shapes, but they cannot when the individual elements lack adequate depth cues and appear to be flat patterns (Bhatt & Waters, 1998). Nor could they differentiate between two displays when critical binding edges and contours are deleted from within local elements of the array (Bhatt & Bertin, 2001). These findings suggest that very young infants attend to at least some of the local depth cues, such as T and Y junctions, needed to process aspects of structure and orientation information present in line drawings.

Questions remain as to whether infants younger than 6 months can, in addition to detecting changes in local depth cue information, integrate these cues to perceive aspects of global shape. To date, only one study has directly examined whether infants can use local T-junctions and interposition information to process coherent versus incoherent shape configuration (Shuwairi, Albert, & Johnson, 2007). That study evaluated whether 4-month-olds are sensitive to inconsistencies in structural information provided in 2D images and can discriminate between pictures of possible and impossible cubes varying in one pictorial dimension involving a reversal of interposition cues in a single bar junction (see Figure 1A and 1B). Infants looked longer at pictures of the impossible cube following a period of habituation as well as in a no-habituation spontaneous preference test; this result obtained not only with color photographs

(in which cues such as color, shading and texture might have been helpful) but also in line drawings, wherein infants may have had to rely primarily on the depth cue of interposition.

An important open question, however, is whether infants might have relied on *local* “critical regions” or whether they genuinely had recourse to more *global* inconsistencies. The possible and impossible figures used in previous work varied along a single pictorial dimension occurring in a “critical region” (i.e., interposition of two bars demarcated by T-junctions). Relative to the binding edges and all other parts of the cube, this interior region was the location in which the depth order of overlapping bars determined whether its global 3D configuration was possible or impossible.

Here, we focus on infants’ early understanding of individual objects, and in particular the largely unstudied question of whether infants can integrate global information such that they can detect structural contradictions in drawings of impossible objects that arise from inconsistencies in local relative depth of surfaces, such as in the display panel shown in Figure 1. Successful performance in this type of task inherently requires that the visual system respond to a number of pictorial depth cues in order to register object parts in appropriate depth planes and ultimately infer a global 3D structural configuration.

In Experiment 1, global structural integrity of the cube is defined by several co-occurring local depth cues, specifically the inclusion of Y junctions present in the critical intersection of adjoining bar segments (see Figure 1C). If 4-month-old infants are sensitive to Y junction information and can integrate spatial relations between parts to interpret overall shape coherence, then results should yield a spontaneous preference (i.e., longer looking time) for the impossible figure. If not, then infants should show equal amounts of looking to both the possible and impossible cubes.

Experiments 2A and 2B (described below) complement Experiment 1 by testing whether a preference for one of these particular stimuli is driven by the central critical region in itself. If longer looking toward the impossible figure is being influenced by a more salient or attractive interior arrangement of lines in the “critical region,” then, in Experiments 2A and 2B longer looking should be observed to the interior critical region of the impossible shapes in the absence of extended lines and binding contours. Alternatively, a preference for the critical region of the impossible cube could arise in Experiment 2A if the configuration of bar segments converging in the center has greater salience than the overlapping Y-bars in the critical region of the possible cube (see Figure 1D). Similarly, in Experiment 2B, a preference for the interior of the impossible cube could arise if the configuration of vertically oriented bars occluding horizontal bars is more interesting than horizontal bars occluding vertical ones (see Figure 1B). However, if infants are processing relevant pictorial cue information, integrating spatial relations among the cues, and perceiving global structural coherence in depicted objects, then equal amounts of looking should be observed toward the unbound interior regions of both the possible and impossible figures, since the critical regions on their own are both possible.

GENERAL METHOD

Participants

Infant participants were selected from a public database of new parents and were recruited by letters and telephone calls. The final sample consisted of 32 four-month-old infants (M age = 119.1 days, SD = 13.3; 18 girls, 14 boys). An additional 8 infants were observed but not included in the sample due to sleepiness or fussiness. Twelve infants participated in Experiment 1, ten infants in Experiment 2A, and ten infants in Experiment 2B. All infants were full-term with no known developmental difficulties.

Stimuli

Stimuli in Experiment 1 were inspired by artist Dirk Huizer's "Cube" (1984, screenprint). All images were redrawn and animated using Flash (Macromedia Studio MX) and presented as QuickTime movies using a Macintosh G4 and a 76 cm monitor. Cube stimuli subtended 25° visual angle in height and width. Between trials, infants viewed an "attention getter" (a circular blue and white checkerboard pattern, 2.5° visual angle, that expanded and contracted in time with a repetitive beeping sound) for approximately 3 sec to re-center their gaze.

