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When What's Inside Counts: Sequence of Demonstrated Actions Affects Preschooler's Categorization by Nonobvious Properties

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This study explores the role of a particular social cue—the *sequence* of demonstrated actions and events—in preschooler's categorization. A demonstrator sorted objects that varied on both a surface feature (color) and a nonobvious property (sound made when shaken). Children saw a sequence of actions in which the nonobvious property was revealed before (shake-first) or after (shake-last) categorization. Four experiments ($N = 150$) showed that both 4-year-olds ($M_{age} = 4.5$ years) and 3-year-olds ($M_{age} =$ 3.5 years) shifted toward categorizing by nonobvious property after the shake-first sequence compared with the shake-last sequence (Experiment 1 and 4); 4-year-olds also generalized their categorization strategy to new objects (Experiment 2) and objects that were both labeled and categorized (Experiment 3). Results are discussed with regard to preschooler's ability to integrate social and pedagogical cues in category learning.

Keywords: social cognition, categorization, causal learning, intentional actions, pedagogy

Imagine you see a shopper picking watermelons in a grocery store. That person taps the watermelons one by one, then puts some watermelons into her cart and puts some others back. As an observer who is naïve about the best way to choose a watermelon, one may naturally infer that the person is picking watermelons with regard to the sound they make when tapped, and that sound is important for distinguishing good watermelons from bad ones.

This inference depends on several assumptions we take for granted as adults. For one thing, we assume people's actions are intentional and rational. The shopper would not bother to tap the watermelon if she did not have a good reason—a reason consistent with her preferences for good watermelons and her knowledge about how to pick a good watermelon. Also, we assume that a feature elicited by performing an action, in this case, the sound made by tapping, tells something important about the object that goes beyond appearance, for example, the sweetness or ripeness of the fruit. Furthermore, we assume that the relative position of the shopper's tapping action in the overall sequence of actions signals the relevance of the revealed feature for her watermelon choice. In this scenario, we assume sound to be relevant because she intentionally taps *before* deciding. Imagine the opposite scenario, in which the sequence of actions is reversed, and the shopper taps the watermelons *after* buying them. In the latter case, we would assume the tapping, and the resulting sound, to be irrelevant for picking a good watermelon.

In this study, we ask whether young children are able to make similar inferences. Previous research suggests that young children understand when people's actions are intentional and rational, consistent with goals, preferences, and knowledge states. From infancy, they distinguish intentional actions from accidental actions (Carpenter, Akhtar, & Tomasello, 1998) and infer the goals of agents based on assumptions of rationality (Baldwin, Baird, Saylor, & Clark, 2001; Gergely, Bekkering, & Király, 2002; Meltzoff, 1995; Woodward, 1998). This understanding is precisely what makes intentional action such a powerful source of social information for conceptual and causal learning. Children can, and do, infer that the intentional actions of rational, knowledgeable agents produce outcomes that reveal the underlying causal structure and function of objects (Bonawitz et al., 2011; Casler & Kelemen, 2007; Gopnik et al., 2004).

Separate from this, young children also understand that nonobvious properties of objects are important for determining category membership. For example, infants and young children categorize objects based on their functions (Booth & Waxman, 2002; Kemler Nelson, Russell, Duke, & Jones, 2000; Träuble & Pauen, 2007) and hidden causal properties (Nazzi & Gopnik, 2000, 2003; Sobel, Yoachim, Gopnik, Meltzoff, & Blumenthal, 2007). By preschool years, children even categorize based on nonobvious properties over surface features when they conflict (Gopnik & Sobel, 2000; Kemler Nelson, 1995; Nazzi & Gopnik, 2000). For some types of categories, they further believe that nonobvious properties reflect real, unchanging, deep qualities of category members, even if the details of the properties are unknown (Gelman, 2003).

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Some recent evidence suggests that these two considerations—the intentions of agents and the relevance of nonobvious properties for categorization—combine in meaningful ways. For example, in one recent demonstration, Williamson, Jaswal, and Meltzoff (2010, Experiment 2) showed 36-month-old children a set of objects that were identical in appearance but different in the sound they produced when shaken. In the focal condition, children watched an experimenter intentionally shake these objects and sort them by sound. In the two control conditions, children watched the experimenter shake the objects but not sort them. Children were more likely to themselves sort the objects by the nonobvious property in the focal condition than in the two control conditions.

Williamson et al.'s (2010) study leaves several questions open. First and foremost, it is unknown whether the sequence of actions in the focal condition, first shake then sort, was critical to children's categorization decisions. Also, because the objects were visibly identical, it is unknown how (or what sort of) social demonstration would influence children's categorization if surface features and nonobvious properties conflict.

