

Perceptual Completion in Newborn Human Infants

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Despite decades of studies of human infants, a still open question concerns the role of visual experience in the development of the ability to perceive complete shapes over partial occlusion. Previous studies show that newborns fail to manifest this ability, either because they lack the visual experience required for perceptual completion or because they fail to detect the pattern of motion. To distinguish these possibilities, newborns' perception of a center-occluded object was tested, using stroboscopic motion. Infants (mean age of 72 hr) perceived the object as a connected unit, providing the first evidence that the newborn is capable of filling in gaps in the visible surface layout when the relevant visual information can be detected by his or her immature visual system.

Many visible objects are partly occluded by other objects, but visual arrays are perceived not as partial images but rather as complete entities that extend into places where they are hidden. Perception of complete and unitary objects depends crucially on the ability to fill in gaps induced by occlusion. To perceive a partly occluded object, for example, an observer must register its missing portion using available information from the visible segments, including their shape, position, orientation, motion, relative distance, luminance, color, and texture (Johnson, 2005). Such tasks usually pose little difficulty for adults, who readily report veridical object perception under most viewing conditions (Kellman & Shipley, 1991).

A fundamental question concerns the role of visual experience in the development of the human capacity to perceive object unity. Many studies reveal that human infants have gained this capacity by 2–4 months of age. After habituation to a moving rod with its center occluded by a box, for example, infants look longer at a nonoccluded presentation of a broken rod, whose portions correspond to the visible portions of the rod presented during familiarization, than at a complete rod (Johnson & Aslin, 1995, 1996; Johnson & Nájuez, 1995; Jusczyk, Johnson, Spelke, &

Kennedy, 1999; Kellman & Spelke, 1983; Slater et al., 1990). Therefore, like adults, infants experience a partly occluded moving rod as more similar to a complete object than to a set of visible fragments. For infants, knowledge of objects goes beyond direct immediate perception. Furthermore, these experiments indicate that common rigid motion provides the critical information used by infants to specify object unity beyond direct, immediate perception.

In contrast, newborn infants have not been observed to show this test preference (Slater et al., 1990; Slater, Johnson, Brown, & Badcock, 1996; Slater, Johnson, Kellman, & Spelke, 1994; Valenza, Zulian, & Leo, 2005). This result provides evidence that newborn infants fail to experience a partly occluded moving rod as complete and unitary. Together, these findings suggest that basic capacities for object perception develop over the first 4 months of postnatal life.

Two contrasting accounts of these findings have been offered. One explanation is that perception of object unity depends on visual experience. Although newborn infants detect the visual cues that specify object unity, they must learn that those cues serve to link separated edges across a spatial gap (Johnson, 2004, 2005; Mareschal & Johnson, 2002). This learning takes place over the first 4 months, as infants observe objects moving in and out of view.

A second explanation is that infants are predisposed from birth to experience objects as bounded, coherent, and continuous across time and space, when objects undergo common motion (Johnson, 2004, 2005; Mareschal & Johnson, 2002). This predisposition is masked in newborn infants, however, because of poor perceptual skills that do not allow newborn infants to detect patterns of common motion over a spatial gap. For these reasons, infants' latent

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object knowledge is expressed only later in development, when they become sensitive to the informative patterns of visual motion (Condry, Smith, & Spelke, 2000; Spelke & Newport, 1998a).

Each of these views has received indirect support from experiments on newborn infants. In support of the view that object perception depends on visual experience, one series of experiments provides evidence that newborn infants who are habituated to a center-occluded rod show the opposite test preference from older infants: They generalize habituation from a center-occluded object to a broken object display. This finding suggests that newborn infants perceive a center-occluded object as a set of distinct, visible fragments, and therefore as more similar to a broken object than to a complete object (Slater et al., 1990, 1994, 1996; Valenza et al., 2005). If infants were unable to detect the object's common motion, they should have shown no preference between the test displays, as do older infants when presented with stationary displays (Kellman & Spelke, 1983).

In support of the view that object perception is masked in newborns because of their poor motion sensitivity, numerous studies provide evidence that sensitivity to motion undergoes dramatic change in the first few months of postnatal life. The commonplace observation that newborns readily attend to moving visual stimuli might suggest that motion sensitivity is already quite mature at birth. However, the ability to distinguish between moving and stationary stimuli may reflect sensitivity to temporal modulation rather than motion as such (Wattam-Bell, 1996). This hypothesis is supported by the fact that newborns show a visual preference for dynamic stimuli that do not move, such as flickering or flashing stimuli (Regal, 1981). Full use of motion information requires sensitivity to speed and direction. Behavioral (Aslin, Shea, & Gallipeau, 1988; Dannemiller & Freedland, 1989; Kaufmann, Stucki, & Kaufmann-Hayos, 1985) and neurophysiologic (Berthenthal & Bradbury, 1992; Freedland & Dannemiller, 1987; Norcia et al., 1991) evidence indicates that sensitivity to the directionality of motion is poorly developed before about 2 months of age, and it might be absent in newborns (Wattam-Bell, 1991, 1993, 1996). Immature cortical motion processing is also indicated by asymmetries in the visual-evoked potentials of infants (Hamar & Norcia, 1994). Developmental changes in motion processing may therefore provide a sufficient explanation for newborn infants' failure to use motion to perceive object unity.

Furthermore support for the view that capacities for object perception are present in young infants, but masked by immature perceptual skills, comes

from studies of developmental changes in infants' eye movements and scanning patterns. Eye movement control undergoes large changes in the first months of life. Although infants younger than 2 months possess sufficient oculomotor control to allow for inspection of static visual scenes (Hainline, 1998), the visuomotor ability to track a moving stimulus improves in the first months of life (Johnson, 1990). When newborn infants track a moving visual stimulus, they perform a series of saccadic eye movements and tend to lag behind the stimulus, rather than predicting its trajectory. This behavior, unlike that of older infants and adults, is not smooth, but is saccadic in nature because eye movements typically fall behind the movement of the stimulus and rarely appear to anticipate its future location: a pattern characteristic of a subcortical oculomotor pathway (Johnson, 1990). Between 2 and 4 months, infants improve their scanning of partly occluded objects. Younger infants are less likely to scan the entire stimulus, and they limit their fixations to the top portion of the configuration. In contrast, older infants produce larger and more frequent movements to explore both the top and the bottom parts of the stimulus (Johnson & Johnson, 2000). These robust age differences suggest that the visual scanning of very young infants is insufficient to allow the extraction of the visual information for object unity.

