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The development of infants' use of property-poor sounds to individuate objects

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ABSTRACT

There is evidence that infants as young as 4.5 months use property-rich but not property-poor sounds as the basis for individuating objects (Wilcox, Woods, Tuggy, & Napoli, 2006). The current research sought to identify the age at which infants demonstrate the capacity to use property-poor sounds. Using the task of Wilcox et al., infants aged 7 and 9 months were tested. The results revealed that 9- but not 7-month-olds demonstrated sensitivity to property-poor sounds (electronic tones) in an object individuation task. Additional results confirmed that the younger infants were sensitive to property-rich sounds (rattle sounds). These are the first positive results obtained with property-poor sounds in infants and lay the foundation for future research to identify the underlying basis for the developmental hierarchy favoring property-rich over property-poor sounds and possible mechanisms for change.

Object individuation, the capacity to determine whether two perceptual encounters belong to the same object or two different objects, is a milestone in early cognitive development. The extent to which infants perceive an object as one they experienced previously, or as a new object, influences the way infants think about and interact with that object. There is evidence that infants can draw on multiple sources of information as the basis for individuating objects (e.g., Aguiar & Baillargeon, 2002; Bonnatti, Frot, Zangl, & Mehler, 2002; Spelke, Kestenbaum, Simons, & Wein, 1995; Wilcox & Baillargeon, 1998a; Wilcox & Baillargeon, 1998b; Wilcox & Schweinle, 2003; Xu, 2002). At the same time, there appear to be developmental hierarchies in the type of information to which infants attend (Wilcox, 1999; Wilcox, Woods, Tuggy, & Napoli, 2006; Woods & Wilcox, 2006; Woods & Wilcox, 2010). For example, in the visual domain infants use form features (e.g., shape and size) as the basis for individuating objects at 4.5 months but do not use surface features (e.g., pattern, color, or luminance) until 7.5 months or later (Wilcox, 1999; Woods & Wilcox, 2006, 2010).

A number of researchers (Coward & Stevens, 2004; Walker-Andrews, 1994; Wilcox et al., 2006; also see Gibson, 1979) have suggested that auditory information can be broadly construed as belonging to two main categories: (1) sounds closely tied to, and that arise from, the physical properties of objects and their interactions (e.g., the sound of a metal bar hitting a glass surface or a handful of marbles bouncing on a tile floor) or (2) sounds that are more arbitrary but that we learn to associate with objects (e.g., a fire truck's siren or the ringing of a telephone). Within the infancy literature, Walker-Andrews (1994) first described this distinction as that between natural and artificial sounds. Natural sounds are those that reflect a specific relation between sensory components of an event and the physical structure of the objects involved (e.g., a compressible objects makes a soft, squishy sound when hit against another object whereas a rigid object makes a sharp, loud sound). In contrast, arbitrary sounds are those sounds that are more constrained by synchrony than by the properties of the objects

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themselves (e.g., a pull toy that plays music as it is dragged across the floor). More recently, Wilcox and her colleagues (Smith & Wilcox, submitted for publication-a; Wilcox et al., 2006) have used the terms property-rich and property-poor. ***Property-rich*** sounds are causally related to the interactions between objects and/or their parts and are directly linked to the physical properties of the objects. There are many components of sound that provide reliable information about the nature of objects and their interactions; for example, frequency is an accurate predictor of object size and temporal and spectral components are predictors of quantity and substance. Even young infants hold expectations for the kinds of sounds objects should produce when they move and interact and recognize that objects with different physical structures produce different-sounds (Bahrick, 1983; Bahrick, 1987; Bahrick, 1992, 2001; Pickens, 1994). For example, 3.5-month-olds recognize that the impact sounds of rigid objects differ from those of compressible objects (Bahrick, 1983). In contrast, ***property-poor*** sounds are not directly or explicitly related to the physical properties of objects or the nature of their interactions. Although it is true that all sounds are caused by physical interactions, this relation is less obvious for some object–sound pairs than others. 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.