A recent study by Butler and Markman (2014) addressed this second question. They found that the manner in which intentional actions were demonstrated was critical to whether children categorized by surface features or nonobvious properties. In their study, intentional actions that were also pedagogical (cued by joint attention and child-directed speech) consistently led children to override surface similarities in categorization, but those that were nonpedagogical did not. For example, they compared children's categorization of objects labeled as "spoodles" based on their color or based on a nonobvious function (that they were magnetic and could pick up paperclips). The function was demonstrated pedagogically, intentionally but nonpedagogically, or accidentally. Children categorized based on magnetism (rather than color) only after a pedagogical demonstration. These findings are consistent with other recent theoretical and empirical work suggesting that pedagogical intent leads children to infer the intention to teach some generalizable information about the world (Csibra & Gergely, 2009; Egyed, Király, & Gergely, 2013; Gelman & Meyer, 2011; Shafto, Goodman, & Griffiths, 2014; Southgate, Chevallier, & Csibra, 2009; Vredenburgh, Kushnir, & Casasola, 2014).

Like Williamson et al. (2010), Butler and Markman (2014) did not manipulate the sequence of events: Pedagogical demonstrations always occurred *after* labeling events, and the labels served as the only marker of categorization (there was no active sorting of objects). Thus, Butler and Markman's findings also leave open the question of whether children attend to the sequence of actions and events, and add to this whether sequence might influence children's categorization even after equally pedagogical demonstrations.

In the following series of experiments, we investigate whether children pay attention to sequence—that is, the timing of intentional actions that reveal a nonobvious property relative to the timing of actions and language that announce categorization decisions—as an important additional social cue. Our experiment was modeled after Williamson et al. (2010), with a few modifications. First, the objects we used to sort differed along two dimensions: a surface feature (color) and a nonobvious feature (sound). This leaves the interpretation of which features are relevant to categorization (color, sound, or both) ambiguous, paralleling previous studies in which nonobvious properties conflict with surface features in determining the object's category membership (e.g., Butler & Markman, 2014; Gelman & Markman, 1986; Gopnik & Sobel, 2000). Second, we randomly assigned children to one of two conditions differing only in the sequence of actions: The demonstrator shook the objects and revealed their sound either *before* sorting (shake-first) or *after* sorting (shake-last). Importantly, we matched the demonstrator's pedagogical intent between the two conditions. In our study, the demonstrator sought children's attention using eye contact and child-directed speech at the beginning of the action sequence, and again when categorizing the object, and he did this identically for the two conditions. The shaking actions were never marked by pedagogical or linguistic cues in either condition.

Experiment 1 tests whether 4-year-olds sort differently based on the demonstrator's sequence of actions; Experiments 2 and 3 examine the robustness of sequence as a cue by asking whether 4-year-olds' categorization generalizes to new objects and new contexts, and whether the sequence continues to influence categorization when objects are labeled in addition to being sorted; and, finally, Experiment 4 asks whether we see the same attention to the sequence in younger children (3-year-olds), who are in general more likely to sort by surface features than 4-year-olds (e.g., Sobel et al., 2007). Across all of these variations, if children use the timing of the intentional actions relative to categorization decisions to infer the relevance of the revealed nonobvious property, their sorting behavior should differ between shake-first and shake-last conditions.

Experiment 1

In Experiment 1, we tested whether 4-year-old children infer the relevance of a nonobvious property (the sound an object makes when shaken) from a particular sequence of actions in the sorting task. We chose 4-year-olds because this is an age when children are able to categorize based on nonobvious properties, either based on their existing category knowledge (Gelman, 2003) or when these properties are revealed by actions in category learning experiments with novel objects (Gopnik & Sobel, 2000; Nazzi & Gopnik, 2000, 2003; Sobel et al., 2007). We could therefore ask whether 4-year-olds would be sensitive to when the nonobvious properties are revealed relative to categorization. If so, they should be more likely to sort objects by sound in the condition in which the demonstrator reveals the sound before sorting (shake-first condition) than in the condition in which the demonstrator reveals the sound after sorting (shake-last condition).

Method

Participants. Forty 4-year-old children (M_{age} = 4.5 years, SD = 0.3 years, range = 4.0 to 5.1 years; 22 boys) participated in Experiment 1. Participants for this experiment as well as all the following experiments were recruited from preschools in a small university town and nearby towns, or from a children's museum in the same area. An equal number of children (n = 20) were assigned to each of the two conditions (shake-first and shake-last); gender and age were matched across conditions.