Moreover, it has been suggested that there is a developmental progression in the perception of object unity from different types of object motion (Eizenman & Berthenthal, 1998). Not all types of motion are equally informative for infants at all ages. For example, the information presented by a translating object is sufficient for perception of object unity by 4-month-old infants, but at the same age infants are not sensitive to the continuity of a rotating object (Eizenman & Berthenthal, 1998). Similarly, 6-month-old infants perceive the unity of a partially occluded rotating rod, but not if it is oscillated (Eizenman & Berthenthal, 1998). These findings suggest that all types of common motion are not equivalent for specifying infant's perception of occluded object.

Because of these conflicting and indirect findings, the origin of object perception in humans has remained obscure despite decades of research. Some investigators have doubted that these origins ever could be elucidated through studies in humans, because newborn infants' sensory and oculomotor skills are too immature to allow for appropriate testing of their perceptual and cognitive capacities (Spelke & Newport, 1998a, 1998b).

Recent findings, however, suggest a way out of this impasse. Although newborn infants have

limited abilities to perceive and track continuous motion, they may be more sensitive to flicker and stroboscopic motion (Farroni, Simion, Umiltà, & Dalla Barba, 2000; Goldberg, Maurer, & Lewis, 1997; Taga, Asakawa, Hirasawa, & Konoshi, 2003; Vehrs & Baum, 1971). Stroboscopic motion, a movement elicited by presenting the same object in temporally and spatially discontinuous positions, is mediated by subcortical structures that are active at birth (Bronson, 1990; Goldberg & Wurtz, 1972; Rock, Taube, & Heller, 1965). Stroboscopic motion of a center-occluded object, therefore, may be more detectable by newborn infants than continuous motion because newborns are not required to switch their visual gaze to track the trajectory of a moving stimulus, but only to make several saccades to keep the image of the target stable on the fovea. In other words, we expect that the responses of newborn infants to stroboscopic motion differ from those to continuous motion because compared with continuous motion, the stroboscopic motion does not require smooth pursuit. In that case, experiments presenting a center-occluded object in stroboscopic motion may serve to test whether mechanisms of object perception are functional in humans at the beginning of postnatal life, before any shaping effects of experience with the visible environment.

Five experiments were conducted to test this possibility. The first experiment tested newborn infants' perception of a continuously moving, center-occluded object. The primary aim of this study was to replicate newborn infants' failure to perceive object unity from a pattern of continuous motion using two different procedures. In Experiment 1, we attempted to replicate previous findings that newborn infants fail to perceive the unity of a center-occluded object in continuous motion (Slater et al., 1990, 1994, 1996).

Given that previous findings were replicated, the remaining experiments focused on newborn infants' perception of a center-occluded object whose visible ends underwent a pattern of stroboscopic motion. Experiment 2 tested whether newborn infants detect stroboscopic motion in a center-occluded object display. Experiments 3 and 4 investigated whether such infants use a pattern of stroboscopic motion to perceive the unity and connectedness of the object behind the occluder. Finally, Experiment 5 tested whether synchronous common motion of two separate parts is necessary for perception of object unity at birth or whether the results of previous experiments could be explained by the fact that newborn's attention is drawn to and focused exclusively by motion to only a simple portion of the stimulus above or below the box.

Experiment 1a

Experiment 1a investigated whether newborn infants perceive a partly occluded rod as connected when it undergoes a continuous, translatory motion behind an occluder box. We used the same method as past studies of newborn infants' perception of partly occluded objects in which newborn infants are habituated to a single central moving partly occluded rod. During the novelty-preference test, two moving unoccluded paired stimuli were presented: a complete rod and a broken rod with a gap at the place where the occluding rectangle was placed during the habituation phase. Both the complete and broken rod test displays moved with the same translatory motion as the habituation display. If infants perceived the center-occluded rod as one connected object, they should look longer at the broken test display. If they perceived the center-occluded rod as two visible surface fragments, they should look longer at the complete test display. If their perception of the object's boundaries was indeterminate, they should look equally at the two test displays.

Method

Participants. Eighteen healthy (10 males), full-term newborn infants were selected from the maternity ward of the Pediatric Clinic of the University of Padova. They were middle-class infants and 92% of them were Caucasian, 6% African, and 2% Asian. Two infants were not included in the final sample because of failure to maintain the desired state (1) or a strong position bias during the preference test phase (more than 80% to one direction: (1). Thus, the final sample consisted of 16 infants. All newborns met the screening criteria of normal delivery, a birth weight between 1.995 and 3.880 kg, and an Apgar score of at least 8 at 5 min. Infants were tested only if they were awake and in an alert state. Their ages at the time of testing ranged from approximately 26 to 120 hr ($M = 69$). Informed consent was obtained from their parents.

Stimuli. The partly occluded rod (14.5 cm high \times 3 cm wide) was located behind a rectangular box (2 cm high \times 8.3 cm wide). At the newborn's viewing distance (about 30 cm), each visible surface of the rod subtended a visual angle of 27.7° (length) and 5.7° (width), and the box subtended angles of 15.8° (horizontally) and 3.8° (vertically). The rod moved 2.5 cm to the right and to the left of the center of a rectangular box, with a continuous movement. Thus, the rod moved back and forth behind the occluder for a total of 5 cm (10°).

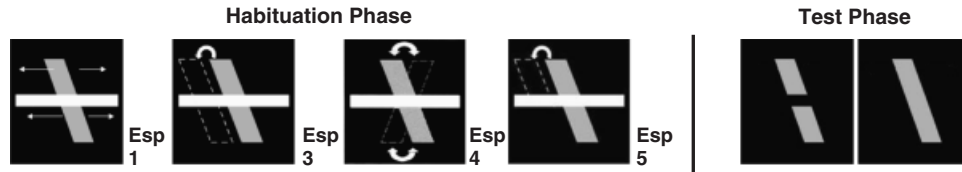


Figure 1. Stimuli presented in Experiments 1, 3, 4, and 5, respectively. Test displays were identical in all experiments except for the motion pattern: either the complete or the broken bars moved with the same motion of the rod in the habituation display.