We 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 and are reliable predictors of an object's identity. In support of this hypothesis, there is evidence that children and adults are more sensitive to sounds that are obviously and directly related to physical objects and the events in which they engage than sounds that are more arbitrary and determined by social convention (Coward & Stevens, 2004; Jacko & Rosenthal, 1997). This is not to say, however, that property-poor sounds never play a role in object individuation. We expect that as infants' gain experience in the physical world and attend to a wider array of information they learn the value of associating more arbitrary sounds with specific objects. Although property-poor sounds are not obviously tied to objects, learning associations between non-obvious sounds and specific objects increases the likelihood that infants will be able to identify individuals in select situations. Indeed, Coward and Stevens (2004) reported that within a testing situation, initially adults have difficulty learning the association between non-obvious sounds and the objects to which they are related. However, with time and experience adults form these associations and, eventually, these associations can be learned with great accuracy (see Jacko & Rosenthal, 1997 for related results with children).

Recently, Wilcox et al. (2006) investigated the extent to which infants use property-rich and property-poor sounds to individuate objects. Infants aged 4.5 months were presented with an auditory event in which two sounds, separated by a temporal gap, emanated from behind a screen. After the sound event, the screen was lowered to reveal either one object or two objects sitting on the platform. In the property-rich condition, the sounds were produced by shaking two rattles filled with different substances (e.g., 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-object than the 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, suggesting that they were ambiguous in their interpretation of the sound event. Additional studies replicated and extended these findings with infants aged 5–7 months using a search method (Smith & Wilcox, submitted for publication-a).

One might be concerned that infants' greater sensitivity to property-rich than property-poor sounds can be explained primarily by sound complexity. The sounds produced by the interaction of objects in the physical world are more rich and complex in their timbre – the organized pattern of harmonics – than sounds generated by a simple electronic keyboard (i.e., contain more acoustic information). Infants may find these rich and complex sounds more interesting and distinct and hence, may be more likely to attend to them within the context of physical events. Wilcox et al. (2006) tested this possibility by presenting infants with property-poor different-sounds events in which electronic tones were made to vary on a number of dimensions, including the notes used, the relation between those notes, and timbre. For example, one property-poor sound was composed of the notes E flat and A (discordant tones) played simultaneously and the other was composed of the notes C and E (concordant tones) played simultaneously; each set of tones had a different timbre. Infants still failed to use the electronic tones as the basis for individuating the objects, even when they were made more complex in their composition (for related results with older infants see Xu, 2002). These findings suggest that infants' greater sensitivity to property-rich than property-poor sounds cannot be attributed to sound complexity.

Although it is now clear that young infants are more sensitive to property-rich than property-poor sounds, what remains open to speculation is the age at which infants first use property-poor sounds to individuate objects. If we are to identify the underlying basis for infants' greater sensitivity to property-rich than property-poor sounds, and the mechanisms that support infants' changing sensitivities, we must ascertain when these sensitivities emerge.

1. Experiment 1A

To identify the age at which infants use property-poor sounds to individuate objects, 7-month-olds were presented with the property-poor different-sounds event of Wilcox et al. (2006; Fig. 1). This age group was chosen for two reasons. First, within the visual domain infants begin to use surface features to individuate objects between 7 and 12 months (Wilcox, 1999). If the developmental hierarchy observed in the visual domain reflects an increased capacity to draw on information that is less directly linked to the physical structure of objects (surface features are less directly linked to the physical