Materials. Toy barrels (cylinder-shaped, 1.5 in. diameter, 1.5 in. tall) were used as stimuli for all experiments. Unbeknownst to the child, some barrels were filled with sound-making material and others were hollow inside. Sound-making and soundless barrels were indistinguishable when looking from the outside. We created two sets of barrels: those in Set A were either yellow or blue in color, and contained either some grains of hard rice kernels (sound-making) or nothing (soundless); those in Set B were either orange or green in color, and contained either one jingle bell (sound-making) or nothing (soundless). The weight differences between sound-making and soundless barrels were about 10% (~21 g for sound-making barrels, ~19 g for soundless barrels). A pretest in which five adults weighed each set of objects showed that adults could not reliably tell the difference between barrels with and without sound-making material (they correctly reported the sound-making barrel as heavier on two trials, incorrectly reported the soundless barrel as heavier on one trial, and reported the two barrels as of the same weight on seven trials). Two transparent boxes (6 × 8 × 4 in., open on the top) were used to hold the barrels after they are sorted.

Procedure. Children were tested individually in a quiet space with one table and two chairs. The experimenter and children sat across the table, facing each other. The experimenter first presented children with four barrels from one set (e.g., Set A) in the middle of a table. Among these four barrels, two were one color (e.g., blue) and sound-making, and the other two were a different color (e.g., yellow) and soundless. We counterbalanced between children on which set was presented first and which color the sound-making barrels were. The four barrels were always presented as a 2 × 2 array, with the locations of the sound-making and soundless barrels randomized.

The experimenter started the first demonstration by telling children, "Here I have four toys. They belong to two groups, so now I'm going to put them into the two boxes." At the same time, he brought out two boxes, and put them on the two sides of the barrels. He then performed one of the action sequences listed in Figure 1, depending on which condition the children were in. The individual actions and language were identical between the shake-first and shake-last conditions, and the only difference was the relative positions of shaking and sorting in the sequence of actions. No matter which condition was demonstrated, the end state was always the two sound-making barrels (both were blue in the example) in one box and two soundless ones (yellow) in the other. Therefore, it was ambiguous whether the experimenter sorted by color, by sound, or by both.

After this first demonstration, the experimenter took the four barrels out of the boxes and put them back in the middle of the table. The four barrels were rearranged into a different, random 2 × 2 array. The experimenter then said, "Now watch me again," and demonstrated sorting for a second time. The manner and end state of the second demonstration were identical to the first one. After the two demonstrations, the experimenter presented four new barrels (one yellow and sound-making, one yellow and soundless, one blue and sound-making, one blue and soundless) in the middle of the table, in a random 2 × 2 array. He then removed the four