Test displays, presented without the occluder, were a complete or broken rod moving with the same translatable motion of the rod in the habituation display (Figure 1). The broken rod corresponded exactly to the visible portions of the rod presented during the habituation phase.

Apparatus. Using a Macintosh computer, the partly occluded rod was presented on a single computer monitor. The same computer recorded looking time judgments, and calculated the habituation criteria for each infant, who sat on a student's lap in front of a black panel. The panel had two squared holes where the black screens of two computer monitors appeared. The horizontal midline of the stimuli was aligned with a red flickering LED that was located in the center of the panel, between the screens. At the start of each trial, the LED was used both to attract the infant's gaze and to check that the infant's sight was level with the horizontal midline of the panel during the testing session. To prevent interference from irrelevant distracters, peripheral vision was limited by two panels placed on both sides of the infant.

Procedure. Testing began as soon as the newborn looked at the center of the monitor. An experimenter, who watched the infant's eyes by means of a video-monitor system, pressed a key on the notebook keyboard projecting the stimulus on the monitor. Newborns were tested with an infant control habituation procedure (Horowitz, Paden, Bhana, & Self, 1972). During the habituation phase, the stimulus remained on the screen until a look-away criterion was met. Habituation was established by recording the duration of individual fixations. The duration of each fixation on the stimulus was recorded by pressing one of two buttons connected to the computer, depending on whether the infant looked at the right or left side of the display. Each trial ended when a continuous look away from the stimulus was 2 s or more. Trials repeated in this manner until, from the fourth trial on, the sum of fixations on any 3 consecutive trials was 50% or less than the total of the first 3 trials. When the habituation criterion was reached, the habituation phase was terminated

and the preference test phase began. This phase consisted of 2 trials in which two stimuli were presented. Stimuli were always shown in either left or right positions, the position being reversed from test trial 1 to test trial 2. The initial left-right order of presentation was counterbalanced across subjects. Presentation lasted until each stimulus had been fixated at least once and a total of 20 s of looking had been accumulated.

Results

Habituation score. The average total looking time to habituate to the stimuli was 41.83 s ($SD = 17.6$ s; range = 21.2–87.9), and the average number of trials to reach the criterion was 8 ($SD = 2.1$; range = 6–14).

Preference test score. Newborns oriented equally often toward the two test stimuli ($M = 8$ number of orienting toward the complete and the broken stimuli), but they tended to look slightly longer at the complete stimulus ($M = 23.3$ s, $SD = 5.8$ s; range = 13.3–37.5) than at the broken one ($M = 19.6$, $SD = 5.9$; range = 10.3–30.7). The percentage of total looking time devoted to the complete stimulus was 54.25 ($SD = 12.9$), and did not significantly differ from chance (50%), $t(15) = 1.319$, $p = .21$, one tailed.

Discussion

The results of Experiment 1a, like those of previous findings (Slater et al., 1990, 1994, 1996), suggest that newborns fail to perceive a partly occluded rod as connected when it moves with a continuous translatable motion. Although Experiment 1a provided no evidence for perception of object unity, it could be argued that the method used by that experiment is not optimally sensitive.

Experiment 1b

In Experiment 1b, we presented two peripheral rod and box displays, at the left and right sides of a central fixation point. Side-by-side rather than central presentation was adopted for two reasons. First,

photoreceptors in the central fovea are very immature at birth, resulting in poor vision in the central area of visual field (Abramov et al., 1982; Atkinson & Braddick, 1989). Second, it is difficult for an observer to decide whether infants are actually looking at a single, central stimulus or rather are simply staring at the same position where they were looking at before the stimulus appeared. For these reasons, we replicated Experiment 1a using side-by-side rather than central presentation.

Method

Participants. Fifteen healthy (8 males), full-term newborn infants were selected from the maternity ward of the Pediatric Clinic of the University of Padova. They were middle-class infants and 88% of them were Caucasian, 6% African, and 6% Asian. All newborns met the screening criteria of normal delivery, a birth weight between 2.010 and 4.100 kg, and an Apgar score of at least 8 at 5 min. Infants were tested only if they were awake and in an alert state. Informed consent was obtained from their parents.

Stimuli, apparatus, and procedure. We used the same stimuli presented in Experiment 1a. The only difference was that the computer-generated displays were presented by two monitors so that newborns were presented with a paired of images, either during the habituation or the preference test phase.

Results

Habituation score. The average total looking time to habituate to the stimuli was 53.79 s ($SD = 13.8$ s; range = 31.99–77.84), and the average number of trials to reach the criterion was 8 ($SD = 2$; range = 6–12).

Preference test score. Newborns oriented equally toward the test stimuli ($M = 6$ number of orienting toward the complete and the broken stimuli), but they tended to look longer at the complete stimulus ($M = 26.08$ s, $SD = 4.5$; range = 19.2–36.7) than at the broken one ($M = 21.7$, $SD = 6.7$; range = 8.2–33.7). The percentage of total looking time that was devoted to the complete stimulus was 55.2 ($SD = 11.3$), which did not significantly differ from chance (50%), $t(14) = 1.78$, $p = .10$, one tailed.

To test whether the percentage of total looking time to the complete stimulus observed in Experiment 1a differed from that observed in Experiment 1b, a t test for independent samples were calculated. The test revealed no significant difference, $t(29) = 0.22$, $p = .83$.

Discussion

The results of Experiment 1b replicate those of Experiment 1a and show that newborns are not able to perceive a partly occluded rod as connected when it moves with a translatory motion behind an occluder. More intriguing, the findings of Experiment 1b rule out the hypothesis that newborn's failure to perceive object unity might be due to the familiarization procedure used (one central rod vs. two peripheral rods) and support the idea that a deficit to detect common motion prevents newborn infants from perceiving object unity.

In contrast to previous findings, Experiment 1 provides no evidence that newborn infants perceive the moving, center-occluded object as two separate visible fragments. This is because habituation to the occlusion display was not followed by a reliable preference for the complete test display. A possible interpretation, therefore, might be that newborn infants perceived the boundaries of the center-occluded object as indeterminate between a complete and a broken object. Because older infants perceive center-occluded objects as indeterminate when they are stationary, this finding is consistent with the hypothesis that newborn infants' failure to perceive the unity of the center-occluded object stems from a failure to perceive the common motion of the two visible surface fragments.