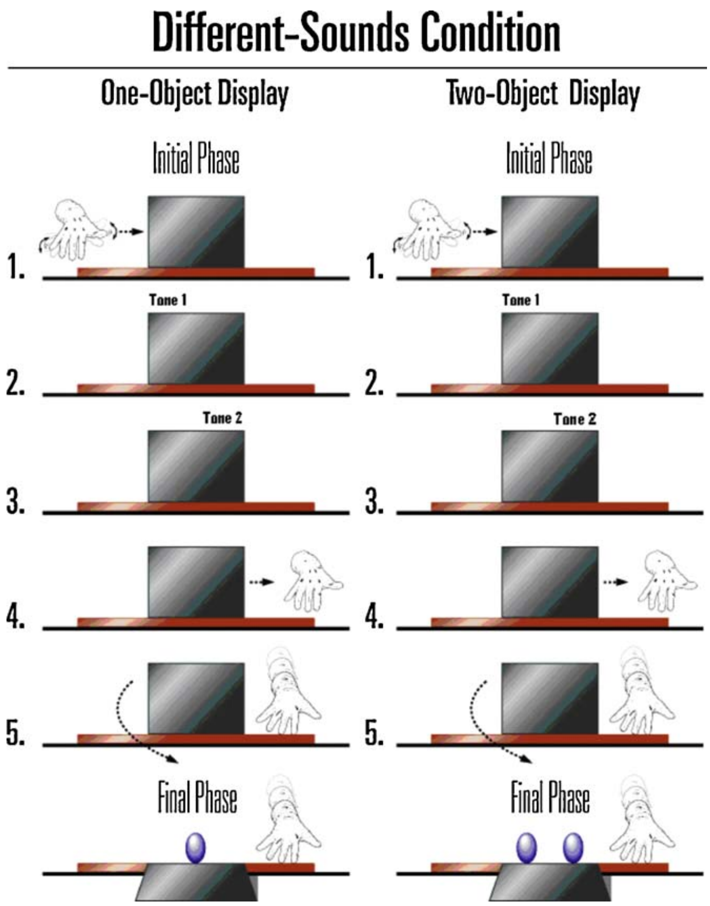

Fig. 1. Test events of the property-poor, different-sounds condition of Experiments 1A and 2. In the initial phase of the test event the gloved hand moved behind the screen (Step 1), two different tones were heard separated by a temporal gap (Steps 2 and 3), the hand emerged from behind the screen (Step 4), and the screen was lowered (Step 5). In the final phase of the event, infants saw either one egg (one-object display) or two eggs (two-object display) on the platform. The test events of the same-sounds condition were identical to those of the different-sounds condition except that infants heard two identical sounds (i.e., Tone 1 twice or Tone 2 twice).

structure of objects than form features), then 7 months is a reasonable target within the auditory domain. Second, increased motor capacities between 5 and 7 months provide infants with more opportunities for object exploration and, hence, for learning about property-poor sound. The sounds were produced by an electronic keyboard and differed in pitch and timbre. If infants use the difference in sound to individuate the objects, they should find the one-object but not the two-object display unexpected (i.e., look reliably longer at the one- than the two-object display). In contrast, if infants fail to use the sound difference to individuate the objects, they should look about equally at the one- and two-object display. To control for preferences for displays containing one object or two objects, infants were also tested in a same-sounds condition that was identical to the different-sounds condition except that the two sounds were identical.

1.1. Methods

1.1.1. Participants

Thirty-two healthy full-term infants, 14 male (M = 7 months, 6 days; range = 6 months, 2 days to 8 months, 18 days). Two additional infants were tested but eliminated from analyses because of crying or procedural problems. Eight infants were randomly assigned to each of four groups formed by crossing condition (different or same-sounds) and test display (one or two objects).

1.1.2. Apparatus and objects

The events were presented in a puppet-stage apparatus (213 cm high × 105 cm wide × 43.5 cm deep) whose floor and walls were cream-colored. A platform (1 cm × 91 cm × 19 cm) lay flush against the back wall, centered between the left and right walls. The test objects were egg-shaped (7.5 cm in diameter at their widest point and 11 cm tall), hollow, made of plastic and covered with blue papier-mâché. Each egg contained a small speaker and each speaker was connected to a Youthtronics 32 key play keyboard (there were two speaker-filled eggs and two keyboards). Hence, all sounds originated from within an object. Infants heard two sounds (Tone 1 and Tone 2 or Tone 1 (or Tone 2) heard twice) separated by 2 s of silence. Tone 1 was treble F played as a violin and Tone 2 was middle C played as a mandolin. Although the violin and mandolin sounds differed in timbre, they were not obvious replications of a violin and mandolin. The sounds were equated for duration (2 s each) and amplitude (68 dB). To equate the conditions (see below) as much as possible, two objects were used to produce the different- and the same-sounds events. The occluding screen was 32 cm high × 35 cm wide, made of green cardboard, and attached to a wooden dowel that extended out of the right side of the apparatus through a small hole in the wall. By rotating the dowel's right end (out of the infants' view), an experimenter could lower the screen to the apparatus floor. During the initial phase of the test event, the objects were moved along the platform by a gloved hand that entered the apparatus through a slit in the back wall.

1.1.3. Events

Three trained experimenters worked together to produce the test events. The first experimenter (E1) moved the egg-shaped objects, the second experimenter (E2) surreptitiously manipulated the eggs from behind the screen, and the third experimenter (E3) lowered the occluding screen at the end of the auditory event. The numbers in parentheses indicate the time taken to produce the actions described. 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 s (the sound was turned off).

