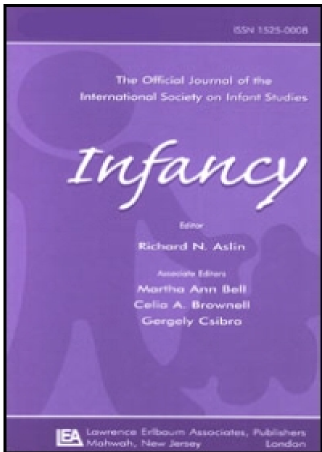

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Shake, Rattle, and … One or Two Objects? Young Infants' Use of Auditory Information to Individuate Objects

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Shake, Rattle, and … One or Two Objects? Young Infants' Use of Auditory Information to Individuate Objects

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Most research on object individuation in infants has focused on the visual domain. Yet the problem of object individuation is not unique to the visual system, but shared by other sensory modalities. This research examined 4.5-month-old infants' capacity to use auditory information to individuate objects. Infants were presented with events in which they heard 2 distinct sounds, separated by a temporal gap, emanate from behind a wide screen; the screen was then lowered to reveal 1 or 2 objects. Longer looking to the 1- than 2-object display was taken as evidence that the infants (a) interpreted the auditory event as involving 2 objects and (b) found the presence of only 1 object when the screen was lowered unexpected. The results indicated that the infants used sounds produced by rattles, but not sounds produced by an electronic keyboard, as the basis for object individuation (Experiments 1 and 2). Data collected with adult participants revealed that adults are also more sensitive to rattle sounds than electronic tones. A final experiment assessed conditions under which young infants attend to rattle sounds (Experiment 3). Collectively, the outcomes of these experiments suggest that infants and adults are more likely to use some sounds than others as the basis for individuating objects. We propose that these results reflect a processing bias to attend to sounds that reveal something about the physical properties of an object—sounds that are obviously linked to object structure—when determining object identity.

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The capacity to individuate objects—to determine whether two perceptual instances belong to the same object or different objects—is one of our most basic cognitive abilities. This capacity allows us to represent the world in terms of distinct objects that persist in space and time and forms the foundation for more complex thought and behavior. Given the importance of object individuation to human cognition, a great deal of effort has been expended to identify the origins and development of this capacity (e.g., Aguiar & Baillargeon, 2002; Bonnatti, Frot, Zangl, & Mehler, 2002; Leslie, Xu, Tremoulet, & Scholl, 1998; Spelke, Kestenbaum, Simons, & Wein, 1995; Tremoulet, Leslie, & Hall, 2001; Wilcox, 1999, 2003; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Schweinle, 2002, 2003; Xu, 2002; Xu & Carey, 1996). Most of this research has focused on the kind of information infants use to individuate objects within the visual domain, and how this changes with time and experience.

The outcome of this research has revealed that spatiotemporal information is fundamental to the individuation process. From a very early age, infants interpret spatiotemporal discontinuities as signaling the presence of distinct objects. For example, when shown an event in which an object disappears behind the first of two spatially separate screens, and then emerges from behind the second screen without appearing between the two screens, infants as young as 3.5 months are led by the discontinuity in path of motion to conclude that two distinct objects are involved in the event (Aguiar & Baillargeon, 2002; Baillargeon & Graber, 1987; Spelke et al., 1995; Wilcox & Schweinle, 2002). Likewise, when presented with an event in which an object disappears behind one edge of a wide screen and then reappears immediately at the other edge, 3.5-month-olds take the discontinuity in speed of motion to signal the presence of two objects (Wilcox & Schweinle, 2003). There is also evidence that, in the absence of spatiotemporal discontinuities, infants can use featural information to individuate objects (Hespos, 2000; Leslie & Glanville, 2001; Wilcox, 1999; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Chapa, 2002, 2004; Wilcox & Schweinle, 2002; for a review of the evidence see Needham & Baillargeon, 2000; Wilcox, Schweinle, & Chapa, 2003). However, infants are not equally sensitive to all types of featural information. Object features can be grouped into two general categories: those that specify three-dimensional form and those that constitute surface properties. There is evidence that infants are more likely to use form features than surface features as the basis for object individuation (Leslie et al., 1998; Tremoulet et al., 2001; Wilcox, 1999; Woods & Wilcox, in press; also see Craton, Poirier, & Heagney, 1998; Needham, 1999). For example, by 4.5 months infants use shape and size differences, but it is not until 11.5 months that they use color or luminance differences to signal the presence of distinct objects (Wilcox, 1999; Woods & Wilcox, in press).

At the same time that there is an increasing body of knowledge about infants' use of information from the visual domain to individuate objects, little is known about infants' use of information acquired through other sensory modalities. In light of the fact that infants live in a multimodal world—they routinely see, touch, taste, and listen to the objects with which they come in contact—this gap in knowledge is problematic. We cannot fully understand how infants solve the problem of object individuation in everyday situations without investigating their capacity to use information from other sensory modalities.

The present research moves object individuation research in a new direction, by investigating infants' capacity to use auditory information to signal the presence of distinct objects. The auditory system is one of the most mature sensory systems at birth (for a review of infants' auditory capacities see Aslin, Jusczyk, & Pisoni, 1998). Young infants demonstrate a remarkable capacity to discriminate between auditory stimuli and are more sensitive to some kinds of auditory information than others (Aslin, 1987; Aslin et al., 1998). There is also evidence that infants are sensitive to numerosity in auditory events (Starkey, Spelke, & Gelman, 1983, 1990; vanMarle & Wynn, 2002). For example, 7-month-olds can discriminate between auditory sequences composed of a different number of tones even when the continuous properties of the tones or sequences are strictly controlled (vanMarle & Wynn, 2002). Infants can also detect intermodal numerical correspondences involving auditory stimuli. For example, infants 6 to 8 months of age can match the number of items presented in an auditory event (e.g., drumbeats separated by a temporal gap) with those presented simultaneously in a visual array (e.g., dots separated in space), even when the two sets of stimuli have no natural relation to each other (Starkey et al., 1983, 1990). Finally, infants use auditory information to localize objects in space (Clifton, Perris, & Bullinger, 1991; Perris & Clifton, 1988) and hold expectations for the kinds of sounds objects should produce when they move and interact (Bahrick, 1983, 1987, 1992, 2001; Pickens, 1994). For example, by 3.5 months infants recognize that the sounds produced by the impact of two rigid objects differs from that produced by two compressible objects, and correctly match an auditory event with the appropriate visual display (Bahrick, 1983). Collectively, these results suggest two conclusions. First, infants are capable of parsing auditory information into distinct units, representing and remembering the number of units heard, and integrating this information with information from the visual domain. Second, infants recognize that the sounds objects make when engaged in physical events depend, at least to some extent, on the physical properties of those objects. Objects with different physical structures produce different types of sounds. Together, these results also raise the possibility that infants might be capable of linking sounds to objects and then of using that information as the basis for object individuation. These experiments test this hypothesis.