Experiment 2

Experiment 2 investigated whether newborns detect and prefer a stroboscopically moving, center-occluded object over a stationary, center-occluded object. Newborn infants were presented with two center-occluded objects, side by side, that were identical except for their motion: one object appeared in stroboscopic motion whereas the other was stationary. In one condition, the stroboscopic motion presented a displacement similar to that of Experiment 1: a horizontal, translatory motion. In a second condition, the stroboscopic motion presented a horizontal, oscillatory motion. Based on the findings of past studies of motion sensitivity (Bronson, 1990; Farroni et al., 2000; Goldberg & Wurtz, 1972; Goldberg et al., 1997; Rock et al., 1965; Taga et al., 2003; Vehrs & Baum, 1971), it was hypothesized that newborn infants under both conditions would look longer at the stroboscopically moving object, demonstrating sensitivity to stroboscopic motion in partial occlusion displays.

Method

Participants. Twenty-nine healthy (14 males), full-term newborn infants were selected from the

maternity ward of the Pediatric Clinic of the University of Padova. They were middle-class infants and 96% of them were Caucasian, and 4% Asian. Four infants were removed from the study: 3 infants because they failed to maintain the desired state and another 1 because he showed a strong position bias during the preference test phase. The final sample therefore consisted of 25 infants, randomly assigned to two different test conditions: 14 to the translatory motion condition and 11 to the oscillatory motion condition. All infants met the screening criteria of normal delivery, a birth weight between 2.400 and 2.940 kg, and an Apgar score of at least 8 at 5 min. As in Experiment 1, infants were tested during the hour before the scheduled feeding time only if they were awake and in an alert state. The mean newborns' age at the time of testing was 48 hr for infants of Group 2A, and 41 hr for infants of Group 2B. Informed consent was obtained from their parents.

Stimuli. Two partially occluded rods, each of the same dimensions as in Experiment 1, were presented. Each rod moved with a stroboscopic motion, consisting of two successive changes of stimulus position that led to the perception of continuous motion. Specifically, under the translatory motion condition, the partially occluded rod appeared in the center and at the left side of the occluder. The distance between the central and the peripheral partly occluded rods was 1.5 cm (3°). As the partially occluded rod in the central position flashed on and off, the partially occluded rod in the peripheral position flashed off and on. Each stimulus was onset shortly after the other was offset, but it stopped in the same position for a short period of time (500 ms), so that an adult would perceive a rod that "jumps" back and forth from the center to the side of the occluder.

In the oscillatory motion condition, the rod moved with a stroboscopic oscillatory motion. The partially moving rod was alternatively presented right in the center of the occluder and oriented at the left or the right side. The oscillatory motion occurred at the same rate and distance as for the stroboscopic translatory motion.

Apparatus. The apparatus was identical to that used in the previous experiment.

Procedure. Newborns were tested with a visual preference test: As soon as the infant fixated on the LED, the coder started the sequence of trials. When the infant shifted his/her gaze from the display for more than 10 s, the experimenter turned off the stimuli and the central LED automatically started flickering again. The coder, who was unaware of the hypotheses being tested and of the stimuli presented,

recorded the duration of each fixation by pressing one of two buttons depending on whether the infant looked at the right or left position.

Results

Preference test score. The average number of fixations to orient toward the two stimuli and the average total looking time to attend to the stimuli were calculated for each group. Under both test conditions, newborns orient more frequently toward the moving than toward the static partially occluded rod. In the translatory motion condition, the average number of fixations was 13 ($SD = 3$; range = 8–21) for the moving rod and 9 ($SD = 5$; range = 4–21) for the stationary rod, $t(13) = 4.374$, $p < .01$. In the oscillatory motion condition, the average number of fixations were 8 ($SD = 3$; range = 5–12) for the moving rod and 6 ($SD = 2$; range = 3–10) for the stationary rod, $t(10) = 1.814$, $p < .1$.

Under both the test conditions, newborns looked longer at the moving than at the static display: newborns fixated for 82.5 s ($SD = 21.2$; range = 44–122 s) and 75.4 s ($SD = 21.2$; range = 47–110 s) on the translatory and oscillatory stimuli, respectively, whereas they fixated on the static stimulus for 43.8 s ($SD = 20.3$; range = 15.9–80.2) in the translatory motion condition and 28.8 s ($SD = 17.7$; range = 7–50 s) in the oscillatory motion condition. To test the reliability of this preference for moving stimulus, looking times were converted to percentage scores as in Experiment 1. The mean preference score was 65.8% ($SD = 13.9$) in the translatory motion condition, $t(13) = 4.244$, $p < .05$, and 72.9% ($SD = 11.4$) in the oscillatory motion condition, $t(11) = 6.677$, $p < .05$. The preference scores obtained in two test conditions did not differ significantly, $t(23) = 1.373$, $p = .45$. Infants in each of the test conditions showed a reliable preference for the moving over the stationary display.

Discussion

The findings of Experiment 2 provide evidence that newborn infants are sensitive to stroboscopic motion. Infants detect and prefer stroboscopic motion even when the motion occurs only on the surfaces of an object that is partly hidden by a central occluder. Newborn infants therefore attended to the surfaces of center-occluded objects and detected their motion. The following two experiments accordingly investigated whether infants use the detectable stroboscopic motion to perceive a unitary object that is partially occluded.

Experiment 3

Experiment 3 followed the method of Experiment 1b, using a rod and box display in which the rod moved laterally behind the occluder with stroboscopic instead of continuous motion. After habituation to this display, infants were tested with complete and broken test displays that again were presented in stroboscopic motion. As stroboscopic motion is detected by newborn infants in these displays, Experiment 3 serves to test whether newborn infants are capable of perceiving the complete shape of a partly occluded object. If they can link the two separate parts, then infants who are habituated to the center-occluded display should look longer at the broken test display. If they cannot, then infants should look equally at the broken and complete test displays, as in Experiment 1. To avoid the possibility that newborns have spontaneous preference for one test display over the other, even without being exposed to the habituation phase of the experiment, a baseline control condition was included. If no baseline preference exists, we can assume that the differences in looking at the test stimuli in the experimental condition are caused by the stimulus presented to the newborns during the habituation phase of the study.