Infants in the ***different-sounds condition*** (Fig. 1) first saw two pretest trials designed to acquaint them with the testing situation. In the first pretest trial, E1's right gloved hand was seen tilting (1 s each tilt) to the left of the screen. In the second pretest trial, E1's hand underwent the same motions to the right of the screen. After the two pretest trials, infants saw two test trials. Each test trial began with E1's hand tilting to the left of the screen. The two eggs sat behind the screen next to each other separated by 1.5 cm. After the computer signaled that the infant had looked at the hand for 2 cumulative s, the initial phase of the test event began. E1's hand stopped tilting (1 s), moved behind the left edge of the screen (2 s), grasped the left egg (1 s) and E2 played Tone 1 (2 s). Next, E1 gently replaced the left egg on the platform (1 s), grasped the right egg (1 s), E2 played Tone 2 (2 s), and E1 gently replaced the right egg on the platform (1 s). For half of the infants Tone 1 was heard first; for the other half Tone 2 was heard first. Sound production was monitored by E3; 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 s) and came to rest at the right edge of the platform. During the last 2 s the E2 surreptitiously opened a small door in the back of the apparatus (directly behind the occluding screen) and either removed one of the eggs (one-object display) or made a motion as if removing one of the eggs (two-object display). Finally, the second experimenter lowered the screen to the apparatus floor (2 s). During the final phase of the test event, infants saw either one egg (one-object display) or two eggs (two-object display) centered on the platform.

Infants in the ***same-sounds condition*** saw a test event that was identical to that of the different-sounds condition with one exception: The same tone was used for both sound presentations. Half of the infants heard Tone 1 twice and the other half heard Tone 2 twice.

1.1.4. Procedure

Infants sat on a parent's lap centered in front of the apparatus with their head 78 cm from the objects on the stage. The parent was asked not to interact with the infant during the experiment and to close his or her eyes during the test events.

Infants were first presented with the two pretest trials described above. The pretest trials ended when the infant either (a) looked away for 2 consecutive s after having looked for at least 5 cumulative s or (b) looked for 30 cumulative s without looking away for 2 consecutive s. Next, infants saw the test event appropriate for their condition on two successive trials. Looking time during the initial phase was recorded but not reported because infants looked almost continuously during the initial phase. The final phase of each trial ended when the infant either (a) looked away for 1 s after having looked for at least 10 cumulative s or (b) looked for 60 cumulative s without looking away for 1 s. The criteria for ending the final phase of the test event differed from that for ending the pretest trials because the pretest trials were meant only to equate the infants with the testing situation.

Infants' looking behavior was monitored by two observers who watched infants through peepholes in 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 observer held a button connected to a computer and depressed the button when the infant watched the events. Looking times recorded by the primary observer determined when a trial had ended and were used in the data analyses. Inter-observer agreement averaged 94%.

Preliminary analyses of Experiments 1A, 1B, and 2 data revealed no reliable sex differences on infants' responses to the test events. Preliminary analyses also revealed no reliable effects of trial on looking times. Hence, the data were collapsed across sex and trial in all experiments.

[1] In Experiments 1A, 1B, and 2 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 98 primary observers that responded 52 guessed correctly, a performance not significantly different from chance (cumulative binomial probability, $p > .05$).