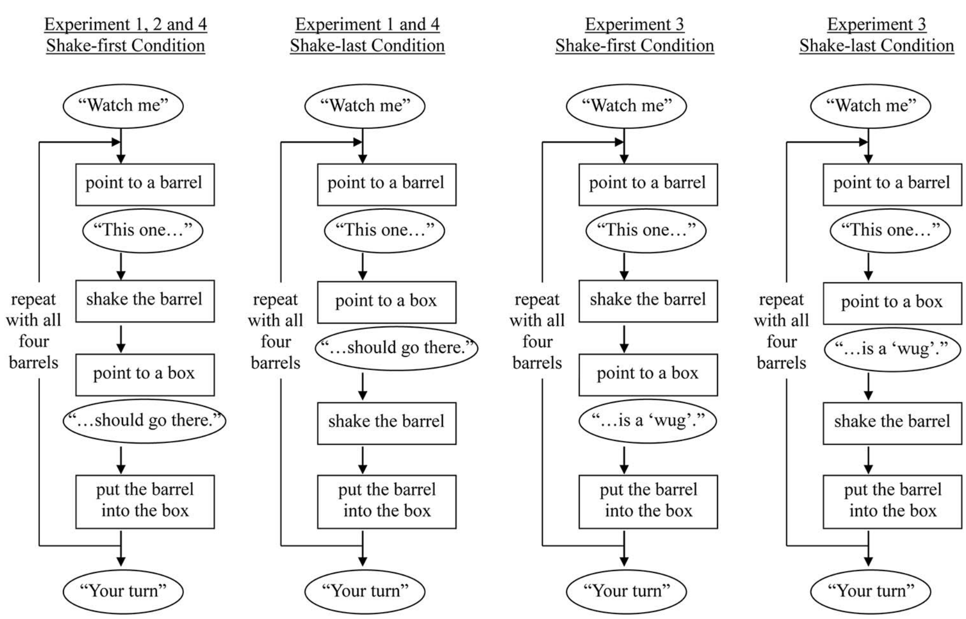

Figure 1. Action sequences demonstrated in four experiments. Texts in squares are the experimenter's actions, and texts in circles are the experimenter's language. For the circles and squares grouped together, the corresponding language and actions happened simultaneously. The experimenter used eye gaze to attract children's attention to the objects in the beginning (pointing to a barrel and saying "This one . . ."), and again used eye gaze to attract children's attention to the box when making the categorization decision (pointing to a box and saying ". . . should go there" or ". . . is a 'wug.'"). When the experimenter shook the barrels, he raised the barrel close to his ear, shook the barrel three times, and listened intently. Critically, the experimenter did not look at or speak to children when shaking the barrels. Therefore, although the shaking action is intentional, it is not marked by pedagogical or linguistic cues; and this is true for both shake-first and shake-last conditions in all four experiments.

barrels used for demonstration from the two boxes. He said to the children, "Now it's your turn. You can put these new toys into the two boxes," and pushed the new barrels over to the child. If children only pointed or said where the barrels should go, the experimenter would encourage them to carry out the sorting actions ("You can do it"). The trial ended when children put all barrels into boxes. The whole trial (including demonstration and testing) was then repeated with a different set of barrels (e.g., Set B). The whole procedure was videotaped.

Coding. All videos of children's responses were coded by two hypothesis- and condition-blind coders. For each trial, coders determined children's sorting strategy and the number of barrels that had been shaken by the child. Sorting strategy was determined by the end state of children's sorting, and was coded as *sort by sound* (two sound-making barrels in one box and two soundless ones in another), *sort by color* (two blue ones in one box and two yellow ones in another), or *sort in other ways* (barrels in the same box differed in both sound and color). Number of barrels shaken was determined by how many barrels children shook during the testing phase, which had a maximum of four for each trial.

Results

Two coders agreed on the sorting strategy for all children on all trials. Intercoder reliability for the number of barrels shaken was also high (Cohen's $\kappa = 0.88$), and when there was inconsistency, the average number of the two codes was used. Boys and girls were not significantly different on any of the dependent measurements; therefore, data were combined across genders.

Group means of children's sorting strategies are shown in Figure 2. A 2 (condition: shake-first vs. shake-last) × 3 (sorting strategy: sound vs. color vs. others) mixed-design analysis of variance on the number of trials in which children used each strategy showed a significant interaction effect between condition and sorting strategy, $F(1.1, 43.4) = 8.53$, $p = .004$, $\eta_p^2 = 0.18$. Children were equally likely to sort by sound and color in the shake-first condition, $t(19) = 0.84$, *ns*, but they sorted more by color than by sound in the shake-last condition, $t(19) = 3.77$, $p = .001$, $d = 0.84$. Analysis of individual children's sorting strategies (see Table 1) confirmed different sorting behavior across conditions—the proportion of children who consistently sorted by sound or by color were significantly different between shake-first and shake-last conditions, Fisher's exact $p = .02$.

Children in the shake-first condition also shook more barrels than their peers in the shake-last condition, $M_{\text{shake-first}} = 6.45$ (out of 8), $M_{\text{shake-last}} = 4.25$, $t(38) = 2.07$, $p = .05$, $d = 0.65$. It should be noted, though, that children in the shake-last condition still shook an average of 4.25 of the eight barrels (53%), and 16 out of 20 children (80%) in this condition shook at least one object (see Figure 3). Also, most children shook objects only before sorting them; a few children shook objects both before and after sorting them, but no child shook objects only after sorting them (see Figure 3). Thus, children often reproduced the sound of the objects before sorting even when they did not use this property in their sorting.

Discussion

In Experiment 1, 4-year-old children watched an experimenter sort objects into two groups. The end state can be interpreted as either sorted by a surface feature of the objects (their color) or by a nonobvious property (their sound) that was revealed by an intentional action. In the shake-first condition, the experimenter performed the action and revealed the nonobvious property ahead of sorting, whereas in the shake-last condition, the experimenter performed the action after sorting. In the following test, children's sorting behavior differed by condition: Although they showed a bias to sort by surface feature in the shake-last condition, that bias is not present in the shake-first condition. Analysis on an individual level confirmed that the proportion of children who consistently sorted by sound, compared with those who consistently sorted by color, was higher in the shake-first condition than in the shake-last condition.