Method

Participants. Thirty-three newborn infants (12 males) were recruited as in the previous experiments, but 3 of them were not included in the final sample because of state changes (1 infant) or a position bias (2 infants). Newborns were middle-class infants and 95% of them were Caucasian, 2% African, and 3% Asian. The final sample therefore consisted of 30 healthy, full-term newborns with a birth weight between 3.000 and 4.120 kg, an Apgar score of at least 8 at 5 min, and a mean age of 64 hr randomly assigned to two different test conditions: 15 to the experimental condition (Group 3A) and 15 to the control condition (Group 3B).

Stimuli and apparatus. The rod and box display from Experiment 1 was used in an apparatus that was identical to that of previous experiments. The only differences between the stimuli used in Experiment 1 and those presented in Experiment 3 concerns motion: In Experiment 3 the rods underwent a stroboscopic translatory motion (Figure 1).

Procedure. Infants were randomly assigned to the experimental or control condition, with 15 subjects in each. The conditions differed only with respect to the habituation phase. For Group 1A (experimental

condition), testing began with the central flickering LED. As soon as the infant's gaze was properly aligned with the LED, the habituation was initiated by a second experimenter who watched the infant's eyes by means of a video-monitor system. The start of habituation automatically turned off the central LED and activated the onset of the stimuli. The same stroboscopically moving, center-occluded rod was projected bilaterally, to the left and the right of the central LED. When the habituation criterion was reached, a complete rod and a broken rod, both moving with the same motion as in the habituation display, were shown. As in Experiment 1, the initial left-right order of presentation was counterbalanced across subjects and the presentation lasted until the infant has fixated on each stimulus at least once, and a total of 20 s of looking had been accumulated.

For Group 3B (control condition), we used the same procedure adopted during the test phase of Group 3A, but without prior habituation: Each subject was shown two paired stimuli for 2 trials. Each trial continued until at least 20 s of looking had accumulated; the left/right positions of the stimuli were changed from trial 1 to trial 2. The order of presentation across trials was counterbalanced across subjects.

Results

Habituation score. The average total looking time to habituate to the stimuli was 68.9 s ($SD = 19.1$). The average number of trials to reach the criterion was 7 ($SD = 2$).

Preference test score. The average number of fixations to orient toward the two stimuli and the average total looking time to attend to the stimuli were calculated separately for the experimental and control conditions. For the experimental condition, the average number of fixations was 4 ($SD = 2$; range = 2–8) toward the complete rod and 5 ($SD = 2$; range = 2–8) toward the broken rod. For the control condition, the average number of fixations was 6 ($SD = 5$; range = 4–21) for the complete rod and 7 ($SD = 2$) for the broken rod. Newborn infants, therefore, oriented equally toward the test stimuli under both the test conditions.

In contrast, newborn infants looked longer at the broken stimulus ($M = 38.1$ s, $SD = 17.1$) than at the complete stimulus ($M = 19.0$, $SD = 7.1$) under the experimental conditions, whereas newborns infants in the control condition showed no preference between the two test stimuli ($M = 22.8$, $SD = 6.2$ and $M = 22.4$, $SD = 6.4$ for the broken and the complete rod, respectively).

More specifically, infants in the experimental condition showed a significant preference for the broken rod ($M = 65.3\%$, $SD = 12.6$; chance = 50%), $t(14) = 4.732$, $p < .05$, (one tailed), whereas those in the control condition did not ($M = 49.4\%$, $SD = 13.8$), $t(14) = 0.160$, $p = .88$, one-tailed. A t test for independent samples revealed a significant difference between the two groups, due to the presence or the absence of the habituation phase, $t(28) = 3.307$, $p < .005$.

Discussion

After habituation to a center-occluded rod undergoing stroboscopic translatory motion, infants showed a reliable preference for a broken rod over a complete one. This preference does not reflect a natural or spontaneous preference for the broken bar, because no preference was present in newborns who viewed the same test displays with no prior habituation. Therefore, the findings of Experiment 3 indicate that even newborns are able to perceive the unitary, complete shape of a partly hidden object, when the aligned parts of the object undergo a common simultaneous stroboscopic motion. Previous failures to demonstrate this ability in newborn infants likely stem from limitations of infants' motion processing, rather than to limits of their capacities to perceive object unity.

The next experiment investigated whether newborn infants show the same abilities when presented with a more complex pattern of motion. It has previously been demonstrated that, at 4 months of age, infants have shown inconsistent abilities to perceive the unity of an object that undergoes an oscillatory motion (Eizenman & Berthenthal, 1998; Kellman & Spelke, 1983). In light of the present findings, one may ask whether this failure also stems from a failure to detect the relevant motion information. As the results of Experiment 2 demonstrate that newborn infants detect the stroboscopic oscillatory motion, Experiment 4 was aimed at investigating newborn infants' perception of the unity of a center-occluded object that undergoes a stroboscopic oscillatory motion.

Experiment 4

Experiment 4 replicated Experiment 3, with the only exception that objects undergo an oscillatory motion consisting of alternating presentations of the partially occluded rod in the center of the occluder that alternately oriented toward the left or the right side.

To avoid interference of spontaneous preference, infants were randomly assigned to the experimental

or the control condition. The conditions differed only with respect to the habituation phase.

Method

Participants. The same criteria used in the previous experiments were adopted. Thirty-nine newborns (18 males) were recruited as in the previous experiments, but 6 of them were not included in the final sample because of state changes (4 infants), or technical errors (2 infants). The final sample therefore consisted of 33 healthy, full-term newborns with a birth weight between 2.700 and 4.800 kg, an Apgar score of at least 8 at 5 min, and a mean age at the time of testing of 53 hr, randomly assigned to two different test conditions: 16 to the experimental condition (Group 4A) and 17 to the control condition (Group 4B). They were middle-class infants, and 96% of them were Caucasian, 2% African, and 2% Asian.

Stimuli. The only difference between the stimuli used in Experiment 3 and those presented in Experiment 4 concerns the kind of motion: In Experiment 3 the rod underwent a translatory stroboscopic motion, and in Experiment 4 the rod moved with an oscillatory stroboscopic movement (Figure 1).

Apparatus and procedure. They were identical to the previous experiment.

Results

Habituation score. The average total looking time to habituate to the stimuli was 75.01 s ($SD = 48.4$), and the average number of trials to reach the criterion was 8 ($SD = 3$).