Infants aged 4.5 months were presented with an event in which they heard two sounds, separated by a temporal gap, emanate from behind a wide screen. The sounds were either acoustically distinct (different-sounds condition) or identical (same-sounds condition). The screen was then lowered to reveal either one or two objects on the platform. Two predictions were made. First, if the infants in the different-sounds condition (a) perceive that the two sounds were produced by two different objects and (b) expect to see two objects revealed when the screen is lowered, then they should find the one-object display novel or unexpected (i.e., they should look reliably longer at the one- than the two-object display). In contrast, if the infants in the different-sounds condition fail to use the acoustic difference between the two sounds to form an interpretation about the number of objects behind the screen, then they should look about equally at the one- and the two-object display. The second prediction is that if the infants in the same-sounds condition (a) perceive that the two sounds were made by one and the same object and (b) expect to see one object when the screen is lowered, then they should find the two-object display novel or unexpected (i.e., they should look reliably longer at the two- than the one-object display). In contrast, if the infants in the same-sounds condition fail to form an interpretation about the number of objects present, they should look about equally at the two displays.

EXPERIMENT 1

Infants aged 4.5 months were presented with a different- or same-sounds event. The two sounds, presented successively, were produced by shaking papier-mâché eggs. In the different-sounds event, one egg was partially filled with uncooked rice and the other with small jingle bells (see Figure 1). In the same-sounds event, both eggs were filled with the same substance, rice or bells. One of the goals of this study was to examine whether object individuation in the auditory domain is based primarily on temporal parameters or whether infants attend to the acoustic properties of auditory stimuli as well. If temporal differences are sufficient to support object individuation, then hearing two sounds separated by a temporal gap should signal the presence of two distinct objects, regardless of the acoustic properties of the sounds. In contrast, if the presence of acoustic differences between auditory stimuli is necessary for object individuation, then infants should perceive that two objects are present only when the sounds are sufficiently different in their acoustic content.

Method

Participants

Participants were 16 male and 16 female healthy full-term infants (*M* = 4 months, 13 days; range = 3 months, 17 days–5 months, 6 days). Eight additional infants were tested but eliminated from the analyses, 1 because of fussiness, 2 be-

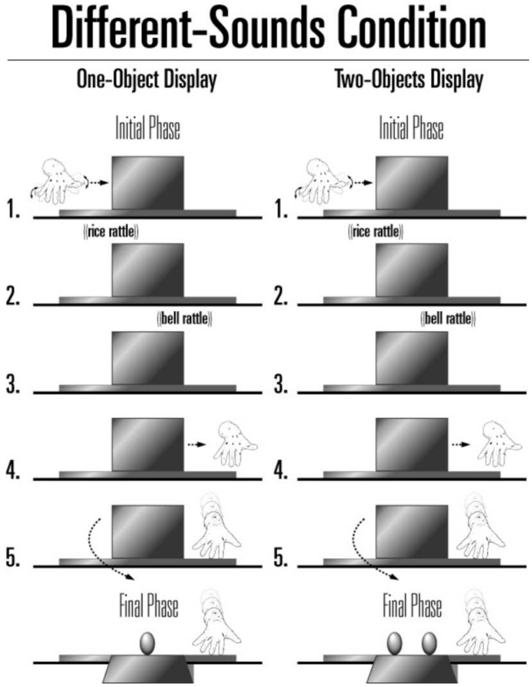

FIGURE 1 The test event of the different-sounds condition of Experiment 1.

cause the primary observer was unable to determine the infant's direction of gaze, and 5 because of procedural problems. Eight infants were randomly assigned to each of four groups formed by crossing event (different or same sounds) and test display (one or two objects).

Apparatus

The apparatus was 213 cm high × 105 cm wide × 43.5 cm deep with an opening 51 cm high × 93 cm wide in its front wall. The floor and walls of the apparatus were cream or covered with lightly patterned contact paper. A cream and blue colored platform 1 cm high × 91 cm wide × 19 cm deep lay flush against the back wall, centered between the left and right walls. The experimenter's hand moved through a slit 9 cm high × 70 cm wide, located 14 cm above the apparatus floor; cream-colored fringe helped conceal the slit. The eggs could be moved in or out of the apparatus through a concealed door, 12 cm high × 10 cm wide, that was located behind the screen.

The screen used in the pretest and test events was 32 cm high × 35 cm wide, made of green cardboard, and attached with metal clips to a wooden dowel that lay directly in front of the platform. The right end of the dowel exited the apparatus through a small hole in the right wall. By rotating the dowel's right end (out of the infants' view), an experimenter could lower the screen to the apparatus floor.

The egg rattles used in the test events were 7.5 cm in diameter at their widest points and 11 cm tall, made of papier-mâché, lined with plastic, hollow, and painted blue. Two eggs were partially filled with uncooked rice and two with small jingle bells. To equate the conditions as much as possible (see later), two objects were used to produce the different- and the same-sounds events.

Events

Three trained experimenters worked together to produce the pretest and test events. The first experimenter created the sounds by moving the eggs, the second experimenter surreptitiously removed an egg from behind the screen, and the third experimenter lowered the screen at the end of the auditory event. To help the experimenters adhere to the events' scripts, a metronome with a light source was placed within the experimenters' view and blinked once per second (the sound was turned off).

Different-sounds condition. Infants first saw pretest events designed to acquaint them with the hand and the testing situation. In the first pretest event, the first experimenter's right gloved hand was seen tilting gently left to right (1 sec for each tilt) to the left of the screen. In the second pretest event, the hand underwent the same motions to the right of the screen. After the pretest events, infants saw a test event that consisted of an initial and a final phase. The test event began with the hand tilting gently left to right to the left of the screen. Two eggs, one filled with rice and one filled with small bells, sat behind the screen directly next to each other (separated by only 1.5 cm). After the computer signaled that the infant had looked at the hand for 2 cumulative sec, the initial phase of the test event began. The numbers in parentheses indicate the time taken to produce the actions described. The hand stopped tilting (1 sec), moved behind the left edge of the screen (2 sec), grasped the left egg (1 sec), moved it in a circular motion continuously (2 sec; approximately four full rotations per sec), and then gently replaced it (1 sec). The circular motion produced a continuous rattle sound as the internal elements made contact with the inside wall of the egg. Next, the hand grasped the right egg (1 sec), moved it in a circular motion continuously (2 sec; approximately four full rotations per sec), and then gently replaced it (1 sec). For half of the infants the rice-filled egg was on the left and the bell-filled egg was on the right; for the other half the reverse was true. The two sounds in each test event were equated for duration (2 sec each) and amplitude (approximately 65 dB). Sound production was monitored by the second experimenter; if the sounds were not produced uniformly the data for that infant were eliminated. The hand then moved from behind the right edge of the screen (2 sec) and came to rest at the right edge of the platform. During these last 2 sec, the second experimenter surreptitiously opened the small door in the apparatus, located directly behind the upright screen, and either removed one of the eggs (for the one-object display) or made a motion as if removing one of the eggs (for the two-object display). Finally, the second experimenter lowered the screen to the apparatus floor (1 sec). During the final phase, the infants saw either one egg (one-object display) or two eggs (two-object display) centered on the platform.