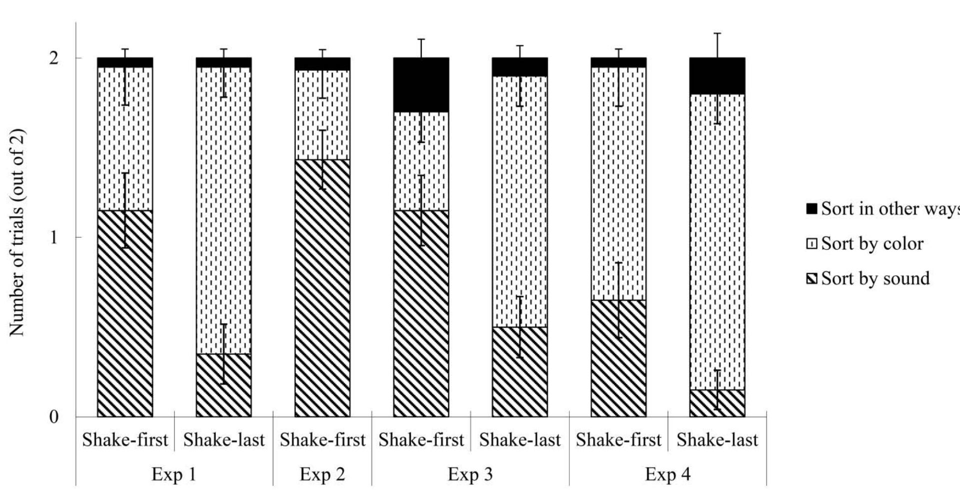

Figure 2. Group means of the number of trials children sorted by sound, color, or in other ways. Error bars denote standard error. Exp = Experiment.

Table 1
Individual Children's Sorting Strategies by Experiment and Condition

Condition	Exp 1		Exp 2	Exp 3		Exp 4	
	Shake first	Shake last	Shake first	Shake first	Shake last	Shake first	Shake last
2 sound	10 (50%)	3 (15%)	21 (70%)	9 (45%)	3 (15%)	6 (30%)	1 (5%)
2 color	7 (35%)	15 (75%)	7 (23.3%)	3 (15%)	11 (55%)	13 (65%)	16 (80%)
1 s 1 c	2 (10%)	1 (5%)	0	2 (10%)	4 (20%)	0	1 (5%)
1 s 1 o	1 (5%)	0	1 (3.3%)	3 (15%)	0	1 (5%)	0
1 c 1 o	0	1 (5%)	1 (3.3%)	3 (15%)	2 (10%)	0	0
2 other	0	0	0	0	0	0	2 (10%)
Last 4	3 (15%)	2 (10%)	2 (6.7%)	8 (40%)	6 (30%)	1 (5%)	3 (15%)

Note. The first number in each cell denotes the number of children who used each type of strategy; the second number in parentheses denotes the percentage of children who used that strategy. "2 sound" = sorted by sound in both trials; "1 c 1 o" = sorted by color in one trial and sorted in other ways in the other trial. "Last 4" = the sum of 1s1c, 1s1o, 1c1o, and 2 other; This shows the number and percentage of children who did not sort consistently by sound or by color. Exp = Experiment.

Importantly, observing children's actions on the objects suggests that they were attending to and interested in the nonobvious property in both conditions. Most children in both conditions shook at least one object, even when they sorted by color. Critically, these children often shook the objects before sorting, even when they did not use the nonobvious property to sort. Thus, our results suggest that children learned about the sound of the objects from both demonstrations, but they made different inferences about the relevance of the sound to categorization depending on the sequence of actions they saw.

Experiment 2

The results of Experiment 1 suggest that sequence of actions may be part of a list of social cues that facilitate children's learning of category knowledge. However, it is still an open question whether children in Experiment 1 learned a *strategy* for categorization that is both generalizable (applies more broadly to a class of similar objects) and transferable (applies beyond the social context of being instructed and supervised by the experimenter). To test this, we added a generalization trial in Experiment 2 in which children were asked to sort a new set of objects that differed in color and sound from the demonstration set. Furthermore, we gave children the choice to freely play after the experiment was completed, to see if they would continue to sort objects in the same way even when not instructed to do so. Evidence of using a new nonobvious property to sort new objects and evidence of spontaneous categorization during free play would suggest that children learned a strategy for categorization from the action sequence.

