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Young Infants' Perception of Object Unity in Rotation Displays

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Much research has been devoted to questions regarding how infants begin to perceive the unity of partly occluded objects, and it is clear that object motion plays a central role. Little is known, however, about how infants' motion processing skills are used in such tasks. One important kinetic cue for object shape is structure from motion, but its role in unity perception remains unknown. To address this issue, we presented 2- and 4-month-old infants with displays in which object unity was specified by vertical rotation. After habituation to this display, infants viewed broken and complete versions of the object to test their preference for the broken object, an indication of perception of unity in the occlusion display. Positive evidence for the perception of unity was provided by both age groups. Concomitant edge translation available in 1 condition did not appear to contribute above and beyond simple rotation. These results suggest that structure from motion, and perhaps contour deformation and shading cues, can contribute important information for veridical object percepts in very young infants.

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Object boundaries are specified by differences in reflectance characteristics of surfaces (color, luminance, texture, contour, distance, orientation, and motion). Gibson (1966) suggested that such information was both necessary and sufficient for object perception tasks, and there is ample evidence that adults are highly skilled at distinguishing objects and their distances relative to the observer (Cutting & Vishton, 1995; Gibson, 1979). An important question concerns how infants come to detect and utilize visual information to perceive objects.

This question has been addressed with stimulus displays in which individual visual cues are manipulated (i.e., included or excluded); infants' responses to the displays are assessed in light of what adults perceive. One particularly fruitful line of research has used a technique developed by Kellman and Spelke (1983). Four-month-old infants were presented with a center-occluded rod until habituation of looking occurred. Following habituation, the infants were shown two test displays, a "broken" rod (with a gap in the space formerly occupied by the occluder), and a "complete" rod. Both test stimuli matched the visible portions of the rod in the habituation stimulus, but the infants looked longer at the broken rod, suggesting that it was experienced as more novel and the complete rod as more familiar. In other words, the infants seemed to perceive the rod parts in the rod-and-box display as continuing behind the box, comprising a single, continuous object. Infants as young as 2-month-olds perceive the unity of aligned rod parts undergoing a common, rigid translation in the frontal plane (Johnson & Aslin, 1995), but the percept is abolished in static displays (Jusczyk, Johnson, Spelke, & Kennedy, 1999). Unity percepts are also sensitive to the alignment of edges across the occluder (Johnson & Aslin, 1996; Smith, Johnson, & Spelke, 2003).

Past experiments involved partly occluded objects translating horizontally or vertically in the frontal plane, or back and forth in depth. Little is known about other kinds of information that may specify unity, and the goal of these studies was to explore infants' unity perception in displays containing object rotation around the vertical axis. In one display, a wedge shape rotated behind an occluding box, such that the top and bottom portions of the wedge underwent a common rotation (Figure 1). After habituation, the infants viewed broken and complete wedge test displays. Note that it is possible, however, to perceive unity in the wedge display not from vertical rotation, but instead from the common lateral motion of the edges of the wedge as it rotated. We habituated a second group of infants, therefore, to a rotating display formed by joining two blocks in a shape resembling an upside-down "T" with its center portion occluded, followed by broken and complete T shapes. There was no static view in which visible top and bottom edges were aligned, and the horizontal, relative distance of these edges varied over time. Consequently, there was no chance of the availability of a common, rigid motion in this stimulus. If infants detect and utilize vertical rotation to achieve perceptual completion, we would expect posthabituation preferences for the broken object in both wedge and T conditions. On the other hand, if