In Experiment 1, infants viewed a single possible cube and a single impossible cube (see Figure 1C), each presented in alternating sequence on each of three separate trials. Cubes differed exclusively in the "critical region" (see Figure 1D), both of which contained 18 line segments, 6 bar segments, and several T, Y and arrow junctions. In relation to all other regions of the figure, this particular spatial location is where the depth order of overlapping bar junctions, adjoining surfaces and binding edges of the cube made its global 3D structure either possible or impossible.

All infants were naïve to the stimuli presented in these experiments. Possible (P) and impossible (I) displays, and their respective interior regions, were presented sequentially in alternating order (i.e., P-I-P-I-P-I, or I-P-I-P-I-P). Order was counterbalanced in all experiments.

Procedure

Infants sat in a testing chamber approximately 100 cm away from the visual display. An observer, blind to the stimulus presentation screen at all times, viewed only the infant on a separate video monitor. The observer pressed a key when the infant looked toward the stimulus and released the key when the infant looked away. The computer presented the stimuli and stored the observed looking times. In all three experiments stimuli were presented using a standard infant-controlled procedure in which each test trial ended when the infant looked away from the display for more than 2 sec or when the infant had looked at the display for 60 sec, whichever came first.

The primary dependent measure was the amount of time spent looking at each type of object display in test trials. Analyses were based on mean looking times across the 3 test trials for each display type. An *impossible preference score* was calculated based on the proportion of looking time for the impossible cube relative to the sum of looking time for both the possible and impossible cubes. All tests of statistical significance used an alpha level of .05 and all *t* tests were two-tailed.

EXPERIMENT 1

Experiment 1 investigated whether 4-month-olds could use available Y-junction information to perceive global coherence and discriminate between pictures of structurally possible and impossible cubes.

Participants

Participants were 12 four-month-olds (*M* age = 114.2 days, *SD* = 13.13; 7 girls, 5 boys).

Stimuli

Infants viewed line drawings of possible and impossible *Huizer* cubes (see Figure 1C) in alternating sequence.

Results and Discussion

Infants looked reliably longer at pictures of the impossible cube relative to the possible one, $t(11) = 3.41$, $p = .006$, and the proportion of looking to the impossible differed significantly from chance, mean *impossible preference score* = .605, $t(11) = 3.66$, $p = .004$ (see Table 1). Results of a 2 (Sex) $\times$ 2 (Order) $\times$ 2 (Display) $\times$ 3 (Trial) repeated-measures ANOVA revealed a main effect of display type, $F(1, 8) = 7.93$, $p = .023$, partial eta squared = 0.50, which was due to longer looking toward the impossible figure in each of three trials (Trial 1: $M_{\text{Possible}} = 28.8$ sec (SD = 18.2), $M_{\text{Impossible}} = 43.0$ sec (SD = 15.7); Trial 2: $M_{\text{Possible}} = 18.2$ sec (SD = 15.2), $M_{\text{Impossible}} = 31.7$ sec (SD = 20.2); Trial 3: $M_{\text{Possible}} = 15.0$ sec (SD = 15.0), $M_{\text{Impossible}} = 18.2$ sec (SD = 18.5). There were no effects of sex or stimulus order, and no interactions. Increased looking toward the impossible figure was consistent across test trials for 10 of the 12 infants.

These results suggest that 4-month-old infants are sensitive to Y-junction information specifying shape in line drawings. Early sensitivity to these fundamental junction and edge cues may facilitate infants' ability to represent aspects of global 3D shape and detect structural anomalies in impossible figures.

EXPERIMENT 2A

In Experiments 2A and 2B, infants viewed displays containing only the interior critical region, without extended binding contours, of the possible and impossible cubes. These experiments tested whether the longer looking toward impossible figures was evoked by a preference for the interior spatial arrangement of lines and parts (i.e., the "critical region") independent of external binding edges. Thus, if infants' preference for impossible objects is based on a more salient or perceptually interesting critical region of the impossible figures, then longer looking should be observed to the unbound interiors of the impossible shapes. However, if infants are processing relevant pictorial cue information and integrating spatial relations between parts, then equal amounts of looking should be observed toward the unbound interiors of possible and impossible figures, since in the absence of binding contours both are technically possible.