Same-sounds condition. The test event of the same-sounds condition was identical to that of the different-sounds condition with one exception: Two eggs that made identical sounds were used. Half of the infants heard two rice-filled eggs; the other half heard two bell-filled eggs.

Procedure

The infant sat on a parent's lap centered in front of the apparatus with his or her head approximately 80 cm from the objects. The parent was asked not to interact with the infant while the experiment was in progress, and to close his or her eyes during the test events.

Each infant participated in a two-step procedure that consisted of a pretest period and a test period. In the pretest period, infants were presented with the two pretest trials already described. The pretest trials ended when the infant either (a) looked away for 2 consecutive sec after having looked for at least 5 cumulative sec or (b) looked for 30 cumulative sec without looking away for 2 consecutive sec. During the test period, infants saw the test event appropriate for their condition on two successive trials. Looking time during the initial and final phase of each trial was monitored separately. The final phase of each trial ended when the infant either (a) looked away for 2 consecutive sec after having looked for at least 10 cumulative sec or (b) looked for 60 cumulative sec without looking away for 2 consecutive sec.

The infant's looking behavior was monitored by two observers who watched the infant through peepholes in the cloth-covered frames on either side of the apparatus. The observers wore headphones through which they heard white noise during the experimental session. In addition, observers were not told, and could not determine, whether infants saw a final display containing one or two objects.[1] Each

[1]In Experiments 1, 2, and 3 infants saw a final display containing either one object or two objects. Observers were asked to guess, at the end of each session, whether the infant saw a one-object or a two-object display. Of the 96 primary observers that responded, 50 guessed correctly, a performance not significantly different from chance (cumulative binomial probability, $p > .05$).

observer held a button connected to a computer and depressed the button when the infant attended to the events. The looking times recorded by the primary observer, who was usually more experienced, determined when a trial had ended (see earlier) and were used in the data analyses. Each trial was divided into 100-msec intervals, and the computer determined in each interval whether the two observers agreed on the direction of the infant's gaze. Interobserver agreement was measured for 26 of the infants (for 6 of the infants, only one observer was present) and was calculated for each test trial on the basis of the number of intervals in which the computer registered agreement out of the total number of intervals in the trial. Agreement averaged 90% per test trial per infant.

Preliminary analyses were conducted for each of the experiments reported herein to explore whether boys and girls responded differently to the test events. These analyses failed to reveal reliable sex differences. Consequently, in this and the following experiments the data were collapsed across sex.

Results

Pretest Trials

The infants' looking times during the two pretest trials were averaged and analyzed by means of an analysis of variance (ANOVA) with event (different or same sounds) and test display (one or two objects) as between-subject factors. The main effects of event and test display and the interaction between these two factors were not significant, $F(1, 28) < 2.5$, ps < .05, indicating that the infants in the four groups did not differ reliably in their mean looking times during the pretest trials (different-sounds, one-object, $M = 24.8$ sec, $SD = 5.5$, and two-object, $M = 17.9$ sec, $SD = 7.6$; same-sounds, one-object, $M = 17.0$ sec, $SD = 8.2$, and two-object, $M = 18.9$ sec, $SD = 10.3$).

Test Trials

The infants' looking times during the final phase of the two test trials (Figure 2) were averaged and analyzed in the same manner as the pretest trials. The Event × Test Display interaction was significant, $F(1, 28) = 4.67$, $p < .05$; partial eta-squared (effect size) = .133. Planned comparisons revealed that the infants who heard the different-sounds event looked reliably longer at the one-object display ($M = 40.6$ sec, $SD = 17.8$) compared with the two-object display ($M = 23.8$ sec, $SD = 8.0$), $F(1, 28) = 9.00$, $p < .01$. A Mann–Whitney U test confirmed that the distributions of these two groups were reliably different, $Z = -1.89$, $p < .05$ (one-tailed). In contrast, the infants who heard the same-sounds event looked about equally at the one-object ($M = 18.4$ sec, $SD = 7.5$) and the two-object displays ($M = 18.1$ sec, $SD = 5.1$), $F(1, 28) < 1$.

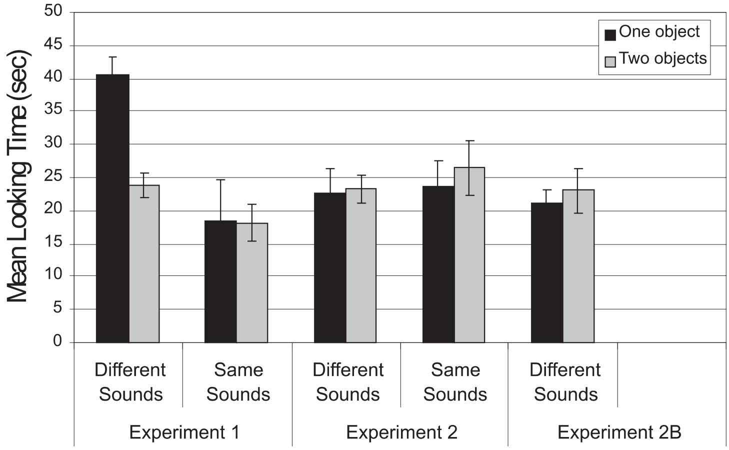

FIGURE 2 Infants' mean looking times (and standard errors) to the one-object and the two-object displays in Experiments 1, 2, and 2B (different- and same-sounds events).

Discussion

The infants in the different-sounds condition looked reliably longer at the one-object display compared with the two-object display, suggesting that they (a) perceived, on the basis of the difference in sound between the rice- and bell-filled eggs, that two separate and distinct objects were behind the screen; and (b) found the presence of only a single object when the screen was lowered screen unexpected. In contrast, the infants in the same-sounds condition looked about equally at the two displays, suggesting that they (a) were unsure of whether the two identical sounds were produced by one and the same object or two different objects and, hence, (b) showed no preference for either display. Hence, the infants in the same-sounds condition, unlike the infants in the different-sounds condition, were ambiguous in their interpretation of the acoustic event. It is possible that the infants recognized that the same sound heard twice could be produced by either two identical objects or the same object shaken twice. Together, these results suggest that the infants did not use the temporal gap between the two sounds alone to individuate the objects. Only when the two sounds were distinct, so that it was unlikely that the same object could have made both sounds, did the infants infer that the two sounds were produced by different objects.

It is worthwhile to compare these results to those obtained in the intermodal correspondence studies cited earlier. In the studies of Starkey et al. (1983, 1990), infants matched the number of items presented in an auditory event with those presented in a visual event on the basis of the number of temporally distinct auditory units, without obvious regard for the acoustic properties of the sounds. For example, infants found two identical drumbeats consistent with seeing two dots or two objects (e.g., a bowl and a lemon), but not with seeing three dots or three objects. In the experiments reported here, the relation between the number of temporally separate sounds that infants heard and the number of objects infants expected to see when the screen was lowered was not veridical. Sometimes infants interpreted two sounds as being produced by two separate objects (i.e., different-sounds event) and sometimes they did not (i.e., same-sounds event). Although it is difficult to draw firm conclusions on the basis of these results (there are many differences between these studies and those conducted by Starkey et al.), it appears that, at least under some conditions, intermodal matching occurs at a more abstract level than object individuation. In intermodal matching, the number of temporally distinct sounds presented is more important than the specific properties of those sounds; in object individuation, the acoustic properties of the sounds are important.