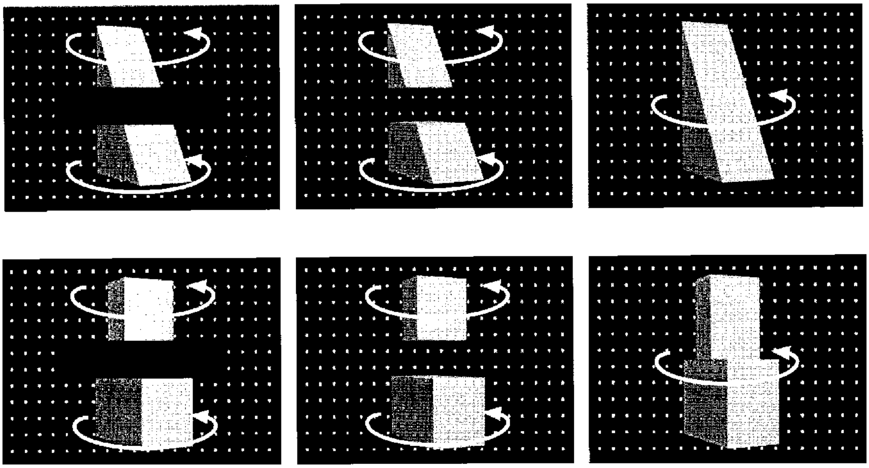

FIGURE 1 Displays used in Experiment 1 to investigate 2- and 4-month-olds' perception of object unity in rotating displays. Left column: Partly occluded wedge (top) and T (bottom) shapes. The shapes underwent clockwise rotation around the center vertical axis (if viewed from above) and were presented to the infants until habituation. Center column: Broken test shapes. Right column: Complete test shapes. A reliable preference for the broken shapes relative to the complete shapes after habituation provides evidence of unity perception in the occlusion display.

only common, rigid motions specify unity to infants, this pattern of performance should obtain only in the wedge condition.

There are reasons to expect robust performance in the wedge condition. Kellman (1984) habituated 4-month-olds to two-dimensional depictions of wedge-shaped objects that rotated around two different axes, followed by a wedge rotating around a new axis alternating with a rotating novel object. The infants looked longer at the novel object, suggesting that the shape of the wedge was available to the infants as it rotated in the two-dimensional projection. Nevertheless, rotation may present difficulties in object unity tasks. Eizenman and Bertenthal (1998) described experiments in which 4- and 6-month-olds viewed a partly occluded rod undergoing either rotation in the frontal plane through 360° (like a propeller), or oscillatory motion through 90°. The younger infants provided no evidence of unity perception in either display. The older infants perceived unity only when the shape of the occluder was circular, and the visible surfaces of the rod remained constant across rotation (i.e., the visible portions did not shorten and lengthen as the rod rotated). It is not known at present why some kinds of rigid motion, such as translation, support robust performance in occlusion tasks, whereas others, such as frontal rotation and oscillation, do not (see "General Discussion" section). A need exists, therefore, for a more thorough investigation of infants' sensitivity to different kinds of motion in object perception tasks; rotational motion in particular. It is also unknown whether there are improvements with development in the use of rotation to perceive unity. Two-month-olds' performance, for example, is sensitive to display characteristics such as occluder width and the amount of visible surface area of the partly occluded object (Johnson & Aslin, 1995; Johnson & Náñez, 1995), and their responses to object rotation are unknown at present.

EXPERIMENT 1

Two- and 4-month-old infants were assigned randomly to one of four conditions: wedge experimental, T experimental, wedge control, or T control. Infants in the experimental conditions viewed a rotating wedge or T whose center portion was occluded by a blue rectangle. Following methods developed by Kellman and Spelke (1983) to assess baseline responses to the test displays, we habituated infants in the control condition to stimuli in which only the top object part rotated; the bottom part remained stationary (such a display is unlikely to induce a percept of unity). After habituation, infants in all conditions were shown the same test displays.

Method

Participants. The final sample consisted of 128 2- and 4-month-olds (73 girls and 55 boys), with a mean age of 63.4 days (SD = 7.0) and 114.9 days (SD = 12.4), respectively. An additional 26 infants were observed but not included due to fussiness (16), sleepiness (5), persistent inattention (3), or prematurity (2).

Apparatus and stimuli. A Macintosh computer presented displays on a computer monitor, recorded looking time judgments, and calculated the habituation criterion for each infant. The habituation display consisted of a blue box (10.9° × 2.2° visual angle) and a green wedge or T (approximately 7.4° × 10.3°; its projected size varied as it rotated), undergoing clockwise rotation (if viewed from above) around its center vertical axis. Rotation through 360° took 4 sec. Control displays were identical except only the top object part rotated. Objects were presented against a black background with a 12 × 20 grid of white dots (17.9° × 11.7°). Examples of the experimental and control displays used in Experiment 1 (and the control displays used in Experiment 2) can be found at www.infancyarchives.com and can be downloaded as QuickTime movies.

Procedure. Infants were seated approximately 110 cm or 140 cm from the display, depending on availability of testing rooms. A video camera, located on the table below the stimulus, recorded the infant's face, which was viewed by an observer behind a partition. The observer did not know when the displays changed from habituation to test. The infant was recorded onto videotape for later coding by a second observer, naive to our hypothesis. Interrater reliability was high (*M* Pearson $r = .98$).