Participants

Participants were 10 four-month-old infants (M age = 123.8 days, $SD = 15.6$; 5 girls, 5 boys).

Stimuli

Infants viewed interior regions of the possible and impossible *Huizer* cubes used in Experiment 1 (see Figure 1D). Each display was presented in alternating sequence on each of three different trials. *Impossible preference scores* were calculated based on infants' looking times to interior regions of the possible and impossible figures.

Results and Discussion

Results of Experiment 2A revealed no reliable differences in looking time to either display across all test trials, $t(9) = .775$, $p = .458$. The proportion of looking to the interior of the impossible cube did not differ from chance, (mean *impossible interior preference score* = .518, $t(9) = .884$, $p = .397$) (see Table 1). There were no reliable effects of sex or stimulus order.

EXPERIMENT 2B

Experiment 2B tested whether young infants would also show equal amounts of looking toward the unbound interior "critical regions" of the cubes used by Shuwairi and colleagues (2007).

Participants

Participants were 10 four-month-old infants (M age = 118.9 days, SD = 10.8; 6 girls, 4 boys).

Stimuli

Infants viewed interior regions of the possible and impossible cubes originally used by Shuwairi et al. (2007) (see Figure 1B). Each display was presented in alternating sequence on each of three different trials. *Impossible preference scores* were calculated based on infants' looking times to interior regions of the possible and impossible figures.

Results and Discussion

Results of Experiment 2B revealed no reliable differences in looking time to either display, $t(9) = .187$, $p = .856$, and the proportion of looking to the interior section of the impossible cube did not differ from chance (mean *impossible interior preference score* = .460, $t(9) = 1.13$, $p = .289$) (see Table 1).

In addition, there were differences in impossible preference scores between experiments, $F(3,38) = 5.27$, $p = .004$. Pairwise comparisons revealed that preference scores in Experiment 1 using displays of the possible and impossible *Huizer* cube were significantly greater than preference scores obtained in Experiment 2A using just the interior regions of the same cubes, $t(21) = 2.13$, $p = .039$, $d = 0.93$. Similarly, the mean preference scores obtained in earlier work with the original possible and impossible cubes (Shuwairi et al., 2007, Experiment 3) were significantly greater than preference scores obtained in Experiment 2B using images of just the critical regions of these particular displays, $t(19) = 2.98$, $p = .005$, $d = 1.37$.

The observed pattern of behavior (i.e., longer looking to the impossible figure and equal looking to the interior regions of both possible and impossible figures in the absence of extended contours) are suggestive of infants' early abilities to register local depth cues and integrate pictorial information appropriately to represent more global aspects of shape.

GENERAL DISCUSSION

This study used a task of possible and impossible object discrimination to examine coherent 3D shape processing in early infancy. The goal was to evaluate whether 4-month-olds are sensitive to particular line junction cues needed to interpret structural coherence, and determine whether infants' responses are driven by a particular spatial configuration in the critical region of impossible figures. In Experiment 1, 4-month-old infants looked longer at the impossible *Huizer* cube, which suggests that young infants are sensitive to differences in Y-junction information specifying shape in line drawings of objects. This yields a robust extension of earlier findings demonstrating that 4-month-olds were responsive to T-junctions and interposition cues in static images.

In Experiments 2A and 2B, equal looking times were observed toward the interior critical regions of the possible and impossible cubes, both of which are possible in the absence of their extended binding contours. The data indicate that isolated internal junction information is not sufficient for infants to make a distinction, and suggest in addition that external edges and binding contours are necessary to evaluate global coherence (i.e., whether the drawing depicts a possible or an impossible object). These results help to negate an alternative hypothesis that infants' preference is driven by a particularly attractive spatial configuration in the critical region of impossible cubes.

That young infants can differentiate between pictures of possible and impossible cubes may be indicative of an early capacity to represent depicted objects in three dimensions and perceive

global structural anomalies conveyed via contradictory line junction cues present in the impossible figure. These results extend the Shuwairi et al. (2007) findings by further suggesting that 4-month-old infants are sensitive to Y-junctions in addition to interposition cues and binding contours in static object displays, and they can use this information to infer an object's global integrity.