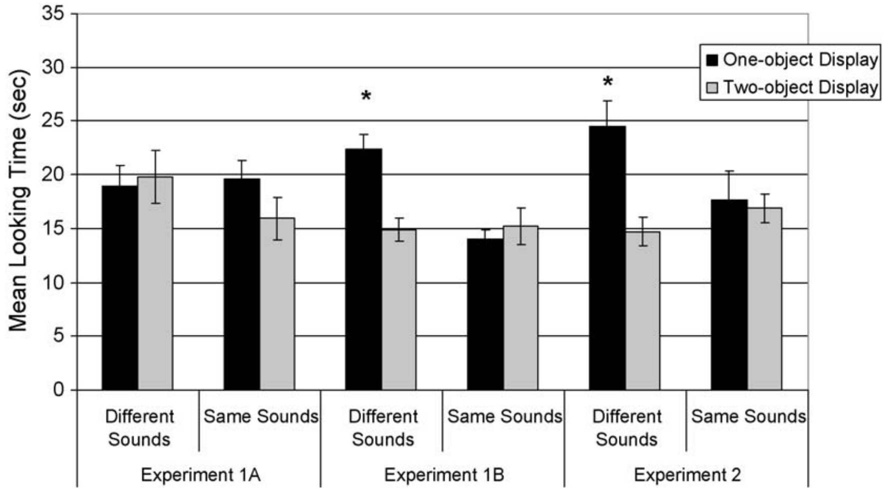

Fig. 2. Infants' mean looking times (and standard errors) to the one-object and the two-object display in Experiment 1A (property-poor sounds, 7-month-olds), Experiment 1B (property-rich sounds, 7-month-olds) and Experiment 2 (property-poor sounds, 9-month-olds) after hearing the different- or same-sound property-poor event. *$p < .05$ for that comparison.

1.2. Results and discussion

1.2.1. Pretest trials

Infants' looking times during the two pretest trials were averaged and analyzed by means of an ANOVA with condition and test display as between-subjects factors. The main effects of condition and test display, and the interaction between these two factors, were not significant, $F(1, 28)$s < 1, 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 = 22.2 s, SD = 5.6, and two-object display, M = 23.9 s, SD = 4.8; same-sounds, one-object display, M = 21.9 s, SD = 5.0, and two-object display, M = 21.3 s, SD = 8.9).

1.2.2. Test trials

Infants' looking times during the final phase of the two test trials (Fig. 2) were averaged and analyzed in the same manner as the pretest trials. The main effects and the interaction were not significant, all $F(1, 28)$s < 1.4. Planned comparisons confirmed that the infants who heard the different-sounds event looked about equally at the one-object (N = 8, M = 18.9 s, SD = 5.7) and the two-object (N = 8, M = 19.8 s, SD = 7.0) display, as did the infants who heard the same-sounds event (one-object display, N = 8, M = 19.6 s, SD = 4.7; two-object display, N = 8, M = 15.9 s, SD = 5.6), $F(1, 28)$s < 1. Together, these results suggest that 7-month-olds do not use property-poor sounds as the basis for individuating objects. Before drawing firm conclusions about these null results, however, alternative interpretations of the data need to be tested. It is possible that this paradigm is not sufficiently sensitive to use with 7-month-olds or that 7-month-olds do not use sound information to individuate objects. To this end, we assessed 7-month-olds' response to property-rich sounds.

2. Experiment 1B

To test 7-month-olds' capacity to use property-rich sounds to individuate objects, the property-rich test events of Wilcox et al. (2006) were used. These events were identical to the different- and same-sounds events of Experiment 1A except that the tones produced by the electronic keyboard were replaced with sounds produced by shaking an object partially filled with dried rice or small metal jingle bells. In the different-sounds event, one object contained dried rice and the other jingle bells. In the same-sounds event, both objects contained the same substance (rice or bells).

2.1. Methods

2.1.1. Participants

Thirty-two healthy full-term infants, 15 male (M = 7 months, 17 days; range = 6 months, 19 days to 8 months, 14 days). Six additional infants were tested but eliminated from the analyses because of procedural problems. Eight infants were randomly assigned to each of four groups formed by crossing condition (different or same-sounds) and test display (one or two objects).

2.1.2. Apparatus, objects, and events

The apparatus, objects, and events were identical to those of Experiment 1A except that the speakers were removed from the egg-shaped objects and the objects were filled with dried rice or small metal jingle bells. To produce the rattle sounds the egg-shaped object was moved in a circular motion for 2 s (four full rotations per sec) behind the screen and then returned to the platform. The circular motion produced a continuous rattle sound as the internal elements made contact with the inside wall of the egg. In the different-sounds condition half the infants heard the rice-rattle sound followed by the bell-rattle sound and half heard the reverse. In the same-sounds condition half the infants heard the rice-rattle twice and half heard the bell-rattle twice.

2.1.3. Procedure

The procedure was identical to that of Experiment 1A. Inter-observer agreement averaged 94%.