The positive results obtained in Experiment 1 raise the question of whether infants would respond in a similar way to other kinds of sounds or whether these findings are unique to rattles. The rattle sounds used in Experiment 1 could be thought of as property-rich sounds: They reveal something about the physical properties (e.g., shape, size, substance) of the objects involved. Typically, when objects move about and interact in the world they produce sounds in accord with their physical structure, including their shape, size, and material of which they are composed, and the nature of the interactions in which they are engaged. For example, on the basis of auditory information alone, one could infer that the different-sounds event of Experiment 1 involved two hollow, rigid objects, and that each object contained a different collection of smaller rigid objects that rattled when shaken. If perceptive, adults might even correctly guess that one collection consisted of small bells and the other of some hard, dry material (e.g., uncooked rice, dried beans, or sand). Most important, however, is that auditory information clearly specified different rigid collections moving inside rigid containers.

Not all sounds are property-rich sounds, however. There are many sounds that do not immediately reflect the physical properties of the objects involved. We refer to these as property-poor sounds. Consider, for example, the sound an electronic toy makes, the tones produced by a music box, or the ringing of a telephone. These sounds are more contrived and are not obviously tied to the physical structure of the objects making them. As a result, infants might find these sounds less useful as an indicator of object identity. The next experiment tests this hypothesis.

EXPERIMENT 2

Experiment 2 examined whether 4.5-month-olds would individuate objects using property-poor sounds. The sounds were produced by an electronic keyboard and differed in pitch and timbre. The dissimilarity between the two property-poor sounds used in this experiment was judged by adults to be equivalent to the dissimilarity between the two property-rich sounds used in Experiment 1.[2] Infants were tested in different- and same-sounds conditions that were identical to the different- and same-sounds conditions of Experiment 1 with one exception: The sounds made by the rice- and bell-filled eggs were replaced with the two tones produced by the electronic keyboard.

Method

Participants

Participants were 16 male and 16 female infants (*M* = 4 months, 12 days; range = 3 months, 17 days–5 months, 5 days). Eleven additional infants were tested but eliminated from analysis: 3 because of fussiness, 1 because the primary observer was unable to determine the direction of the infant's gaze, and 7 because of procedural problems. Eight infants were randomly assigned to each of four groups formed by crossing event (different or same sounds) and test display (one object or two objects).

Apparatus and Procedure

The apparatus and procedure were identical to those of Experiment 1 except that the two eggs used in each test event each contained a small speaker, and each speaker was connected to a Youthtronics 32-key play keyboard (distributed by Spectra). The rice rattle sound was replaced with Tone 1, which was the note F directly below middle C played as a violin, and the bell rattle sound was replaced with Tone 2, which was middle C played as a mandolin. The sounds were equated for duration (2 sec each) and amplitude (approximately 68 dB). Interobserver agreement was measured for 29 of the infants and averaged 91%.

[2]Thirty-two naive adults (*M* age = 19 years, range = 17–21 years) heard two pairs of sounds presented in one of two orders: (a) rice–bells and tone1–tone 2 or (b) tone 1–tone 2 and rice–bells. Within each pair, the order of the sounds was also counterbalanced. After each pair, adults were asked to rate on a scale of 1 (*very similar*) to 5 (*very different*) how they perceived the sounds. Prior to the test trials, participants were presented with two practice trials with different sound pairs (i.e., keys jingling–sandpaper rubbing and pencil sharpener–handheld vacuum). A mixed-model ANOVA was conducted with sound type (rice–bells or electronic tones) as the within-subjects factor and order (rice–bells or electronic tones first) as the between-subject factor. The main effects of sound type and order, and the interaction between these two factors, were not significant, all $F(1, 18) < 1$. The adults' rating of the difference between the rice and bells (*M* = 2.25, *SD* = 0.84) did not differ reliably from that of the two electronic tones (*M* = 2.06, *SD* = 0.98). These results suggest that the adults perceived the two rattle sounds and the two electronic tones as equally distinct. Although the extent to which adult similarity ratings map onto infants' perception of similarity has yet to be fully explored, these findings provide tentative evidence that the two rattle sounds were not more distinct than the two electronic tones.

Results

Pretest Trials

The infants' looking times during the two pretest trials were averaged and analyzed by means of an ANOVA with event and test display as between-subject factors. The main effects of event and test display, $F(1, 28) < 2.20$, and the interaction between these two factors, $F(1, 28) = 3.78$, were not significant (ps < .05), indicating that the infants in the four groups did not differ reliably in their mean looking times during the pretest trials (different-sounds, one-object display, $M = 24.4$ sec, $SD = 6.3$, and two-object display, $M = 23.3$ sec, $SD = 8.0$; same-sounds, one-object display, $M = 17.5$ sec, $SD = 7.4$, and two-object display, $M = 25.8$ sec, $SD = 5.5$).

Test Trials

The infants' looking times during the final phase of the two test trials (Figure 2) were averaged and analyzed in the same manner as the pretest trials. The main effects and the interaction were not significant, all $F(1, 28) < 1$; partial eta-squared for the interaction = .003. Planned comparisons confirmed that the infants who heard the different-sounds event looked about equally at the one-object ($M = 22.6$ sec, $SD = 10.9$) and the two-object ($M = 23.3$ sec, $SD = 10.0$) displays, as did the infants who heard the same-sounds event (one-object display, $M = 23.6$ sec, $SD = 10.9$; two-object display, $M = 26.5$ sec, $SD = 11.9$), $F(1, 28) < 1$.

Adult Participants

In light of the 4.5-month-olds differential responding to the rattle sounds and electronic tones, we assessed how more experienced participants would respond to these two sets of auditory stimuli. Eighty-nine adults, 46 men and 43 women (M age = 20 years, range = 16–43 years), were randomly assigned to one of four groups formed by crossing sound type (rattles or electronic tones) by event (different or same sounds). Participants were presented with different- and same-sounds events similar to those of Experiments 1 and 2 with two main differences. First, the screen was never lowered. Second, after hearing the two sounds, participants were asked to rate on a scale of 1 (*definitely one object*) to 5 (*definitely two objects*) whether they thought one object or two objects stood behind the screen. A score of 3 was interpreted as reflecting an ambiguous interpretation of the event.

