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Shaking things up: Young infants' use of sound information for object individuation

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ABSTRACT

A search task was used to assess 5- to 7-month-olds' ability to use property-rich sounds to individuate objects. Results suggest that infants interpret an occlusion event involving two distinct rattle sounds as involving two objects but are unsure of how to interpret two identical rattle sounds.

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Infants use experience with and knowledge about auditory cues in many ways, including those for the purpose of interpreting physical events and learning about the physical world. By 4.5 months, infants recognize the visually discernable, physical components of an auditory stimulus (Spelke & Owsley, 1979; LaGasse, VanVorst, Brunner, & Zucker, 1999). For example, young infants can identify whether a sound event is produced by a single object, or multiple objects, moving inside a container and whether impact sounds are consistent with rigid or compressible objects (Bahrick, 1983, 1987). These results suggest that infants are sensitive to the temporal structure of multimodal events and can identify whether the sounds objects produce are consistent with the objects' physical properties. Most important to the present research is that infants may be capable of linking sounds to individual objects.

Infant researchers (Walker-Andrews, 1994; Wilcox & Smith, 2010; Wilcox, Woods, Tuggy, & Napoli, 2006) have suggested that object-related sounds can be classified as belonging to one of the two broad categories. One category, referred to here as *property-rich sounds*, includes sounds that are causally related to the interactions between objects and/or their parts and are directly linked to the physical properties of the objects (e.g., a compressible object makes a soft, squishy sound when hit against a hard surface whereas a rigid object makes a sharp, loud sound). These sounds reveal something about the physical composition and structure of objects and the nature of their interactions. The other category, referred to here as *property-poor sounds*, includes sounds that are more contrived and not directly or explicitly related to the physical properties of objects. For example, it is difficult to predict the sound a cell phone or an electronic toy will produce based on its physical composition; likewise, it is difficult to draw inferences about the physical properties of these objects on the basis of the sounds they produce or whether different sounds signal the presence of numerically distinct objects. Wilcox and colleagues (Wilcox & Smith, 2010; Wilcox et al., 2006) suggest that young infants, who have limited information processing capacities, are more likely to attend to sounds that are naturally and readily linked to objects. These sounds, which typically result from physical interactions, reveal something about the physical properties of the object and hence are more reliable predictors of an object's identity. A similar distinction between these types of sounds has been made in the adult literature, and there

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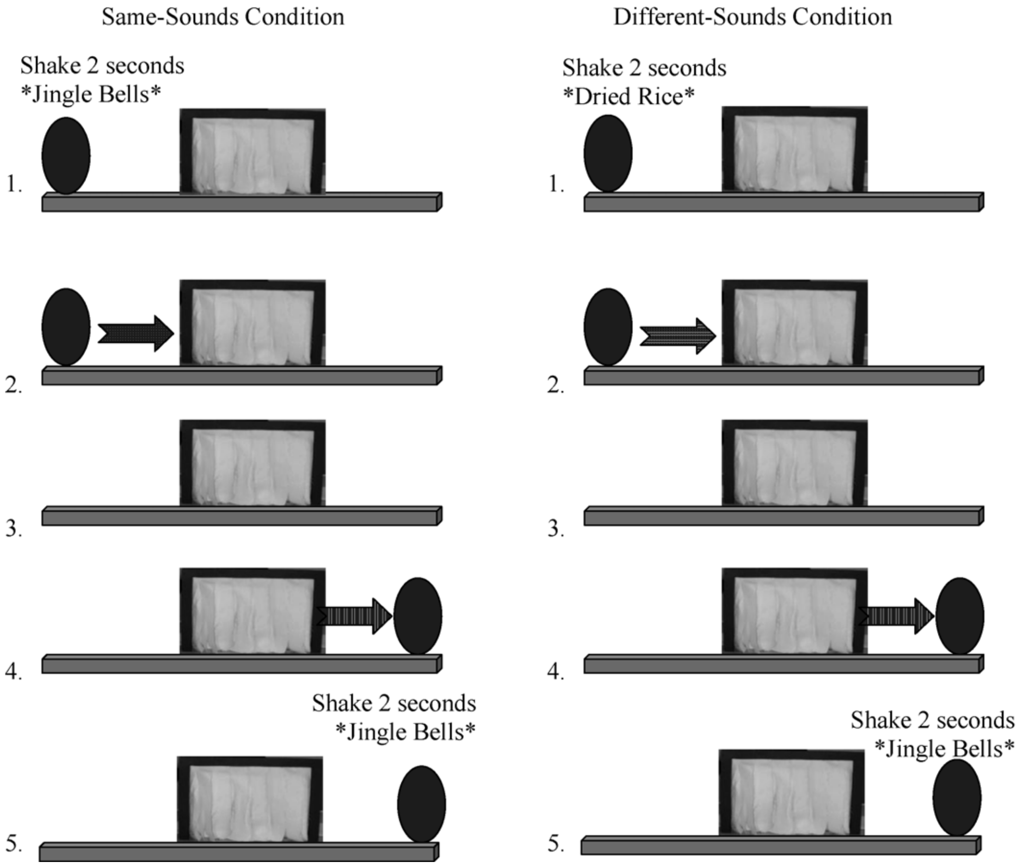