Preference test score. The average number of fixations to orient toward the two stimuli and the average total looking time to attend to the stimuli were calculated separately for the experimental and the control conditions. The average number of fixations was 6 ($SD = 4$) and 7 ($SD = 2$) for the broken and the complete rods, respectively, in the two conditions. Under both the conditions, newborns tended to orient equally to the two stimuli.

In contrast, infants in the experimental condition looked longer at the broken stimulus ($M = 28.6$, $SD = 8.8$) than at the complete one ($M = 19.9$, $SD = 7.3$), whereas newborns in the control condition looked equally at the two test stimuli, ($M = 21.4$, $SD = 8.6$ for the broken rod, and $M = 25.8$, $SD = 7.4$ for the complete rod).

When fixation times were analyzed as in Experiment 3, infants of the experimental condition showed a preference score for the broken rod that significantly differed from chance ($M = 58.4\%$,

$SD = 15.4$), $t(15) = 2.185$, $p < .05$, one tailed, whereas those in the control condition did not ($M = 45$, $SD = 16$), $t(16) = 1.279$, $p = .50$, one tailed. The percentage of total looking time to the broken stimulus differed reliably between the two conditions, $t(31) = 2.444$, $p < .05$.

A final analysis compared the test-trial looking preferences of infants under the experimental conditions of Experiments 3 and 4. This analysis revealed no significant difference between the two motion conditions, $t(29) = -1.358$, $p = .258$.

Discussion

Experiment 4 replicates and extends the findings of Experiment 3. It provides evidence that newborn infants perceive the unity of a center-occluded object that undergoes stroboscopic oscillatory motion. Comparisons across the experiments reveal that translatory and oscillatory motion have comparable effects on newborn infants' object perception, despite the differing effects of continuous oscillatory and translatory motions at later ages in infancy.

Whereas the infants in Experiment 3 perceived object unity from a pattern of rigid, translatory motion, those in Experiment 4 perceived object unity from a pattern of rigid, oscillatory motion. In previous experiments, 4-month-old infants failed to perceive the unity of a center-occluded object that was presented in a continuous oscillatory motion about its hidden center that resulted in motion in opposite directions above and below the occluder. Because the pattern of motion was the same in those experiments as in the present study, the present findings suggest that veridical object perception is observed at birth, even when the object is partly occluded and undergoes a complex displacement, provided that the object undergoes detectable stroboscopic motion.

Experiment 5

The final experiment of this series tested whether the perception of common motion of two separate parts is necessary to specify object unity at birth or whether stroboscopic motion of a single portion of the bar would have similar consequences. The results of Experiments 3 and 4 might be due to the fact that newborn's attention is drawn to exclusively by motion of only a single portion of the stimulus above or below the box. As neither of the two parts is broken, if attention is focused on a single part, newborns should manifest a novelty preference for the two bars instead of a single bar. This alternative

hypothesis is supported by the evidence arising from a study conducted by Johnson and Johnson (2000) with an eye-tracking system. Those authors explored the relation between perception of a partly occluded object and visual scanning skills in 2, 3, and 5-month old infants. They found that younger infants were less likely to scan the entire stimulus, and tended to limit their fixations to the top portion of the configuration. In contrast, older infants produced larger and more frequent movements to explore both the top and the bottom parts of the stimulus. In other words, they found robust age differences in scanning regions of the displays that are informative with respect to perception of object unity. These findings suggest that the visual attentional and perceptual skills of very young infants may be insufficient to facilitate consistently the extraction of important visual information that supports perception of object unity.

To rule out this alternative hypothesis, Experiment 5 was aimed at assessing whether a rod and box configuration, in which the surfaces of the rod did not move together, also produces preference for a broken rod display, or whether it has a different effect as compared with common stroboscopic motion of two parts of the bar. Newborns were habituated to a rod and box configuration in which the surfaces of the rod were not aligned and did not move together, and then they were shown two test displays without any occluder. If newborns' attention is triggered by the motion of a single part of the bar, a novelty preference for the two bars should also be expected in the condition where only one bar moves. On the contrary, we predict that when the two bar segments do not move simultaneously, newborns should fail to perceive the unity of a center-occluded rod, and they should look equally at the two test displays.

Method

Participants. Twelve newborn infants (5 males) were recruited as in the previous experiments, but one of them was not included in the final sample because of state change. The final sample therefore consisted of 11 healthy, full-term newborns with a birth weight between 2.800 and 4.200 kg, an Apgar score of at least 8 at 5 min, and a mean age of 64 hr. Newborns were middle-class infants, and 98% of them were Caucasian and 2% Asian. Informed consent was obtained from their parents.

Stimuli and apparatus. The rod and box display of Experiment 3 was used. The only difference between the stimuli used in Experiment 3 and those presented in Experiment 5 regards the alignment or nonalignment of the two visible parts of the partially

occluded rod. In Experiment 5 only the top of the rod underwent a stroboscopic translatory motion, while the bottom of the rod remained stationary (Figure 1).

Apparatus and procedure. They were identical to Experiment 3.

Results

Habituation score. The average total looking time to habituate to the stimuli was 102.6 s ($SD = 51.1$). The average number of trials to reach the criterion was 8 ($SD = 2$).

Preference test score. The mean number of fixations was 6 ($SD = 2$; range = 3–11) toward the complete rod and 7 ($SD = 4$, range = 3–15) toward the broken rod. Newborn infants therefore oriented equally toward the two test stimuli.

Newborn infants looked at the broken and at the complete displays for 22.2 s ($SD = 7.7$) and 25.5 s ($SD = 10$), respectively. Infants did not show a significant preference for the broken rod ($M = 47\%$, $SD = 14.4$; chance = 50%), $t(10) = 0.678$, $p = .513$. Therefore, under this condition, newborns looked equally at the two test displays. A further analysis compared the percentage of total looking time to the broken stimulus in Experiment 5 (47%) and in the no-habituation control condition of Experiment 3 (49%), respectively. This analysis revealed no significant difference between the two experiments, $t(24) = -0.421$, $p = .678$. A final analysis compared the percentage of total looking time to the broken stimulus in Experiment 5 (47%) and in the experimental condition of Experiment 3 (67%), respectively. The percentage of total looking time to the broken stimulus differed reliably between the two experiments, $t(24) = -3.444$, $p < .005$.