Method

Thirty 4-year-olds ($M = 4.6$ years, $SD = 0.4$ years, range = 4.0 to 5.0 years; 15 boys) participated in Experiment 2. The demonstration and children's first sort were identical to the shake-first condition[1] of Experiment 1. This was followed by a *generalization trial*, in which children saw no further demonstration and the experimenter simply asked them to sort four new barrels from another set (two new colors, and one barrel of each color made a new sound and the other ones were soundless). After the two sorts were completed, the experimenter offered children the option to "play more." Children who chose to do so were given all barrels (24 in total, three sound-making and three soundless barrels for each of four colors) as well as two boxes, and were told to "play as you wish." The experimenter turned away during children's play. Two hypothesis- and condition-blind coders agreed on the sorting strategy for all children on all trials. For the number of barrels shaken, Cohen's $\kappa = 0.70$. Children's free play was recorded and coded according to what activities they engaged and what types of barrels they used, and the two coders agreed on all of these activities.

Results

Across two trials, children were more likely to sort by sound than by color, $t(29) = 2.94$, $p = .006$, $d = 0.54$ (see Figure 2), and this is true for both the original trial (binomial test, $p = .02$) and the generalization trial (binomial test, $p = .008$). Among the 30 children, 21 sorted by sound in both the original trial and the generalization trial, and seven sorted by color in both trials. Only two children sorted differently between the two trials—one sorted in other ways first and then changed to sort by sound, and another sorted by color first and then changed to sort in other ways (see Table 1).

The way children sorted during the experiment also influenced the way they played after the experiment. Eleven children stayed for the free play: nine who sorted by sound during the experiment and two who sorted by color. Of the nine who sorted by sound, eight sorted or stacked barrels by sound. Only one put barrels into boxes without referring to their sound or color. Of the two who sorted by color, both of them stacked barrels in towers without referring to color or sound.

[1] We only included a shake-first condition in Experiment 2. We assume that the same result would apply to the shake-last condition. However, had we included the shake-last condition, given that most children sorted by color in this condition (as shown in Experiment 1), we would not be able to rule out that children just sort new objects by color because color is an obvious feature. Therefore, just including a new shake-last condition here would not help differentiate whether children learned a strategy that is generalizable and transferable.

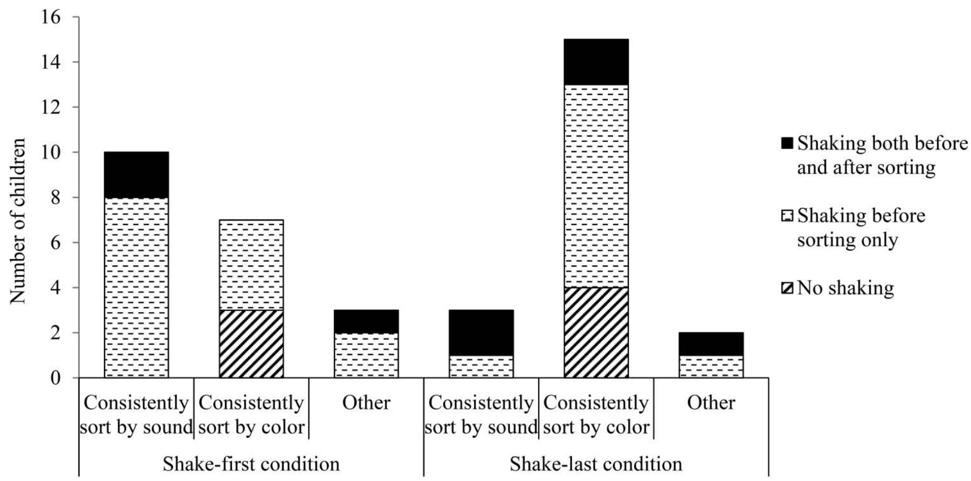

Figure 3. Children's shaking behavior in Experiment 1. We separated children in each condition into three groups according to their sorting responses in the two testing trials. Consistently sort by sound = sorted by sound in both trials; Consistently sort by color = sorted by color in both trials; Other = changed sorting strategy between trials, or sorted in other ways in at least one trial. No child shook objects only after sorting.

Discussion

In Experiment 2, when 4-year-olds were presented with a new set of objects with different color and sound, a significant majority sorted these objects by the same property (color or sound) as they did with the original set. Moreover, children who sorted by sound initially continued to do so during free play after the experiment, even when the demonstrator was not supervising or observing their actions. We take this as evidence that after watching a properly timed action sequence, children learned a sorting strategy that is both generalizable and transferable.