Each trial commenced with presentation of an "attention-getter" (a beeping ball). The observer ended the attention-getter and began the stimulus for each trial when the infant looked at the display. A trial ended when the infant looked away for 2 sec, or when 60 sec had elapsed; the stimulus was then replaced by the attention-getter to begin the next trial. The habituation stimulus was presented until looking times declined across four continuous trials that summed to less than half the total during the first four trials. The minimum number of habituation trials, therefore, was 5, and the maximum was 16. Infants viewed the test displays three times each in alternation. Order was counterbalanced.

Results and Discussion

Data consisted of log-transformed looking times during test trials. Preliminary analyses revealed no sex differences in performance. A 2 (age) × 2 (condition: experimental vs. control) × 2 (shape: wedge vs. T) × 2 (order: broken vs. complete object first) × 2 (display: broken vs. complete object) mixed analysis of variance (ANOVA) yielded a significant main effect of age, $F(1, 111) = 15.06$, $p < .001$, the result of longer looking by the younger infants. There was also a significant Age × Condition interaction, $F(1, 111) = 3.96$, $p < .05$, a significant Condition × Display interaction, $F(1, 111) = 13.06$, $p < .001$, and a significant Age × Condition × Display interaction, $F(1, 110) = 5.45$, $p < .05$. (The omnibus analysis was repeated omitting infants who did not reach the habituation criterion before viewing the test displays [N = 25]. There was no difference in the overall pattern of outcomes or their interpretation.) Simple effects tests revealed that the preference for the broken objects in the experimental condition was significant for both age groups, $F(1, 111) = 10.42$, $p < .01$ (see Figure 2). The 4-month-olds in the control condition exhibited no significant preference, $F(1, 111) = .06$, *ns*, but the 2-month-olds in the control condition showed a preference for the complete object, $F(1, 111) = 8.63$, $p < .01$. Analyses of looking time recovery (calculated by comparing looking times during test trials to the last habituation trial) revealed that infants in the experimental condition recovered interest more in the broken objects, $t(63) = 3.58$, $p < .01$. The 4-month-olds in the control condition showed no reliable difference in recovery, $t(31) = .72$, *ns*. The 2-month-olds recovered more to the complete object, $t(31) = 2.65$, $p < .05$. There were no reliable interactions as a function of shape, implying similar responses to unity in both the wedge and T displays.

The preference for the broken object by infants in the experimental group suggests that they detected and utilized vertical rotation as information for unity, an effect that is not dependent on the concomitant translation of aligned edges.

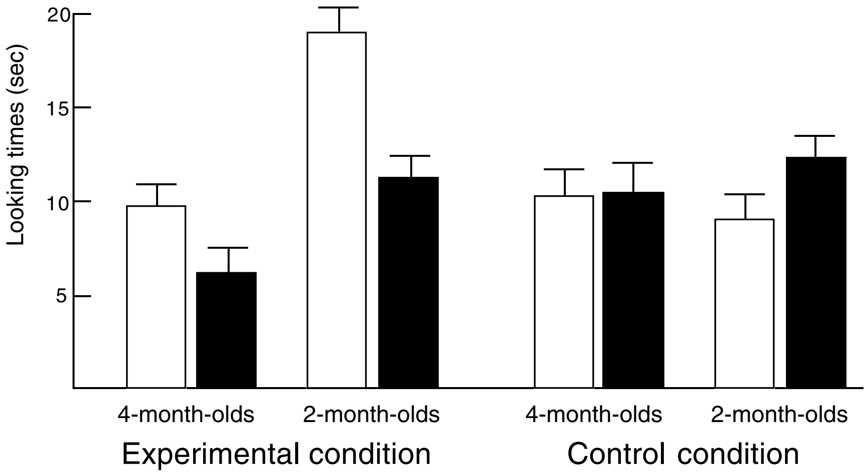

FIGURE 2 Looking times during test from Experiment 1. Infants in the experimental condition (left) were habituated to the partly occluded wedge or T. Both 2- and 4-month-olds looked longer at the broken test shape. There was no reliable difference in performance as a function of stimulus shape (wedge vs. T). Looking times for infants in the control condition are shown at right. The 4-month-olds, as predicted, showed no consistent test display preference. The 2-month-olds unexpectedly looked longer at the complete test display. Possible reasons for this preference were explored in Experiment 2.