Fig. 1. Schematic of the initial phase of the test trial for the same-sounds and the different-sounds conditions. A hand (not pictured) manipulated the objects. Immediately following step 5 the platform was pushed forward so that it was directly in front of the infant and the infant was allowed to reach.

is evidence that adults find property-poor sounds more difficult to link to individual objects than property-rich sounds (Coward & Stevens, 2004; Gaver, 1986; Petocz et al., 2008).

To investigate infants' capacity to use sound information to individuate objects, Wilcox et al. (2006) presented 4.5-month-olds with an auditory event in which two different sounds, separated by a temporal gap, emanated from behind a screen. The screen was then lowered to reveal either one object or two objects on the platform. In the property-rich condition, the sounds were produced by shaking two rattles filled with different substances (dried rice or small bells). In the property-poor condition, an electronic keyboard was used to produce two tones that differed in pitch and timbre. The infants in the property-rich condition looked reliably longer at the one- than two-object display, suggesting that they interpreted the sound event as involving two objects and found the presence of a single object behind the screen unexpected. In contrast, the infants in the property-poor condition looked about equally at the two displays, as if they failed to draw a conclusion about the number of objects present. Subsequent studies revealed that infants use property-poor sounds to individuate objects by 9 months (Wilcox & Smith, 2010). Finally, when infants are presented with two identical property-rich sounds (e.g., two dried rice rattles), they look equally at a one- and two-object display, a finding that warrants further investigation (Wilcox et al., 2006).

The present experiment assessed 5- to 7-month-olds' ability to use property-rich sounds to individuate objects using a two-phase search task similar to that of McCurry, Wilcox, and Woods (2009), In the initial phase (Fig. 1), infants were presented with an occlusion event in which objects seen successively to each side of a screen produced either the same sound when shaken (e.g., both objects were filled with dried rice) or different sounds (e.g., one object was filled with dried rice and the other with small bells). In the final phase of the task, the platform was moved forward so that the screen was directly in front of the infant (the visible object sat at the right end of the platform) and the infant was allowed to search. If infants in the different-sounds condition interpret the event as involving two distinct objects, they should spend more time searching for the object behind the screen than reaching for the object at the end of the platform. If the infants in the same-sounds condition interpret the event as involving a single object that comes to rest at the end of the platform, they should spend more time reaching to the visible object than through the screen (since the screen does not hide an object).

1. Method

Participants were twenty-six 5- to 7-month-olds (15 male, *M* age = 6 months, 22 days; range = 5 months, 20 days–7 months, 15 days) and included 18 Caucasian, 3 African-American, 4 Hispanic, and 1 Asian/Pacific Islander infant. Five additional infants were eliminated because they failed to engage in the task. Infants were randomly assigned to the same- or different-sounds condition.

Infants sat in a parent's lap at a table 122 cm × 94 cm with a rectangular section 13 cm × 18 cm cut out of one side. To normalize infants' relation to the table, the seat was adjusted so that the tabletop was midway between the infant's bottom and the top of the infant's shoulder. The test event was presented on a wooden platform 80 cm × 40 cm partially covered with flannel. The occluding screen was a 30 cm × 22 cm blue wooden frame with four layers of vertically cut muslin attached. Infants could not see through the screen, which was firmly attached to the platform by wooden pegs placed equidistant from the right and left edges of the platform. The egg-shaped objects were 7.5 cm in diameter at their widest points and 11 cm tall, made of paper-mâché, lined with plastic, hollow, and painted blue. Two eggs were partially filled with uncooked rice and two with small jingle bells. A computer program, Raven Interactive Sound Analysis Software, was used to analyze sound frequency. The rice-rattle sound measured about 3000 Hz with spikes at 16,000 Hz and the bell-rattle sound about 2250–3000 Hz (without spikes).

In the initial phase of the *different-sounds* event (Fig. 1) the experimenter placed the object on the left end of the platform (infant's point-of-view). Once the infant looked at the object the experimenter shook the object for 2 s in an up-and-down motion (3 shakes per second at 70 db) then slid the object across the platform until it became fully occluded behind the fringed-screen. After an interval appropriate for the object's rate of motion, an identical object emerged from behind the other side of the screen and moved right until it reached the end of the platform where it was shaken for 2 s in the same manner as seen previously, but a different sound was heard. The object was then placed on the platform. The entire event was smooth in motion and 12 s in duration. Sound order was counterbalanced; seven infants heard dried rice first and six heard jingle bells first. An identical procedure was used for the initial phase of the *same-sounds* event except that the egg seen to the left and the right of the screen produced the same sound. Six infants heard jingle bells, and seven heard dried rice, on both sides of the screen.