Although infants showed reliably greater fixation time to the impossible cubes, the precise visual information (i.e., edges, line junctions, or other depth cues) on which infants are relying as well as the nature of infants' perceptual experience of the impossible figures remains unclear. To further investigate the phenomenon, additional research in our lab has explored how young infants register and process "impossible" shapes relative to their possible counterparts. A recent eye-tracking investigation with 4-month-olds revealed that infants engage in greater oculomotor activity (i.e., longer fixation and more eye movements) in response to the impossible cube, both on the figure overall and within the critical region, relative to the possible cube display (Shuwairi, 2008; Shuwairi & Johnson, 2006). From these observations, young infants appear capable of registering the available visual cues and detecting inconsistent spatial relations between parts that ultimately render a depicted object impossible.

These results may seem surprising given that previous reports from reaching studies indicate that reliable responses to pictorial cues in static images develop later in infancy (Yonas et al., 2002). Kavsek (1999) also reported that 8-month-olds, but not 5-month-olds, were sensitive to curved line junctions specifying edges relative to surface markings present in line drawings of cylinders. It is possible that equal looking times were observed with younger infants in previous studies (e.g., Kavsek, 1999; Kellman & Short, 1987, Experiment 3A) because the differences between post-habituation displays consisted of very small perceptual changes and test stimuli were spatially possible. Therefore, one could question whether previous tasks effectively assessed younger infants' sensitivity to pictorial depth cues and the integration of these cues to perceive coherent shape. The study presented here, on the other hand, used line junctions arranged as either a coherent (possible) or an incoherent (impossible) figure, thus generating a more salient difference between the two stimuli in terms of the global percept.

Impossible objects provide a new way of testing infants' sensitivity to pictorial cues and for investigating the development of coherent 3D object representations in early infancy. This investigation revealed that 4-month-old infants respond to pictorial depth cues present in static images and detect contradictory spatial relations that ultimately a depicted object impossible to render in real 3D space. Additionally, the infant visual system is capable of detecting critical shape defining contours, processing local depth cues and integrating spatial relations among parts in order to represent more global aspects of shape. Indeed, these perceptual mechanisms may be functional earlier than reaching paradigms with older infants had previously suggested.

This work provides evidence supporting the hypothesis that young infants can integrate local cues to interpret global spatial and pattern information, which is a necessary aptitude for perceiving structural inconsistencies found in pictures of impossible objects. Young infants appear capable of selectively attending to line junction cues that, according to a number of models of object recognition, assume that edges and junctions are critical for determining structure and spatial relations among parts (e.g., Biederman, 1987; Biederman & Ju, 1988; Marr & Nishihara, 1978). The results of the current experiments suggest that at least some of the perceptual mechanisms involved in deriving 3D structural information from edges and junctions in static images are available within the first few months of life. Taken together, these studies attempt to clarify the nature and development of 3D object perception and the mechanisms by which infants learn to process and represent global object coherence. The findings bring us closer to understanding the nature of coherent object representations and inform the question of whether they are similar to those of adults.

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Figure 1.

Figure 1A. Schematic diagram of possible (left) and impossible (right) object stimuli used in previous research by Shuwairi et al. (2007).

Figure 1B. Schematic diagram of interior critical regions of the Possible (left) and Impossible (right) cube stimuli used in Experiment 2B.

Figure 1C. Schematic diagram of possible (left) and impossible (right) cube stimuli used in Experiment 1. Figures inspired by Dirk Huizer's "Cube" (1984, screenprint).

Figure 1D. Schematic diagram of interior critical regions of the Possible (left) and Impossible (right) Huizer cube stimuli used in Experiment 2A.

TABLE 1

Mean Looking Times and Impossible Preference Scores

	Impossible	Possible	Difference Score	<i>t</i>	<i>p-value</i>	Mean Impossible Preference Score	<i>t</i>	<i>p-value</i>
Experiment 1	31.0 (15.0)	20.7 (10.9)	10.3	3.41	0.006	0.605	3.66	0.004
Experiment 2A	30.1 (16.7)	28.3 (16.9)	1.8	0.78	0.458	0.518	0.88	0.397
Experiment 2B	19.7 (18.0)	20.3 (13.6)	0.6	0.19	0.856	0.460	1.13	0.288
Experiment 3 *	22.8 (17.1)	17.2 (16.2)	5.6	3.72	0.005	0.583	3.10	0.013

*. Experiment 3 data presented for comparison (from Shuwairi, Albert & Johnson, 2007)