The adults' ratings of the two test events were averaged and analyzed by means of an ANOVA with sound type and event as between-subject factors. The Sound Type × Event interaction was significant, $F(1, 85) = 8.01$, $p < .01$, partial eta-squared = .086. Planned comparisons revealed that in the rattles condition, the mean ratings of the adults who heard the different-sounds event ($n = 23$, $M = 4.5$, $SD = 1.0$) and the same-sounds event ($n = 22$, $M = 2.2$, $SD = 1.0$) events differed reliably, $F(1, 85) = 42.12$, $p < .001$. The adults responded as if they interpreted the different-sounds event as involving two objects and the same-sounds event as involving only one object. In the electronic tones condition, the mean ratings of the adults who heard the different-sounds event (n = 24, M = 3.4, SD = 1.4) and the same-sounds event (n = 20, M = 2.5, SD = 1.3) also differed reliably, $F(1, 85)$ = 6.23, $p < .05$. These results suggest that in this condition the participants were unsure about how many objects were involved in the different-sounds event, but judged that only one object was involved in the same-sounds event. A final comparison indicated that the adults who heard rattles and electronic tones responded reliably different to the different-sounds event, $F(1, 85) = 10.82$, $p < .01$, providing converging evidence for the conclusion that adults are more likely to use rattle sounds than electronic tones to individuate objects.

Discussion

In contrast to the positive results obtained with the 4.5-month-olds in Experiment 1 when rattles were used, null results were obtained in Experiment 2 when electronic tones were used. The infants in both the different- and same-sounds condition responded as if they were uncertain of whether there was one object or two objects behind the screen, suggesting that the 4.5-month-olds failed to individuate the objects on the basis of the acoustic information.

Data collected with adult participants revealed ways in which adults are both similar to, and different from, infants in their interpretation of the auditory events. Like the infants, the adults used the difference in sound produced by the two rattles, but not the electronic keyboard, to individuate the objects. Within the context of different-sounds events, both groups demonstrated a greater sensitivity to rattle sounds than electronic tones. Unlike the infants, who were ambiguous in their interpretation of the same-sounds events, the adults appeared to interpret events involving two identical sounds as involving a single object (regardless of whether it was a rattle or an electronic tone). Perhaps adults' experiences with a wide variety of sounding objects lead them to infer that it is unlikely that two identical sounds are produced by two different objects.

The next experiment explored whether infants would be more likely to attend to electronic tones if they were made more distinct.

EXPERIMENT 2B

Infants aged 4.5 months were tested using the different-sounds procedure of Experiment 2 with one exception: The sounds produced by the electronic keyboard were made more distinct by increasing the number of components that each sound contained and by altering the relation between those components. Specifically, Tone 1 was replaced by two discordant notes played simultaneously and Tone 2 by two harmonic notes played simultaneously. The data obtained in this experiment will be compared to the data obtained in the different-sounds conditions of Experiment 1 (rattle sounds) and Experiment 2 (electronic tones).

Method

Participants

Participants were 10 male and 6 female infants (*M* age = 4 months, 17 days; range = 3 months, 25 days–5 months, 4 days). Three additional infants were tested but eliminated from analysis: 2 because of fussiness and 1 because he was an outlier (i.e., his mean looking time during the test trials was more than 2 *SD*s above the mean of the group). An equal number of infants saw the one-object and the two-object displays.

Apparatus and Procedure

The apparatus and procedure were identical to those of the different-sounds conditions of Experiment 2 with one exception: Tone 1 was replaced with notes E flat and A (one octave below middle C) played simultaneously as a trumpet and Tone 2 was replaced with notes C and E (one octave above middle C) played simultaneously as a bell. The notes included in Tone 1 were not of the same chord, whereas the notes included in Tone 2 were harmonic. Hence, Tone 1 and Tone 2 of this experiment differed in the musical notes of which they were composed, the relation between those notes, and their timbre. Together, these factors made them more complex than Tone 1 and Tone 2 of Experiment 2 as well as more distinct from each other.

Interobserver agreement was measured for 14 of the infants and averaged 92%.

Results

Pretest Trials

The looking times of the infants in the one-object condition ($M = 29.2$ sec, $SD = 2.4$) and the two-object condition ($M = 24.8$ sec, $SD = 6.0$) did not differ reliably, $t(14) = 1.85$, $p > .05$. The infants' mean looking times during the pretest trials were then compared to those of the infants in the different-sounds conditions of Experiment 1 and Experiment 2 by means of an ANOVA with event (rattles, tones, or complex tones) and test display (one or two objects) as between-subject factors. The interaction between event and test display was not significant, $F(1, 42) < 1$.

Test Trials

The infants looked about equally at the one-object display ($M = 21.1$ sec, $SD = 5.7$) and the two-object display ($M = 23.0$ sec, $SD = 9.6$), $t(14) < .5$ (Figure 2). The infants' mean looking times during the final phase of the test event were then compared to those of the infants in the different-sounds conditions of Experiment 1 and Experiment 2 by means of an ANOVA with event and test display as between-subject factors. The Event × Test Display interaction was significant, $F(2, 42) = 3.43$, $p < .05$, partial eta-squared = .140. Planned comparisons indicated that the infants in the rattles condition looked reliably longer at the one-object display compared with the two-object display, $F(1, 42) = 8.78$, $p < .01$, whereas the infants in the tones and the complex tones conditions looked about equally at the two displays, $F(1, 42) < 1$.

Discussion

These results provide additional evidence, using a different set of electronic tones, that young infants are more sensitive to sounds produced by rattles than sounds produced by an electronic keyboard as the basis for individuating objects. Even when the electronic tones were made more distinct by playing two notes simultaneously, one pair of which was discordant and the other harmonic, infants still failed to use the acoustic difference between the tones to draw inferences about the number of objects behind the screen.

The next experiment examined, in greater detail, young infants' capacity to use rattle sounds to individuate objects.

EXPERIMENT 3

Recall that the event sequences of Experiments 1 and 2 involved a hand that performed the following visible actions: moved behind one edge of the screen and, after two successive sounds, reemerged from behind the other edge of the screen. A hand was included in the test events because, typically, inert objects make sounds only when acted on and we were concerned that young infants would have difficulty interpreting an event involving inert sounding objects without the presence of a hand. That is, infants might fail to use rattle sounds as the basis for object individuation without some mechanism by which the rattles could have produced the sounds. Our reasoning was based on the fact that infants have extensive experience with events in which hands produce effects on objects (e.g., releasing, catching, uncovering, pounding) and, given the appropriate physical knowledge, infants demonstrate the capacity to interpret the outcome of physical events involving hands (e.g., Baillargeon, Graber, DeVos, & Black, 1990; Baillargeon & Wang, 2002; Needham, 1999; Woodward & Sommerville, 2000). The shaking of objects to produce rattle-like sounds is a particularly common experience for infants, one in which they routinely observe and participate. These findings led us to predict that infants would be more likely to successfully interpret the test event if a hand was present, providing a means by which the objects could have produced the sounds.

However, it is possible that the hand played a different role from that hypothesized. One possibility is that the hand served, instead, as an attention-getting mechanism to orient infants' attention to the stage of the apparatus prior to presentation of the auditory event. According to this view, the presence of the hand is important because it draws infants' attention to the stage, but contact between the hand and the objects hidden behind the screen is not critical to infants' interpretation of the event. Another possibility is that the presence of the hand is not important to infants' processing and interpretation of the test event. On this view, infants' performance is unrelated to the presence or absence of the hand.