Discussion

Experiment 5 provides evidence that the presence of stroboscopic motion of a single part of a bar is not sufficient to evoke perception of a unitary object or preference for a broken rod display in newborn infants. Together with Experiments 3 and 4, these findings support the conclusion that common motion underlies perception of object unity for newborn infants, as it does for older infants and adults.

General Discussion

The present five experiments provide evidence that human newborns can link together separate parts of a partially occluded object and perceive object unity by detecting the common motion of the object's

visible surfaces. Together, the results suggest that common stroboscopic motion is critical to newborn infants' perception of object unity. Under the conditions in which neonates could detect the synchronous motion of two separate parts and track its trajectory, they were able to join the separate parts and perceive object unity. These experiments provide evidence that newborns' failure to perceive the unity of a partly occluded object in past research may result from limits in infants' motion processing, rather than limits in object perception. When the commonly moving, visible parts of an object are made more detectable to the newborn's immature visual system, newborns are able to group together those parts to perceive object unity.

Why has stroboscopic motion facilitated newborns to link together the separate parts of a partially occluded object, so that they perceived object unity? Stroboscopic motion, like any other kind of motion, triggers attention and facilitates image segmentation, and it specifies surface boundaries. In contrast to continuous motion, however, stroboscopic motion does not require smooth pursuit. In previous experiments with newborns, the center-occluded object moved back and forth behind the occluder for a total of 5 cm (10°). In contrast, in the present studies the rod moved only a short distance (i.e., 1.5 cm, about 3°). Thus, newborns were required to track the stimulus only for a distance that can be achieved by a single saccade. Moreover as 1- and 2-month-old infants' saccadic latency to localize peripheral target is 240–650 ms range (Aslin, 1981) and as in our experiments the rod remained in the same position for 500 ms, we think that newborns had the time to shift their eyes to refoveate the "jumping" rod. Therefore, two possible reasons can explain the absence of object unity in Experiments 1a and 1b and its presence in Experiments 3 and 4: (1) the different distance covered by the rod and (2) the fact that, under the stroboscopic condition, the rod stopped in the same position for a short period of 500 ms. The different responses of newborn infants in the two conditions suggest that there is a developmental progression in the perception of object unity from different object motions. The absence of object unity with the continuous motion (Experiment 1) and the presence of object unity with discontinuous motion (Experiments 3 and 4) suggest that, whatever system is required for the perception of object unity, it is heavily constrained and depends on perceptual cues that newborns are able to detect. As infants develop, the variety of conditions under which they perceive object unity increases. Indeed, newborn infants in Experiment 4 perceived a unitary object also with a

pattern of displacement that has not previously been found with 4 month olds, that is, oscillatory motion about a point at the occluded center of the object (Eizenman & Berthenthal, 1998). However, it is difficult to compare the two experiments, because the critical variables of speed and continuity vary in the two experiments. Possibly the small distance between the two places where the rod appears and the time of presentation of the rod contribute to render the stroboscopic motion detectable; consequently, the common motion is perceived and allows newborns to group together the separate parts.

Together, the present findings reveal that when newborn infants perceive the common motion of two separate parts of a center-occluded object, then these two separate parts are perceptually unified. Object perception therefore is not wholly shaped by visual experience; it depends in part on mechanisms that are present and functional at the time of the infant's first encounters with the visual world. More specifically, the present findings reveal that newborns are able to segregate separate regions of visual space (Experiments 1, 3, and 4), retain information about a previously visible object (Experiments 3 and 4), detect and prefer moving stimuli over stationary ones (Experiment 2), and link separated moving edges across a spatial gap when the two visible parts of the partly occluded rod are aligned (Experiments 3 and 4), but not when they are not aligned (Experiment 5).

These results suggest that some aspects of the development of object perception stem from intrinsic properties of the human perceptual system and that the system for object perception is operative even at birth but heavily constrained. Even if the role of experience in inducing a clear progression across the first several postnatal months cannot be ruled out (Johnson, 2004; Mareschal & Johnson, 2002), our findings show that the development of object perception seems to be anchored in initial abilities to detect motion. This conclusion does not contradict the hypothesis that other aspects of object knowledge might stem from learning about the particular characteristics of surrounding objects. In other words, the emergence of object unity comes from a combination of endogenous and exogenous mechanisms.

The present findings are consistent with findings from animals, whose sensory and motor systems are more mature at birth. Using an imprinting method, recent studies have provided evidence for perception of object unity in newly hatched chicks (Lea, Slater, & Ryan, 1996; Regolin & Vallortigara, 1995; Regolin, Vallortigara, & Zanforlin, 1995). Mechanisms for representing the complete shapes of partly hidden objects are present and functional at the time of the

chick's first encounter with an occlusion display: an adaptive ability for this precocial animal. Our findings extend this conclusion to humans, the most altricial species. Together with the findings from chicks, they suggest that a capacity for object perception is present at birth in a wide range of vertebrates and is anchored in initial abilities to detect motion. This capacity may provide a foundation for the acquisition of knowledge of the visible world.

References

- Abramov, I., Gordon, J., Hendrickson, A., Hainline, L., Dobson, V., & LaBossiere, I. (1982). The retina of newborn human infant. *Science*, 217, 265–267.
- Aslin, R. N. (1981). Development of smooth pursuit in human infants. In D. F. Fisher, R. A. Monty, & J. W. Senders (Eds.), *Eye movements: Cognition and visual perception* (pp. 31–51). Hillsdale, NJ: Lawrence Erlbaum Associates Ltd.
- Aslin, R. N., Shea, S. L., & Gallipeau, J. M. (1988). Motion thresholds in 3-month-old infants. *Investigative Ophthalmology and Visual Science*, 29(Suppl), 26.
- Atkinson, J., & Braddick, O. (1989). Development of basic visual function. In A. Slater & G. Brenner (Eds.), *Infant development* (pp. 7–41). Hove, UK: Lawrence Erlbaum Associates Ltd.
- Bertenthal, B. I., & Bradbury, A. (1992). Infants' detection of shearing motion in random-dot displays. *Developmental Psychology*, 28, 1056–1066.
- Bronson, G. W. (1990). The accurate calibration of infants' scanning records. *Journal of Experimental Child Psychology*, 49, 79–100.
- Condry, K. F., Smith, W. C., & Spelke, E. S. (2000). Development of perceptual organisation. In F. Lacerda, C. von Hofsten, & M. Heimann (Eds.), *Emerging cognitive abilities in early infancy* (pp. 1–28). Mahwah, NJ: Lawrence Erlbaum Associates.
- Dannemiller, J. L., & Freedland, R. L. (1989). The detection of slow stimulus movement in 2–5-month-olds. *Journal of Experimental Child Psychology*, 47, 337–355.
- Eizenman, D. R., & Berthenthal, B. I. (1998). Infant's perception of object unity in translating and rotating displays. *Developmental Psychology*, 34, 426–434.
- Farroni, T., Simion, F., Umiltà, C., & Dalla Barba, B. (2000). The gap effect in newborns. *Developmental Science*, 2, 174–186.
- Freeland, R. L., & Dannemiller, J. L. (1987). Detection of stimulus motion in 5-month-old infants. *Journal of Experimental Psychology: Human Perception and Performance*, 13, 566–576.
- Goldberg, M. C., Maurer, D., & Lewis, T. L. (1997). Influence of a central stimulus on infants' visual fields. *Infant Behavior and Development*, 20, 359–370.
- Goldberg, M. E., & Wurtz, R. H. (1972). Activity of superior colliculus in behaving monkey Visual receptive field of single neurones. *Journal of Neurophysiology*, 35, 542–547.