Experiment 3

Experiment 3 investigated how children's categorization is influenced by the timing of shaking action in relation to both labeling and sorting. Labeling objects is a powerful way to shape and support category knowledge (see Gelman & Meyer, 2011, and Markman, 1991, for reviews). Both infants and young children expect objects that receive the same label to share nonobvious properties, even if those objects are perceptually dissimilar (Gelman & Markman, 1986, 1987; Gopnik & Sobel, 2000; Graham, Kilbreath, & Welder, 2004; Schulz, Standing, & Bonawitz, 2008; Welder & Graham, 2001). Preschoolers also sort labeled objects based on nonobvious properties instead of surface features (Butler & Markman, 2014). Given the importance of labels for categorization, in Experiment 3, we attached labels ("wug" and "dax") to the two boxes, and demonstrated sorting objects according to their labels. Based on previous research, we might expect children to sort by sound more when objects are labeled. On the other hand, if children's inferences depend on the sequence of actions, we still expect to see a difference in their sorting behavior between the shake-first and shake-last conditions.

Method

Forty 4-year-olds (M = 4.5 years, SD = 0.3 years, range = 4.0 to 5.0 years; 20 boys) participated in Experiment 3. An equal number of children (n = 20) were assigned to one of two conditions (shake-first and shake-last). The materials used in Experiment 3 were identical to Experiment 1, except that the two boxes were labeled. One box was labeled "W" for "wugs" and the other box was labeled "D" for "daxes." These labels were printed on 2.5 × 2.5-in. papers and were taped to all sides and the bottom of the boxes.

During the experiment, the experimenter first presented children with four barrels; the color, sound, and position of the barrels were the same as in Experiment 1. The experimenter said, "Here I have four toys. Some of them are 'wugs' and others are 'daxes.'" He then put the two labeled boxes on the two sides of the barrels and introduced them: "This is the box for the 'wugs' ['daxes']; all 'wugs' ['daxes'] should go here." The labels for the boxes on the left and right and the label being introduced first were counterbalanced between children. He then confirmed that children learned the labels by asking, "Where should the 'wugs' ['daxes'] go?" and explained the labels again if children's answers were wrong. All children were able to remember the labels after, at most, two rounds of explanations.

The experimenter then demonstrated one of the action sequences in Figure 1. Similar to Experiment 1, he shook the barrels either before (shake-first condition) or after (shake-last condition) deciding where to put them. The only difference was that instead of saying "This one . . . should go there," he said, "This one . . . is a 'wug' ['dax']," and then put it into the correspondingly labeled box. The testing phase was identical to Experiment 2—children completed one original trial and one generalization trial. Two hypothesis- and condition-blind coders agreed on the sorting strategy for all children on all trials. For the number of barrels shaken, Cohen's κ = 0.84.

Results

A 2 (condition: shake-first vs. shake-last) × 3 (sorting strategy: sound vs. color vs. others) mixed-design analysis of variance on the number of trials that children used each strategy showed a significant interaction effect between condition and sorting strategy, $F(1.4, 53.3) = 8.45$, $p = .002$, $\eta_p^2 = 0.18$ (see Figure 2). Children sorted marginally more by sound than by color in the shake-first condition, $t(19) = 1.71$, $p = .10$, $d = 0.38$, but they sorted significantly more by color than by sound in the shake-last condition, $t(19) = 2.71$, $p = .01$, $d = 0.61$. Analysis of individual children's sorting strategies (see Table 1) confirmed different sorting behavior across conditions—the proportion of children who consistently sorted by sound or by color were significantly different between shake-first and shake-last conditions, Fisher's exact $p = .02$.[2] Children in the shake-first condition also shook more barrels than their peers in the shake-last condition, $M_{\text{shake-first}} = 6.35$, $M_{\text{shake-last}} = 3.95$, $t(38) = 2.40$, $p = .02$, $d = 0.76$.

To explore the effect of labeling, we compared children's responses in Experiments 1 and 3 using three 2 (label: with label vs. without label) × 2 (condition: shake-first vs. shake-last) analyses of variance—one on the number that children sorted by sound, one on the number that children sorted by color, and one on the number of barrels shaken. All three analyses showed significant main effects of condition ($ps < .002$), but no significant main effects of label or interaction effects between condition and label ($ps > .2$).[3]

Discussion

In Experiment 3, the experimenter labeled and sorted objects either before or after revealing their nonobvious property, and the order influenced children's categorization. These results reinforced and extended results of previous experiments in showing the importance of the sequence of actions to children's inference about objects' category membership, no matter whether the category membership is announced by labeling or sorting. Compared with Experiment 1, we did not observe an overall shift toward categorization by nonobvious property when objects were labeled, as might be predicted by some previous research (e.g., Gelman & Meyer, 2011). We speculate possible reasons for that in the General Discussion.