To test these competing hypotheses infants aged 4.5 months were assigned to one of three conditions: hand, hand no contact, and no hand. In the hand condition, infants were presented with a different-sounds event identical to that of Experiment 1 except that the rice- and bell-rattle sounds were replaced by two other rattle sounds. These sounds were produced by shaking a metal container filled with either metal tacks or glass marbles. Adult participants reported that these two rattle sounds were perceived as equally dissimilar as the sounds of Experiments 1 and 2.[3] In the hand no contact condition, infants were presented with events identical to those of the infants in the hand condition with the following exception: Rather than moving behind the screen, the hand withdrew from the apparatus and, after the two sounds were presented, reentered the apparatus on the other side of the screen. Hence, the hand was in view for the same amount of time in the hand condition and the hand no contact condition. However, because the hand exited the apparatus in the hand no contact condition, rather than moving behind the screen, the hand could not have acted on the objects. Finally, the infants in the no hand condition were presented with test events identical to those of the infants in the hand condition except that the hand was never present in the apparatus.

[3]Sixteen naive adults (*M* age = 19 years, range = 17–23 years) heard two successive rattle sounds presented in one of two orders: the tack rattle followed by the marble rattle, or the reverse. After hearing the sound pair, participants were asked to rate on a scale of 1 (*very similar*) to 5 (*very different*) how they perceived the sounds. Prior to the test trials, participants were presented with two practice trials with different sound pairs. The adults' mean difference rating in this experiment was compared to that of the adults from Experiment 2. However, because the participants in this experiment heard only one pair of test sounds, and the participants in Experiment 2 heard two pairs of test sounds (a mixed-model design was used in Experiment 2), only the ratings of the first pair of sounds for the latter group was used. A one-way ANOVA was conducted with sound type (rice and bell rattles, electronic tones, tack and marble rattles) as the between-subject factor. The main effect of sound type was not significant, $F(1, 45) < 1$. The adults' rating of the difference between the rice and bell rattles ($n = 16$, $M = 2.12$, $SD = 0.62$), the two electronic tones ($n = 16$, $M = 2.13$, $SD = 0.96$), and the tack and marble rattles ($n = 16$, $M = 1.81$, $SD = 0.66$) did not differ reliably. These results suggest that the adults perceived the three sound pairs as equally distinct.

If the hand is important because it provides a structure with which to interpret events involving inert sounding objects, the infants in the hand condition, but not the infants in the other two conditions, should successfully individuate the objects (i.e., should look reliably longer at the one-object display compared with the two-object display). Alternatively, if the hand is important because it orients infants' attention to the apparatus from which the auditory event will be presented, the infants in the two "hand" conditions, but not the infants in the no hand condition, should successfully individuate the objects. Finally, if the hand is irrelevant to infants' processing of the test event, then the infants in all three conditions should succeed on the individuation task.

Method

Participants

Participants were 24 male and 24 female infants (*M* = 4 months, 14 days; range = 3 months, 19 days–5 months, 6 days). Four additional infants were eliminated: 2 because of procedural problems, 1 because of fussiness, and 1 because he was an outlier (i.e., his mean looking time during the test trials was more than 2 *SD*s above the mean of the group). Eight infants were randomly assigned to each of six groups formed by crossing condition (hand, hand no contact, no hand) and test display (one or two objects).

Apparatus and Procedure

The apparatus and procedure were identical to those of Experiment 2 with three exceptions. First, the rice and bell rattles were replaced with rattles made by partially filling round metal containers (8 cm in diameter and 5.5 cm tall) with either small metal tacks or small glass marbles. Second, infants were presented with only different-sounds events. Third, in the hand no contact condition the slit behind the screen (through which the hand moved in the hand condition) was covered with a piece of foam core of the same pattern as the back wall of the apparatus; the hand was withdrawn and reinserted into the apparatus during the test event through two holes, 7.5 cm wide and 9 cm tall, one located to each side of the screen.

Interobserver agreement was measured for 33 of the infants and averaged 90%.

Results

Pretest Trials

The infants' looking times during the two pretest trials were averaged and analyzed by means of an ANOVA with condition and test display as between-subject factors. The main effect of condition was significant, $F(1, 42) = 7.06$, $p < .01$. Post hoc comparisons revealed that the infants in the hand (M = 24.3 sec, SD = 7.7) and the hand no contact (M = 22.8 sec, SD = 8.0) conditions looked reliably longer during the pretest trials than the infants in the no hand condition (M = 12.7 sec, SD = 11.7), $F(1, 42) = 6.97$, $p < .05$, but that the two hand conditions did not differ reliably from each other, $F(1, 42) < 1$. These findings indicate that the infants found the pretest displays that included a tilting hand and an upright screen more interesting than the pretest displays that included only an upright screen. The main effect of test display and the Condition × Test Display interaction were not significant, $F(1, 42) < 1$.

Test Trials

The infants' looking times during the final phase of the two test trials (Figure 3) were averaged and analyzed in the same manner as the pretest trials. The main effects of condition, $F(1, 42) = 4.22$, and test display, $F(1, 42) = 5.49$, were significant, $ps < .025$. In addition, the Condition × Test Display interaction was significant, $F(1, 42) = 3.48$, $p < .05$, partial eta-squared = .142. Planned comparisons revealed that the infants in the hand condition looked reliably longer at the one-object display (M = 31.4 sec, SD = 11.4) compared with the two-object display (M = 17.2 sec, SD = 6.9), $F(1, 42) = 11.88$, $p < .01$. A Mann–Whitney U test confirmed that the distributions of these two groups were reliably different, $Z = -2.21$, $p < .05$ (two-tailed). In contrast, the infants in the hand no contact and the no hand condition looked about equally at the one-object (hand no contact: M = 20.3 sec, SD = 8.7; no hand: M = 17.4 sec, SD = 6.3) and two-object (hand no contact: M = 20.8 sec, SD = 10.1; no hand: M = 14.4 sec, SD = 3.6) displays, $F(1, 42) < 1$.

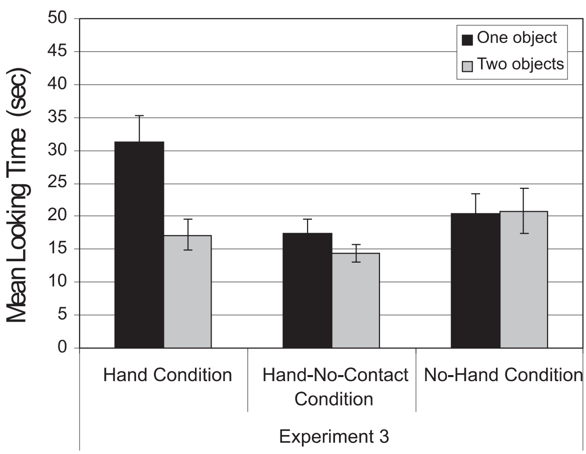

FIGURE 3 Infants' mean looking times (and standard errors) to the one-object and the two-object displays in Experiment 3.