Four-month-olds in the control condition exhibited no consistent preference, but, unexpectedly, the younger infants in the control condition looked longer at the complete object.

We consider two possible reasons for this effect. First, Johnson and Johnson (2000) recorded eye movements in infants viewing partly occluded object displays, and noted that 2-month-olds tended to limit scans to the top visible rod part when presentation times were relatively brief, often ending downward saccades at the top edge of the occluder. Older infants scanned both rod parts in more equal measure. It might be, therefore, that the 2-month-olds in the control condition concentrated on the rotating top of the wedge or T during habituation, especially given that only the top object part moved. When viewing test displays, these infants might have scanned vertically more systematically when confronted with the complete object, because its contours continue downward (uninterrupted by the top horizontal box edge), rendering this display more novel and leading to longer looking times. A second possibility is that 2-month-olds perceived the control stimulus as two separate objects, and looked longer at the single test object because it was more novel.

To explore these possibilities, a second experiment was conducted. The paradigm adopted in Experiment 1 was modified such that in the control display, both the top and bottom visible wedge portions rotated out of phase, in opposite directions. Direction of rotation was counterbalanced across trials, but the out-of-phase motion was preserved. (For the experimental condition, the visible wedge parts rotated in-phase, as in Experiment 1, and direction of motion also was counterbalanced across trials.) Because there was motion in both the top and bottom portions of the control stimulus, we expected that the infants would direct their attention more evenly across the display. Again, both 2- and 4-month-olds were observed to explore possible age differences in performance under these conditions.

EXPERIMENT 2

Method

Participants. The final sample consisted of 64 full-term 2- and 4-month-olds (37 girls and 27 boys), with a mean age of 64.5 days (*SD* = 6.6) and 124.3 days (*SD* = 7.8), respectively. An additional 18 infants were observed but not included due to excessive fussiness (11), sleepiness (4), parental interference (1), or experimenter error (2).

Apparatus, stimuli, and procedure. Apparatus, stimuli, and procedure were identical to Experiment 1, except visible wedge parts underwent out-of-phase rotation around the central vertical axis in the control habituation display. On half the trials, the top part rotated clockwise, while the bottom part rotated counterclockwise. On the other half of the trials directions of motion of top and bottom parts were reversed. Direction of rotation was counterbalanced across trials: Within each block of four consecutive trials, there were two instances of each rotation, order determined randomly. In the experimental condition, the visible wedge parts underwent in-phase rotation. Direction of rotation was likewise counterbalanced. Test displays were the same as Experiment 1.

Results and Discussion

A 2 (age) × 2 (condition: experimental vs. control) × 2 (order: broken vs. complete object first after habituation) × 2 (display: broken vs. complete object) mixed ANOVA yielded a significant main effect of age, $F(1, 56) = 4.76$, $p < .05$, the result of longer looking overall by the younger infants, and a significant main effect of condition, $F(1, 56) = 9.84$, $p < .01$, the result of longer looking overall by infants in the experimental group, and a reliable Condition × Display interaction, $F(1, 56) = 10.03$, $p < .01$. (The omnibus analysis was repeated omitting a single infant who did not reach the habituation criterion before viewing the test displays, with no resulting change in the pattern of results or their interpretation.) Simple effects tests revealed a significant preference for the broken object by infants in the experimental group, $F(1, 56) = 8.64$, $p < .01$, but no reliable preference by infants in the control group, $F(1, 56) = 3.19$, *ns*. Infants in the experimental condition recovered interest more to the broken object, $t(31) = 2.68$, $p < .05$. Infants in the control condition exhibited no reliable test display preference, $t(1.78)$, *ns*. (See Figure 3.) These results confirm our earlier conclusion that young infants perceive object unity from vertical rotation. These results also suggest that the unexpected preference for the complete object by 2-month-olds in the control condition of Experiment 1 may have resulted from selective attention to the upper part of the displays.

GENERAL DISCUSSION

Two- and 4-month-olds viewed displays in which a partly occluded wedge or T shape underwent rotation around its vertical axis, and subsequently looked longer at unoccluded broken versions of these displays, suggesting perception of the shapes' unity during habituation. These results indicate that rotational motion can be an important source of information for young infants' perception of object unity and shape, and help to clarify age-related changes that occur in infants' sensitivity to kinetic information.