Infants were given three familiarization trials designed to acquaint them with the experimental situation. In familiarization trial 1, infants were encouraged to touch and put their hand through the fringed-screen. First the experimenter pushed the platform within the infant's reach (defined as the infant being able to penetrate the fringed screen with at least half the length of their fingers with outstretched arm). Then they reached through the fringe and encouraged the infant to do the same. Once the infant placed his or her hand through the fringed-screen twice the trial ended. In familiarization trial 2, infants saw a small toy (a yellow plastic lion) sitting at the left edge of the platform; the experimenter squeaked the lion to get the infants' attention. Next, the experimenter moved the lion along the platform until it was fully hidden behind the screen, the screen was pushed forward, and infants were allowed to search for 20 s. If an infant failed to search the following steps were taken by the experimenter at 5 s intervals: (1) the lion was pushed forward to show a bulge in the fringe; (2) fringe was pulled back to reveal half of the lion; (3) the remaining fringe was pulled back to reveal the whole lion. If the infant still did not grasp the toy lion, the experimenter handed the lion to infant. The trial then ended and the platform was pulled back to its starting position. Familiarization trail 3 was identical to trial 2 except that the yellow lion was replaced with a red and blue rattle.

Following the familiarization trials, infants were presented with two test trials. During the initial phase of the test trials, infants were presented with the auditory event (same- or different-sounds) appropriate for their condition. Next, the platform was pushed forward to within the infant's reach (as determined by familiarization trial 1) and the infant was allowed to search for 20 s. Since we were interested in persistence of infants' search behavior, the object behind the fringed-screen was positioned so that infants would not come in contact with the object as they reached through the fringe. At the end of each test trial, the experimenter pulled back the platform to its starting position. The session was video-taped and later coded using Noldus ObserverPro 5.0 by two observers blind to the experimental condition (the sound was turned off during coding).

Familiarization trials 2 and 3 were coded by two naïve observers (and agreement was obtained), for the level of experimenter's help required for the infant to attain the hidden toy (familiarization trial 1 was not coded). The following scoring system was used: 0 = retrieved the toy without assistance; 1 = retrieved the toy after it was pushed forward to create a bulge in the fringe; 2 = retrieved the toy after half the toy was made visible; 3 = retrieved the toy when it became fully visible; 4 = failed to retrieve the fully visible toy but accepted it from the experimenter; 5 = failed to touch the toy under any condition.

Two independent and naïve observers also coded the test trials. During the initial phase of the test trials looking behavior was coded for infants' attention to the occlusion sequence. If the infant failed to see the occlusion of the object as the experimenter moved it behind the fringed-screen, or the emergence of the second object as the experimenter moved it out from behind the screen, the trial was excluded from analysis. Of the twenty-six infants included in the sample, 4 infants contributed only one of the two possible trials because they failed to watch the occlusion event. During the final phase of the test trial, which began after the experimenter pushed the platform forward to within the infant's reach, observers coded duration of purposeful, examining behaviors directed toward the screen (Ruff, 1986a,b). These behaviors included fingering the fringe, reaching through the fringe, and lifting the fringe. Observers also coded duration of reaching to the visible object, defined as the infant's arm extended at least half the distance from the front edge of the platform toward the object, with fingers outstretched and pointed in the direction of the object in view. Recall that the visible object at the end of the platform was positioned slightly out of the infant's reach so that infants were unable to successfully grasp the object, which might lead them to become distracted from further search and/or exploratory behavior. Inter-observer reliabilities for reaching behaviors in the final phase were obtained for 23 of the twenty-six infants and averaged 94%.

The two duration measures (time spent engaged in search behaviors directed to the screen and time spent reaching toward the visible object) were then used to calculate percent-to-screen reaching scores (reaching to fringed-screen/(reaching to fringed-screen + reaching to object)). The percent-to-screen scores were used in data analysis. If infants failed to reach toward the fringed-screen or the object in view during the final phase of the test trial, that trial was eliminated from analysis. Of the 26 infants tested, three infants contributed only one of two possible test trials because they refused to engage in reaching and/or search behavior. Preliminary analyses revealed no significant effects involving sex, sound order (different-sounds condition), or sound type (same-sounds condition) so these factors are not considered further.