Discussion

The infants in the hand condition, but not the infants in the other two conditions, looked reliably longer at the one-object display compared with the two-object display. These results suggest that the infants used the auditory information to individuate the objects only when the hand was present in the display and had access to the objects behind the screen. When the hand was present in the display but did not have access to the objects, or was not present in the display at all, the infants failed to use the acoustic difference between the two sounds to individuate the objects. Together, these results provide converging evidence, using a different set of stimuli, that infants use the sounds produced by rattles to individuate objects and reveal conditions under which they attend (or fail to attend) to rattle sounds. These results support the hypothesis that the presence of the hand in the display facilitates infants' processing of the different-sounds event because it provides a structure with which to interpret the rattle sounds, and argue against the hypothesis that the hand serves only as an attention-getting mechanism. The hand was present in both the hand condition and the hand no contact condition. However, only when the hand offered a mechanism by which inert objects could be shaken to produce a sound did the infants use the acoustic difference as the basis for object individuation.

These results add to a growing body of literature indicating that from an early age infants hold expectations for the kinds of events in which inert objects can engage. For example, young infants expect stationary inert objects to remain stationary unless acted on (Kotovsky & Baillargeon, 1998; Leslie & Keeble, 1987; Spelke et al., 1995). Once inert objects are placed in motion, infants expect them to follow continuous, predictable paths (Aguiar & Baillargeon, 2002; Baillargeon & Graber, 1987; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Spelke et al., 1995; Wilcox & Schweinle, 2002). In addition, infants expect inert objects that are acted on to undergo motions (Gibson, Owsley, & Johnston, 1978; Gibson, Owsley, Walker, & Megaw-Nyce, 1979; Gibson & Walker, 1984; Walker, Owsley, Megaw-Nyce, Gibson, & Bahrick, 1980) and to produce sounds (Bahrick, 1983, 1987, 1992, 2001) consistent with their physical structure. The research reported here adds to this composite picture by revealing, first, that infants recognize that distinct sounds signal the presence of distinct physical structures (i.e., objects) and, second, that infants hold expectations for the conditions under which inert objects produce sounds. More specifically, infants recognize that sounds are produced by the interaction between inert objects and their moving parts, and that for these objects to produce sounds they must be acted on. Additional research will be needed to assess the extent to which infants can identify the specific sounds that are associated with a given physical structure. (This is different than recognizing that different physical structures produce different sounds). Objects vary in many dimensions that can affect the sounds they produce (e.g., the material of which they are composed, whether they contain movable parts, etc.) and infants may find some dimensions more meaningful or salient than others. We suspect that with time and experience, infants' expectations for the sounds that objects produce become more fine-grained. That is, infants become more sophisticated in their ability to identify the acoustic signal that should be generated by specific physical structures and their interactions.

GENERAL DISCUSSION

In these experiments, 4.5-month-olds interpreted different-sounds events as involving two distinct objects when the sounds were produced by rattles that contained different collections (e.g., uncooked rice or small jingle bells) but not when the sounds were produced by an electronic keyboard. A similar pattern of results was obtained with adult participants. This is the first evidence of which we are aware that infants use auditory information to individuate objects and suggests that, similar to what has been observed in the visual domain (Tremoulet et al., 2001; Wilcox, 1999), infants are not equally sensitive to all types of information. At the same time, 4.5-month-olds were ambiguous in their interpretation of same-sounds events, regardless of whether the events involved rattle sounds or electronic tones. These data suggest that infants are more adept at interpreting different-sounds than same-sounds events. Together, these findings raise questions about the underlying basis for infants' greater sensitivity to rattle sounds and the extent to which auditory sensitivities can be manipulated.

The Underlying Basis for Infants' Greater Sensitivity to Rattle Sounds

Why do infants and adults demonstrate greater sensitivity to sounds produced by rattles than those produced by an electronic keyboard? One interpretation of these findings, and the one offered earlier, is that these two sets of sounds differ in how transparent they are at revealing the physical properties of the objects and the nature of their interactions. The sounds produced by the rattles (property-rich sounds) provide information about the physical structure of the objects involved. For example, from auditory information alone, one could infer that the different-sounds events of Experiments 1 and 3 involved two hollow, rigid objects, each containing a different collection of small rigid objects that moved inside when shaken. Because these sounds reveal something about the physical structure of the objects making them, they can be used to draw inferences about the number of objects present (e.g., each different-sounding rattle specifies a different physical structure for the object producing it). In contrast, to the novice, the electronic tones (property-poor sounds) revealed little about the physical properties of the objects involved in the event. Only someone experienced with keyboards or musical instruments would be able to draw inferences about the properties an object, or parts of an object, must possess to produce such a sound.

There are alternative interpretations for these findings, however. The rattle sounds and the electronic tones differed in other ways, any one of which could have contributed to the pattern of results obtained in these experiments. One way they differed was in the extent to which they are familiar to infants. Typically, young infants have more experience with the sounds objects make when they are shaken, hit against other objects, or dropped to the ground than with sounds that are produced electronically. Within the context of an individuation task, infants might be more likely to attend to and use sounds with which they are more familiar. Another way the sounds differed was in their complexity. The sounds produced by the interaction of objects in the physical world (e.g., the sound a jar of nails makes when it is shaken or the sound of a wooden ball as it hits a solid surface) are more rich and complex in their timbre—the organized pattern of harmonics—than sounds generated by a simple electronic keyboard. Infants may find these rich and complex sounds more interesting and, hence, may be more likely to draw on them when attempting to make sense of an auditory event. Remember, however, that in Experiment 2B infants were presented with electronic tones that varied on a number of dimensions, including the notes used, the relation between those notes, and timbre. Infants still failed to use the tones, which were more complex in their composition than the tones of Experiment 2, as the basis for individuating objects. Although certainly not conclusive, these results suggest that sound complexity is not a determining factor in object identity.[4]

Another possible explanation for the pattern of results obtained in these experiments has to do with the extent to which infants can discriminate between the sounds. Infants may find it easier to discriminate between sounds produced by rattles than sounds produced by an electronic keyboard for a number of reasons. Infants have more experience, and more varied experience, with rattle sounds than electronic tones. Typically, it is easier to discriminate between highly familiar stimuli than more novel stimuli. In addition, sounds produced by the interaction of objects and their parts—a physical event—might lead infants to draw on their physical knowledge to interpret the event. Access to this knowledge might facilitate infants' capacity to interpret and use the acoustic information available.

[4]There is an interesting body of research that focuses on adults' use of the acoustic signal to reason about auditory events. Investigators agree that mechanically produced (i.e., natural) sounds have complex acoustic properties, and that the acoustic signal is rich in information about the physical nature of the objects and their interactions. There is also evidence that specific components of the acoustic signal, such as temporal pattern or the frequency spectrum, are used to draw conclusions about object and event attributes (Freed, 1990; Klatzky, Pai, & Krotkov, 2000; Lutfi & Oh, 1997; Repp, 1987; van den Doel & Pai, 1998; Warren & Verbrugge, 1984; Wildes & Richards, 1988). However, there is no evidence that timbre alone is a particularly salient cue for reasoning about objects. These findings are consistent with the idea that harmonic complexity, per se, is not sufficient to support object individuation.