2.2. Results and discussion

2.2.1. Pretest trials

Infants' looking times during the two pretest trials were averaged and analyzed using the same method as in Experiment 1A. The main effects of condition and test display, and the interaction between these two factors, were not significant, $F(1, 28)\text{s} < 1.2$. The infants in the four groups did not differ reliably in their mean looking times during the pretest trials (different-sounds, one-object display, $M = 19.6$ s, SD = 8.7, and two-object display, $M = 17.3$ s, SD = 5.9; same-sounds, one-object display, $M = 20.3$ s, SD = 7.3, and two-object display, $M = 17.2$ s, SD = 5.8).

2.2.2. Test trials

Infants' looking times during the final phase of the two test trials were averaged (Fig. 2) and analyzed in the same manner as the pretest trials. The main effects of condition, $F(1, 28) = 13.55$, $p < .01$, $\eta p^2 = .33$, and test display, $F(1, 28) = 8.18$, $p < .01$, $\eta p^2 = .23$, were significant, as was the condition × test display interaction, $F(1, 28) = 15.31$, $p < .01$; $\eta p^2 = .35$. Planned comparisons indicated that in the different-sounds condition, infants who saw the one-object display ($M = 22.4$ s, SD = 3.9) looked reliably longer those who saw the two-object display ($M = 14.9$ s, SD = 3.2), $t(14) = 4.26$, $p < .01$. A Mann–Whitney U test confirmed that the distribution of looking times for these two groups differed reliably, $Z = -3.05$, $p = <.01$. In contrast, in the same-sounds condition, infants who saw the one-object ($M = 14.0$ s, SD = 1.7) and the two-object ($M = 15.2$ s, SD = 3.4) display looked about equally, $t(14) < 1$. In addition, the infants in the different-sounds condition looked significantly longer at the one-object display than the infants in the same-sounds condition, $t(14) = 5.68$, $p < .001$.

Finally, the looking times of the infants in the different-sounds condition of Experiment 1A (property-poor sounds) were compared to those of the infants in the different-sounds condition of Experiment 1B (property-rich sounds) using an ANOVA with experiment and test display as between-subjects factors. The experiment × test display interaction was significant, $F(1, 28) = 5.40$, $p < .05$; $\eta p^2 = .16$, indicating that infants responded differently to the property-rich than the property-poor different-sounds events (i.e., the infants who heard two property-rich, not but property-poor, sounds looked longer at the one- than the two-object display). Together, these results indicate that 7-month-olds, who fail to use property-poor sounds as the basis for individuating objects, do use property-rich sounds for that purpose.[2]

3. Experiment 2

Experiment 2 assessed slightly older 9-month-olds' sensitivity to property-poor sounds.

3.1. Methods

3.1.1. Participants

Thirty-four healthy full-term infants, 17 M ($M = 9$ months, 19 days; range = 9 months, 0 days to 10 months, 22 days). One additional infant was tested but eliminated from the analyses because of procedural problems. Infants were randomly assigned to the different-sounds ($N = 16$) or the same-sounds ($N = 18$) condition; half the infants saw the one-object display.

3.1.2. Apparatus and objects, events, and procedure

The apparatus and objects, events, and procedure were identical to those of Experiment 1A. Seven infants in the different-sounds condition heard Tone 1 first. Eight infants in the same-sounds condition heard Tone 1.

3.2. Results and discussion

3.2.1. Pretest trials

Looking times were analyzed in the same way as Experiment 1A. The main effects of condition and test display, $F(1, 30)\text{s} < 1.40$, and the interaction between these two factors, $F(1, 28) = 3.26$, $p > .05$, were not significant, indicating that the

[2] One might question why infants attach one set of sounds (property-rich) but not another (property-poor) to objects that are identical in outward appearance. Because the objects were opaque the infants could not see that they contained different collections of smaller rigid objects. The interpretation offered here is not that the infants understood how and why the objects produced different sounds but rather that the infants recognized that the two different sounds were produced by objects with different physical structures, and that different physical structures signify numerically distinct objects.

infants in the four groups did not differ reliably in their mean looking times during the pretest trials (different-sounds, one-object display, $M = 23.2$ s, $SD = 6.9$, and two-object display, $M = 21.7$ s, $SD = 7.8$; same-sounds, one-object display, $M = 16.9$ s, $SD = 7.3$, and two-object display, $M = 24.1$ s, $SD = 5.9$).