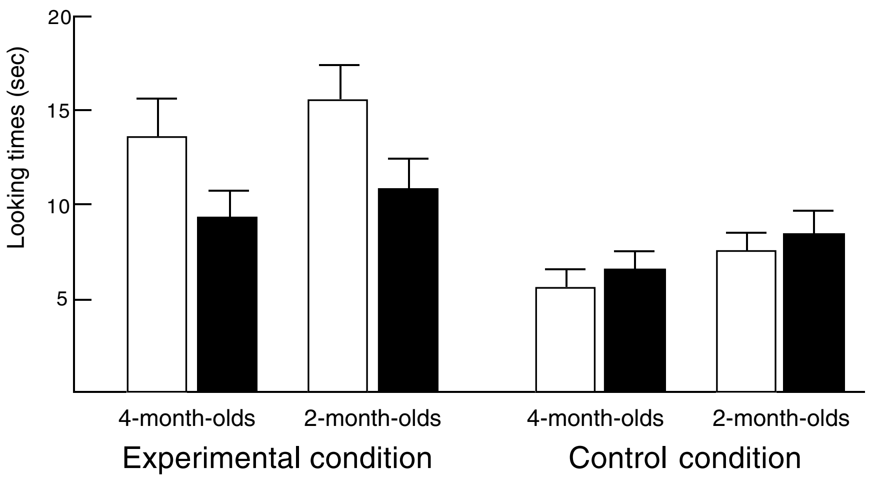

FIGURE 3 Looking times during test from Experiment 2. Infants in the experimental condition (left) were habituated to the partly occluded wedge. Both 2- and 4-month-olds looked longer at the broken test shape. Looking times for infants in the control condition are shown at right. Infants in both age groups consistently did not prefer either test display.

Vertical rotation provides information over time for object structure, and it is part of a larger class of motion known as shear, one of four discriminable types of motion (along with translation, expansion, and rotation in the frontoparallel plane; Regan, 1986). Shear is defined as relative motion in spatially adjacent areas: (a) motion of points in the image in opposite directions, (b) motion in the same direction at different speeds, or (c) moving versus stationary points. Shear specifies object *borders*, such as the border between a moving partly occluded object and its occluder, and it is a common feature of stimuli employed in this report and past investigations of infants' perception of object unity. Shear can also specify object *boundaries* (i.e., the outer contours of individual objects) but until recently, little evidence was available that very young infants use shear to perceive shape, and no evidence was available concerning unity. Indeed, past evidence has indicated that infants' perception of shear in structure-from-motion tasks lags behind sensitivity to translation, expansion, and frontal rotation by several weeks or even months (see Banton & Bertenthal, 1997, for review). For example, infants appear largely insensitive to biological motion until 3 months after birth (Bertenthal, Proffitt, & Kramer, 1987), but responses to translation are present several weeks earlier (Aslin & Johnson, 1996; Banton & Bertenthal, 1996).

The findings of these experiments are consistent with several recent reports suggesting that 2-month-olds are sensitive to relative motion as information for three- and two-dimensional shape of objects (Arterberry & Yonas, 2000; Johnson & Mason, 2002), evinced by a robust ability to perceive surface and object shape in random-dot kinematograms. Our findings are consistent as well with the notion that 2-month-olds perceive object unity in displays in which there is sufficient visual information, provided in this case by rotation and in past reports by translation, but only if the occluding gap is narrow (cf. Johnson & Aslin, 1995). Nevertheless, our results serve to highlight an important limitation in infants' unity perception, which is challenged by frontal rotation (Eizenman & Bertenthal, 1998). Frontal rotation may present special difficulties in visual tasks, relative to translation: Image points in rotation displays move in several directions at different rates, but image points on a rigidly translating object move in only one direction at the same rate. Integration of these motions to yield coherent percepts, therefore, may require more sophisticated information processing skills in rotation displays, relative to translation. Alternatively, the difficulty with frontal rotation, relative to translation, may be rooted in underlying differences in maturational rates of separate motion processing pathways in the cortex (Banton & Bertenthal, 1997).