Finally, infants' greater sensitivity to rattle sounds compared with electronic tones may reflect a tendency to attend to sounds that are more predictable and constrained. Objects that emit electronic tones often produce a wide variety of tones and it is sometimes difficult to predict the sounds that will be produced by such objects. In contrast, objects that emit rattle sounds produce a small constrained set of sounds. When faced with an individuation problem, infants may attend to those sounds that are most reliable and predictable. In fact, because of the unpredictability associated with electronic tones, it is possible that young infants do not spontaneously link electronic tones to objects.

Although all of these explanations are tenable, there are several reasons to favor an explanation that focuses on the extent to which sounds reveal something about the physical nature of objects. First, there is converging evidence that sounds are critical to infants' and adults' interpretation of physical events and that some kinds of sounds are more useful and informative than others (e.g., Bahrick, 2001; Freed, 1990; Klatzky, Pai, & Krotkov, 2000; Walker-Andrews, 1994; Warren & Verbrugge, 1984). For example, in their work on intermodal processing Bahrick (2001) and Walker-Andrews (1994) distinguished between natural and artificial or arbitrary sounds. Natural sounds are those sounds that reflect a specific relation between sensory components of an event and the physical nature of the objects involved (e.g., a compressible object makes a soft "squishy" sound when hit against another object, whereas a rigid object makes a sharp, loud sound). In contrast, artificial or arbitrary sounds are those sounds that are more constrained by synchrony (e.g., a pull toy plays music as it is dragged across the floor) than by the properties of objects. Research indicates that young infants are more sensitive to natural than artificial or arbitrary sounds. More specifically, young infants are more likely to detect multimodal correspondences—to recognize the correspondence between visual and auditory components of an event—if the sounds heard are obviously tied to the physical structure of the visible object than if the sounds and the object are linked only in time (Bahrick, 2001; Walker-Andrews, 1994).

Second, there is evidence that infants link specific sounds to objects and recognize that different sounds are produced by structurally distinct objects (Bahrick, 1983, 1987, 1992, 2001). For example, Bahrick (2001) reported that by about 2 months infants recognize that the sound produced by a single large marble rolling inside of a plastic tube differs from that produced by many smaller marbles, and can correctly match an auditory event (the sound of one marble v. many marbles) with the appropriate visual display. In other words, young infants recognize that hollow objects that contain different "things" (e.g., a single vs. a collection) produce different sounds. In light of these findings, it is not only plausible, but quite probable, that the 4.5-month-olds in Experiment 1 recognized that the sounds emanating from behind the screen were produced by moving collections composed of different things. To be clear, we are not suggesting that 4.5-month-olds are capable of identifying what those particular things are; however, we are proposing that they are capable of recognizing that physically distinct objects or collections produce different sounds.

A third reason to favor a physical properties explanation has to do with the kind of information infants use to individuate objects in the visual domain. Recall that infants are more likely to use form features, such as shape and size, than surface features, such as color and luminance, as the basis for individuating objects (Tremelout et al., 2001; Wilcox, 1999; Woods & Wilcox, in press). We suspect that the developmental hierarchy observed in the visual domain favoring form features, and the developmental hierarchy observed in the auditory domain favoring property-rich features, reflect deeper and more general information processing biases. In the visual domain, we have argued that infants' greater sensitivity to form features reflects a bias to attend to those features that are intricately tied to objects, that make reliable and accurate predictions about the outcome of physical events, and that are most likely to remain stable over time (Wilcox, 1999; Wilcox & Chapa, 2004; Wilcox et al., 2003). A similar argument could be used to explain infants' greater sensitivity to property-rich sounds in the auditory domain. Because property-rich sounds are obviously tied to the physical structure of objects, they make reliable and accurate predictions about the kind of event in which an object will engage. For example, an object that produces a "squishy" contact sound is likely to deform when pressure is applied. Furthermore, because the physical structure of an object typically does not change, the sounds (or range of sounds) an object produces is likely to remain stable over time.

Despite the reasons previously outlined to prefer a physical-properties explanation for these findings, caution is warranted. Systematic investigation of alternative hypotheses will be required before firm conclusions can be drawn about the underlying basis for infants' greater sensitivity to rattle sounds compared with electronic tones.

Conditions That Might Facilitate Infants' Use of Property-Poor Sounds

To what extent can early auditory sensitivities be altered? Would infants demonstrate greater sensitivity to property-poor sounds under more supportive conditions? We proposed earlier that infants' greater sensitivity to property-rich sounds compared with property-poor sounds, like infants' greater sensitivity to visual form compared with surface features, reflects a bias to attend to object properties that are obviously linked to the physical nature of objects and that remain stable over time. Implicit in this analysis is that biases are not fixed but depend on the way in which the physical world is structured and on the kinds of experiences infants have in the physical world. One prediction that follows from this analysis is that modifications in the kinds of experiences infants have with property-poor sounds could alter infants' sensitivity to those sounds. If property-poor sounds could be made more meaningful, if they could be linked in a natural way to objects, infants would be more likely to attend to those sounds in an individuation task.

Although this hypothesis has yet to be tested, similar predictions have been made and tested in the visual domain. For example, Wilcox and her colleagues recently tested the prediction that infants' sensitivity to surface features can be altered by select experiences that link surface features, in a natural and meaningful way, to objects (Wilcox & Chapa, 2004; Wilcox, Chapa, & Woods, 2005). One procedure that has been particularly effective is to pair surface features with object properties, such as function, to which infants are already sensitive. In one series of experiments (Wilcox & Chapa, 2004), infants were presented with events, prior to the individuation task, in which the pattern or the color of an object predicted the function that it would serve. The results indicated that highlighting the functional value of attending to surface features, prior to the test session, increased infants' sensitivity to pattern and color information in the individuation task.

A similar procedure could be used to assess the extent to which infants can be primed to attend to electronic tones. One object property, besides function, to which infants are particularly sensitive are the mechanical properties of objects (e.g., Baillargeon, 1998; Leslie, 1994). Perhaps if infants were shown events in which the tone an object produced predicted the type of mechanical event in which it would engage (e.g., collision or occlusion) infants would demonstrate increased sensitivity to tones in a subsequent individuation task. Findings such as these would provide converging evidence for the idea that early sensitivities are not fixed but can be altered by select experiences and shed light on the mechanisms that support changing sensitivities during the first year.

In conclusion, this research is the first to demonstrate that infants use auditory information to individuate objects and suggests that infants are more sensitive to some types of auditory information than others. Future research is needed to, first, identify the underlying basis for infants' greater sensitivity to rattle sounds than electronic tones and, second, assess the extent to which early sensitivities can be modified. Regardless of the outcome of future research, the results of these experiments make clear that auditory information is an important component of object individuation in infants and adults, and current models will need to account for these findings.

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