2. Results

Infants' scores for familiarization trials 2 and 3 were analyzed separately. For each trial, a *t*-test was used to compare the performance of the infants in the two conditions. There were no significant differences between the groups in the degree to which they required assistance from the experimenter in order to retrieve the hidden object: familiarization trial 2, $t(24) < 1$ (same-sounds condition, $M = 2.69$ and SD = 1.11; different-sounds condition, $M = 3.00$ and SD = 0.71) and familiarization trial 3, $t(24) < 1$ (same-sounds condition, $M = 2.54$ and SD = 0.66; different-sounds condition, $M = 2.46$ and SD = 0.97). Further analysis using a chi-square test revealed that the two groups did not differ reliably in the distribution of scores for familiarization trial 2, $x^2 = 4.80$, df = 3, $p > .05$ and familiarization trial 3, $x^2 = 3.78$, df = 3, $p > .05$.

Infants' percent-to-screen scores were averaged across the two test trials and a grand mean for each condition was calculated. A one-way analysis of variance (ANOVA) was performed on the grand means with condition (same- or different-sounds) as the between-subjects' factor. The main effect of condition was significant, $F(1, 24) = 9.95$, $p < .01$, $\eta p^2 = .29$. The infants who heard the different-sounds event ($M = 92.12$ and SD = 15.71) spent a greater percentage of time reaching toward the fringed-screen than the infants who heard the same-sounds event ($M = 53.59$ and SD = 41.14). We also assessed whether the percentage of time spent reaching toward the fringed-screen differed from chance (50%) for each condition. The infants in the different-sounds condition directed significantly more searching behavior toward the fringed-screen than expected by chance, $t(12) = 9.67$, $p < .001$, Cohen's $d = 5.58$. In contrast, the infants in the same-sounds condition did not direct significantly more searching behaviors toward the fringed-screen than expected by chance, $t(12) < 1$. Non-parametric revealed that 12/13 of the different-sounds infants acted more on the fringed screen than the object (binomial $p < .01$) whereas only 7/13 in the same-sounds infants acted more on the fringed screen than the object (binomial $p > 05$). These were based on duration of reaching behaviors toward the fringed screen (same-sounds $M = 3.00$ and SD = 2.62; different-sounds $M = 5.49$ and SD = 4.32) and the object in view (same-sounds $M = 2.45$ and SD = 2.86; different-sounds $M = 0.32$ and SD = 0.71).

3. Discussion

The results revealed that infants in the different-sounds condition reached significantly more to the fringed-screen than expected by chance, suggesting that they interpreted the different-sounds event as involving two objects, one of which was hidden behind the screen at the end of the occlusion sequence. That is, infants perceived that two objects produced the two sounds and, since only one object was visible on the platform, the second object must still be behind the screen. In contrast, infants in the same-sounds condition did not reach more to the fringed-screen than expected by chance, suggesting that they were ambiguous in their interpretation of the same-sounds event. That is, infants were unsure of whether the two sounds were produced by the same object shaken twice or by two objects with similar physical structures, one of which remained hidden behind the screen. Finally, the different-sounds infants spent a greater percentage of time reaching through the fringed-screen than the same-sounds infants. The fact that the different-sounds infants were more persistent in their reaching to the fringed-screen than the same-sounds infants suggests that the former, but not the latter, interpreted the occlusion sequence as involving two objects.

Together, these results provide converging evidence for the conclusion that young infants use property-rich sounds to individuate objects. Further, they build on previous results in the following way: in the violation-of-expectation studies of Wilcox et al. (2006), infants looked about equally at a one- and two-object display after hearing a property-rich same-sounds event similar to that of the present experiment (they looked longer at a one- than two-object display following a property-rich different-sounds event). One interpretation of this finding is that infants were uncertain as to how to interpret the same-sounds event. As the event unfolded before them, infants recognized that one object or two physically identical objects could produce the event. Hence, in the final phase of the test event the infants looked equally at the one- and two-object display. An alternative interpretation of the violation-of-expectation data is that infants interpreted the same-sounds event as involving a single object but once the screen was lowered to reveal two objects they recognized (at that point in time) that the event could have been produced by two objects with identical physical structures. Hence, they did not demonstrate prolonged looking to the two-object display.

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The search task allows us to distinguish between these two interpretations of the same-sounds violation-of-expectation data. Infants' persistence at searching behind the screen following the occlusion sequence reveals the extent to which infants interpreted the occlusion event as involving one object or two physically distinct objects. The fact that the infants in the same-sounds condition reached about equally to the visible object and the fringed-screen suggests that the infants were unsure of whether the event involved one object or two objects; they did not interpret the event as involving only a single object. Infants' failure to form a strong interpretation of the same-sounds event may reflect the kinds of sound experiences infants have with sound-producing objects in the physical world. Objects with identical physical structures do exist (i.e., two blocks or two pacifiers) and produce similar sounds when acted upon. At the same time, a single object can produce the same sound when acted upon twice. Hence, two presentations of a similar-sounding object could mean one object or two objects and infants respond accordingly. Only when the two presentations are accompanied by two distinct sounds, do infants interpret the event as involving two objects.

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