- Hainline, L. (1998). The development of basic visual abilities. In A. Slater (Ed.), *Perceptual development: Visual, auditory, and speech perception in infancy* (pp. 5–50). UK: Psychology Press.
- Hamar, R. D., & Norcia, A. M. (1994). The development of motion sensitivity during the first year of life. *Vision Research*, 34, 2387–2402.
- Horowitz, F. D., Paden, L., Bhana, K., & Self, P. (1972). An Infant-controller procedure for studying infant visual fixations. *Development Psychology*, 7, 90.
- Johnson, M. H. (1990). Cortical maturation and the development of visual attention in early infancy. *Journal of Cognitive Neuroscience*, 2, 81–95.
- Johnson, S. P. (2004). Theories of development of the object concept. In G. Brenner & A. Slater (Eds.), *Theories of infant development* (pp. 174–203). Oxford, UK: Blackwell Publishing Ltd.
- Johnson, S. P. (2005). Building knowledge from perception in infancy. In L. Gershkoff-Stowe & D. Rakison (Eds.), *Building object categories in developmental time* (pp. 33–62). Mahwah, NJ: Hillsdale.
- 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., & 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.
- Kaufmann, F., Stucki, M., & Kaufmann-Hayos, R. (1985). Development of infants' sensitivity for slow and rapid motions. *Infant Behaviour and Development*, 8, 89–95.
- Kellman, P. J., & Shipley, T. F. (1991). A theory of visual interpolation in object perception. *Cognitive Psychology*, 23, 141–221.
- Kellman, P. J., & Spelke, E. S. (1983). Perception of partly occluded objects in infancy. *Cognitive Psychology*, 15, 483–524.
- Lea, S. E. G., Slater, A., & Ryan, C. M. E. (1996). Perception of object unity in chicks: A comparison with human infant. *Infant Behaviour and Development*, 19, 501–504.
- Mareschal, D., & Johnson, S. P. (2002). Learning to perceive object unity: A connectionist account. *Developmental Science*, 5/2, 151–155.
- Norcia, M., Garcia, H., Humphry, R., Holmes, A., Hamer, R. D., & Orel-Bixler, D. (1991). Anomalous motion VEPs in infants and in infantile esotropia. *Investigative Ophthalmology and Visual Science*, 32, 436–439.
- Regal, D. M. (1981). Development of critical flicker frequency in human infants. *Vision Research*, 21, 549–555.
- Regolin, L., & Vallortigara, G. (1995). Perception of partly occluded objects by young chicks. *Perception and Psychophysics*, 57, 971–976.
- Regolin, L., Vallortigara, G., & Zanforlin, M. (1995). Object and spatial representation in detour problems by chicks. *Animal Behaviour*, 49, 195–199.
- Rock, I., Tauber, E. S., & Heller, D. P. (1965). Perception of stroboscopic movement: Evidence for its innate basis. *Science*, 147, 1050–1052.
- Slater, A., Johnson, S. P., Brown, E., & Badenoch, M. (1996). Newborn infant's perception of partly occluded objects. *Infant Behavior and Development*, 19, 145–148.
- Slater, A., Johnson, S. P., Kellman, P. J., & Spelke, E. (1994). The role of three-dimensional depth cues in infants' perception of partly occluded objects. *Early Development and Parenting*, 3, 187–191.
- Slater, A., Morison, V., Somers, M., Mattock, A., Brown, E., & Taylor, D. (1990). Newborn and older infant's perception of partly occluded objects. *Infant Behavior and Development*, 13, 33–49.
- Spelke, E. S., & Newport, E. (1998a). Nativism, empiricism, and the development of knowledge. In W. Damon & R. M. Lerner (Eds.), *Handbook of child psychology, Vol. 1, theoretical models of human development* (pp. 275–340). New York: Wiley.
- Spelke, E. S., & Newport, E. (1998b). Nativism, empiricism, and the development of knowledge. In W. Damon (Series Ed.) & R. M. Lerner (Vol. Ed.), *Handbook of child psychology (Vol. 1, pp. 257–340)*. New York: Wiley.
- Taga, G., Asakawa, K., Hirasawa, K., & Konoshi, Y. (2003). Hemodynamic responses to visual stimulation in occipital and frontal cortex of newborn infants: a near-infrared optical topography study. *Early Human Development*, 75(Suppl), 203–210.
- Valenza, E., Zulian, L., & Leo, I. (2005). The role of perceptual skills in newborn's perception of partly occluded objects. *Infancy*, 8, 1–20.
- Vehrs, S., & Baum, D. (1971). A test of visual responses in the newborn. *Developmental Medicine and Child Neurology*, 12, 772–774.
- Wattam-Bell, J. (1991). Development of motion-specific cortical responses in infancy. *Vision Research*, 31, 287–297.
- Wattam-Bell, J. (1993). One-month-old infants fail in a motion direction discrimination task. *Investigative Ophthalmology and Visual science*, 34, 1356.
- Wattam-Bell, J. (1996). Visual motion processing in 1-month-olds: Habituation experiments. *Vision Research*, 36, 1679–1685.