Finally, consider the fact that our rotation displays furnished a redundancy of cues: In addition to relative motion, object shape was specified by contour deformation and changes over time in shading of visible surfaces. Contour deformation (i.e., changes in the outer contour of an object as it rotates) provides information for both object shape and axis of rotation when presented in isolation to adult observers (Cortese & Andersen, 1991), but to our knowledge, infants' use of contour deformation to perceive shape remains unexplored. Adults also readily achieve perception of shape from shading cues (e.g., Langer & Bülthoff, 2000), and 7-month-olds have been found to use shading as a depth cue (Granrud, Yonas, & Opland, 1985). However, 5-month-olds provided no evidence of sensitivity to shading as a depth cue, and its contribution to infants' shape perception is unknown. We have few insights, therefore, into the individual contributions of contour deformation and shading changes to young infants' object percepts, nor into how sensitivity to these cues changes with development. Nevertheless, the outcomes of these experiments suggest that the infants may have capitalized on the richness of the information provided by these cues, in addition to relative motion, in perceiving object unity.

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REFERENCES

Arterberry, M. E., & Yonas, A. (2000). Perception of three-dimensional shape specified by optic flow by 8-week-old infants. *Perception & Psychophysics, 62,* 550–556.

Aslin, R. N., & Johnson, S. P. (1996). Suppression of the optokinetic reflex in human infants: Implications for stable fixation and shifts of attention. *Infant Behavior and Development, 19,* 233–240.

Banton, T., & Bertenthal, B. I. (1996). Infants' sensitivity to uniform motion. *Vision Research, 36,* 1633–1640.

Banton, T., & Bertenthal, B. I. (1997). Multiple developmental pathways for motion processing. *Optometry and Vision Science, 74,* 751–760.

Bertenthal, B. I., Proffitt, D. R., & Kramer, S. J. (1987). Perception of biomechanical motions by infants: Implementation of various processing constraints. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 577–585.

Cortese, J. M., & Andersen, G. J. (1991). Recovery of 3D shape from deforming contours. *Perception & Psychophysics, 49,* 315–327.

Cutting, J. E., & Vishton, P. M. (1995). Perceiving layout: The integration, relative potency, and contextual use of different information about depth. In W. Epstein & S. Rogers (Eds.), *Handbook of perception and cognition: Vol. 5. Perception of space and motion.* San Diego, CA: Academic.

Eizenman, D. R., & Bertenthal, B. I. (1998). Infants' perception of object unity in translating and rotating displays. *Developmental Psychology, 34,* 426–434.

Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston: Houghton Mifflin.

Gibson, J. J. (1979). *The ecological approach to visual perception.* Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Granrud, C. E., Yonas, A., & Opland, E. A. (1985). Infants' sensitivity to the depth cue of shading. *Perception & Psychophysics, 37,* 415–419.

Johnson, S. P., & Aslin, R. N. (1995). Perception of object unity in 2-month-old infants. *Developmental Psychology, 31,* 739–745.

Johnson, S. P., & Aslin, R. N. (1996). Perception of object unity in young infants: The roles of motion, depth, and orientation. *Cognitive Development, 11,* 161–180.

Johnson, S. P., & Johnson, K. L. (2000). Early perception-action coupling: Eye movements and the development of object perception. *Infant Behavior and Development, 23,* 461–483.

Johnson, S. P., & Mason, U. (2002). Perception of kinetic illusory contours by 2-month-old infants. *Child Development, 73,* 22–34.

Johnson, S. P., & Náñez, J. E. (1995). Young infants' perception of object unity in two-dimensional displays. *Infant Behavior and Development, 18,* 133–143.

Jusczyk, P. W., Johnson, S. P., Spelke, E. S., & Kennedy, L. J. (1999). Synchronous change and perception of object unity: Evidence from adults and infants. *Cognition, 71,* 257–288.

Kellman, P. J. (1984). Development of three-dimensional form by human infants. *Perception & Psychophysics, 36,* 353–358.

Kellman, P. J., & Spelke, E. S. (1983). Perception of partly occluded objects in infancy. *Cognitive Psychology, 15,* 483–524.

Langer, M. S., & Bülthoff, H. H. (2000). Depth discrimination from shading under diffuse lighting. *Perception, 29,* 649–660.

Regan, D. (1986). Visual processing of four kinds of relative motion. *Vision Research, 26,* 127–145.

Smith, W. C., Johnson, S. P., & Spelke, E. S. (2003). Motion and edge sensitivity in perception of object unity. *Cognitive Psychology, 46,* 31–64.