3.2.2. Test trials

Analysis of mean looking times (Fig. 2) revealed that the main effect of condition was not significant, $F(1, 30) < 1.40$. The main effect of test display was significant, $F(1, 30) = 7.14$, $p < .025$, and the condition × test display interaction was significant, $F(1, 30) = 5.20$, $p < .05$; $\eta p^2 = .15$. Planned comparisons indicated that the infants in the different-sounds condition who saw the one-object display ($M = 24.5$ s, $SD = 6.7$) looked longer than those who saw the two-object display ($M = 14.7$ s, $SD = 3.9$), $t(14) = 3.58$, $p < .01$. A Mann–Whitney U test confirmed that the distribution of looking times for these two groups differed reliably, $Z = -2.73$, $p = <.01$. In contrast, the infants in the same-sounds condition who saw the one-object ($N = 9$, $M = 17.7$ s, $SD = 7.6$) and the two-object ($N = 8$, $M = 16.9$ s, $SD = 3.8$) display looked about equally, $t(16) < 1$. Lastly, the infants in the different-sounds condition looked significantly longer at the one-object display than the infants in the same-sounds condition, $t(15) = 1.94$, $p < .05$ (one-tail).

Finally, the looking times of the 7-month-olds in the different-sounds condition of Experiment 1A were compared to those of the 9-month-olds in the different-sounds condition of Experiment 2 with age group and test display as between-subjects factors. The age group × test display interaction was significant, $F(1, 28) = 6.56$, $p < .025$; $\eta p^2 = .19$, indicating that 7- and 9-month-olds responded differently to the property-poor different-sounds events (i.e., the 9- but not the 7-month-olds looked longer at the one- than the two-object display).

Together, these data suggest that the 9-month-olds, unlike the 7-month-olds, interpreted the different-sounds event as involving two objects and found the presence of a single object on the platform unexpected. This outcome cannot be explained by a preference for one- over two-object displays. The infants in the same-sounds condition, who also saw one- and two-object displays, did not demonstrate prolonged looking to the one-object display. In addition, this outcome cannot be explained by infants' use of temporal parameters. The infants in the same-sound conditions heard two sounds separated by a temporal gap, and they did not show prolonged looking to the one-object display.

4. General discussion

Collectively, these results suggest that 9- but not 7-month-olds use property-poor sounds as the basis for individuating objects. These results extend previous findings by demonstrating the 7-month-olds, like 4.5-month-olds, are sensitive to property-rich but not property-poor sounds, and that infants first demonstrate sensitivity to property-poor sounds later in the first year. Why might be infants slower to identify property-poor sounds as relevant to the individuation problem?

One possibility is that infants have more experience with property-rich than property-poor sounds. Property-rich sounds are an integral part of the physical world, and infants experience them every time they interact with objects or watch others interact with objects. In contrast, property-poor sounds (albeit more common in the electronic age) are not experienced as frequently. To explore this possibility, Smith and Wilcox (submitted for publication-b) examined the sound-producing behaviors of 6.5- and 12.5-month-olds in a free-play situation. Infants were presented with objects that made both property-rich and property-poor sounds. The results revealed that when playing alone, infants spent more time producing property-poor than property-rich sounds, although the proportion of property-poor sounds infants produced increased significantly with age. Parents also produced more property-poor than property-rich sounds (this did not increase significantly with age of the infant) and the proportion of time that infants spent producing property-poor sounds was greater when playing with the parent than when playing alone. More importantly, for the 6.5-month-olds, most of the property-poor sounds were initiated by the parent (produced directly after the parent manipulated the object) than self-initiated (produced without direction from the parent). Furthermore, the amount of time the younger infants and parents engaged in synchronous, coordinated interactions was positively correlated with the percent increase in property-poor sound production from when infant played alone to when infant played with parent. This effect was not observed with the 12.5-month-olds, even though they engaged in the same amount of synchronous interactions as the 6.5-month-olds.

The results of Smith and Wilcox (submitted for publication-b) suggest that 6.5-month-olds get a significant amount of exposure to property-poor sounds, by seeking out these sound experiences on their own, by watching their parents produce these sounds, and by engaging in these sounds experiences when interacting with their parents. Although the extent to which 6.5-month-olds produce parent-initiated sounds depends on the nature of the parent–infant interaction (i.e., more synchronous interactions is related to more sound production), all infants produced property-poor sounds on their own and all infants saw their parents produce property-poor sounds. These data suggest that exposure to property-poor sounds, alone, is not sufficient to support the use of these sounds as the basis for individuating objects (i.e., 6.5-month-olds have repeated exposure to property-poor sounds but do not use them to individuate objects).

A second possibility has to do with the nature of the physical world. Property-rich sounds are a natural by-product of physical events and provide rich information about an object's physical properties. For example, shaking a container of small, metal beads produces a property-rich sound that also maps onto the intensity and rhythm of the object's motion and provides information about the object's physical components and how they interact. In contrast, property-poor sounds provide little information about the properties (e.g., size or composition) of objects. Given that property-rich sounds are more intricately tied to the physical properties of objects and the nature of their interactions, they may be perceived as a more reliable source of information about objects than property-poor sounds. This argument is similar to that offered for the developmental hierarchy observed in the visual domain. Wilcox and her colleagues (Wilcox, Schweinle, & Chapa, 2003; Wilcox & Woods, 2008) have argued that young infants show a greater sensitivity to form than surface features because form features are more deeply embedded in the physical world. Form features specify the physical nature of objects: the space they occupy, their substance, and how they will move and interact with other objects. In contrast, color information has little predictive value; it is not unambiguously linked to objects, relevant to understanding the way in which the physical world operates, or important for predicting the outcome of physical events (e.g., the color of an object does not predict whether it will fit into a container or remain supported on a surface). Because of these factors, infants view form as a more reliable source of information when tracking objects across space and time. Young infants, who have limited information processing abilities, attend to those features with the greatest predictive value.

A third possible explanation for infants' greater sensitivity to property-rich sounds is that they are more likely to be conjugate or synchronous with the visual components of physical events. In most physical events (e.g., contact events, collision events) the sounds produced are temporally synchronized with physical interactions between objects and/or other surfaces. For example, when a rattle is shaken, sounds are created by the movement of a collection of small, hard substances within the object. Hence, the sounds emitted from the object are perfectly correlated with the motion of the object as it is shaken. In contrast, property-poor sounds are not typically synchronized in an obvious way with physical interactions. Property-poor sounds can be made to correlate with an event (e.g., a moving object emits an electronic sound), but the degree of temporal synchrony involved in this type of event is typically not as intricate, detailed, or exact as that experienced in property-rich events. The argument, then, is that given the importance of temporal synchrony in directing infants' attention to what is meaningful, coherent, and/or relevant in complex environments (e.g., Bahrick, 1983, 1987; Bahrick & Lickliter, 2002; Bahrick, Lickliter, & Flom, 2004; Dodd, 1979; Lewkowicz, 1999; Ruff, 1982; Spelke & Owsley, 1979), infants are more likely to perceive property-rich sounds (which possess greater temporal synchrony) as intricately linked to objects. Recent research (Smith & Wilcox, submitted for publication-a) suggests that enhanced temporal synchrony does not facilitate infants' use of property-poor sounds as the basis for individuating objects. The three explanations offered here for infants' greater sensitivity to property-rich than property-poor sounds are not mutually exclusive. In fact, it is likely that all three factors influence the type of auditory information to which infants attend when tracking the identity of objects. The charge of future research will be to identify the conditions under which each of these factors contribute to infants' capacity to individuate objects and how this changes during the first year.

Finally, we acknowledge that not all sounds fall cleanly into the category of property-rich or property-poor. For example, the voice of a human speaker is unique to the individual but not obviously linked to the physical appearance of the person (e.g., a large person could have tenor or a treble voice). Walker-Andrews (1994) suggested that voices and other sounds emitted by animate objects (e.g., the barking of a dog), which are produced by a combination of structural properties that are not visible or obvious to the observer, fall into a different category (which she termed "natural but arbitrary"). It is possible that these types of sounds, while important, are not typically emitted by physical objects and, hence, may not be best understood by the distinction between property-rich and property-poor.

In summary, before the end of the first year infants, like children and adults, can use property-poor sounds as the basis for individuating objects. Although property-poor sounds may not be as reliable for identifying objects as property-rich sounds, they can be quite useful. We can distinguish our cell phone from our colleague's by the ring tone, one neighbor's car from another by the sound of its engine, and whether the approaching emergency vehicle is an ambulance or a fire truck by the sound of its siren. With time and experience we learn that property-poor sounds can be associated with individuals and provide one source of information for tracking the numerical identify of objects.

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