Experiment 4

Experiments 1 to 3 showed that 4-year-olds use the experimenter's timing of revealing a nonobvious property to infer its relevance toward the object's category membership. What about younger children? Previous studies showed that when nonobvious properties of objects conflicted with surface features, 3-year-olds tend to categorize objects by surface similarity (Nazzi & Gopnik, 2000). Also, 3-year-olds are less likely than 4-year-olds to make inferences about "insides" based on revealed nonobvious properties (Sobel et al., 2007). On the other hand, children even younger than 3 years of age are highly sensitive to social cues that signal intentional actions (e.g., Carpenter et al., 1998), and 3-year-olds in particular are more likely to make inferences about insides in social rather than nonsocial scenarios (Sobel & Munro, 2006). We therefore hypothesize that a properly timed action sequence might encourage 3-year-olds to sort objects by nonobvious properties and ignore conflicting surface ones. Experiment 4 explores this by applying the same sorting procedure as in Experiment 1 to 3-year-olds.

Method

Forty 3-year-old children ($M_{age} = 3.5$ years, $SD = 0.3$ years, range = 2.9 to 4.0 years; 20 boys) participated in Experiment 4. An equal number of children ($n = 20$) were assigned to one of the two conditions (shake-first and shake-last). The material, procedure, and coding scheme for Experiment 4 were identical to Experiment 1. Two hypothesis- and condition-blind coders agreed on the sorting strategy for all children on all trials, and intercoder reliability is high for the number of barrels shaken (Cohen's $\kappa = 0.79$).

Results

A 2 (condition: shake-first vs. shake-last) × 3 (sorting strategy: sound vs. color vs. others) mixed-design analysis of variance on the number of trials children used each strategy showed a marginally significant interaction effect between condition and sorting strategy, $F(1.5, 57.9) = 2.59$, $p = .097$, $\eta_p^2 = 0.06$ (see Figure 2). Children were equally likely to sort by sound and color in the shake-first condition, $t(19) = 1.53$, *ns*, but they sorted more by color than by sound in the shake-last condition, $t(19) = 6.10$, $p < .001$, $d = 1.36$. When comparing between conditions, the number of trials children sorted by sound in the shake-first condition was significantly higher than that in the shake-last condition, $t(28.7) = 2.12$, $p = .04$, $d = 0.67$, but there was no between-condition difference in the number of trials they sorted by color, $t(35.5) = 1.27$, *ns*, or in the number of trials they sorted in other ways, $t(23.9) = 1.02$, *ns*. Analysis of individual children's sorting strategies (see Table 1) showed a marginally significant difference in the proportion of children who consistently sorted by sound or by color between the two conditions, Fisher's exact $p = .09$. The number of barrels shaken did not differ between conditions, $M_{\text{shake-first}} = 6.23$, $M_{\text{shake-last}} = 5.40$, $t(38) = 0.85$, *ns*.

Age differences in sorting strategies. To explore the effect of age on children's sorting strategies, we performed an analysis to compare the data from Experiment 4 with data from Experiment 1. A 2 (age group: 3-year-olds vs. 4-year-olds) × 2 (condition: shake-first vs. shake-last) analysis of variance on the number of trials children sorted by sound showed a significant main effect of condition, $F(1, 76) = 13.3$, $p < .001$, $\eta_p^2 = 0.15$, a significant main effect of age group, $F(1, 76) = 3.86$, $p = .05$, $\eta_p^2 = 0.05$, and no interaction effect between condition and age group, $F(1, 76) = 0.7$, *ns*. Four-year-olds were more likely to sort by sound than 3-year-olds, and children were more likely to sort by sound in the shake-first condition than in the shake-last condition. A 2 (age group) × 2 (condition) analyses of variance on the number of trials children sorted by color also revealed a significant main effect of condition, $F(1, 76) = 8.86$, $p = .004$, $\eta_p^2 = 0.10$, but no main effect of age group or interaction effect between condition and age group,

[2] Across conditions, 14 children (35%) changed sorting strategies between Trials 1 and 2. When we separate the two trials, the proportion of children who sorted by sound or by color was significantly different between conditions for both Trial 1 (shake-first: nine sound, seven color, four other; shake-last: three sound, 17 color; Fisher's exact $p = .01$) and Trial 2 (shake-first: 14 sound, four color, two other; shake-last: seven sound, 11 color, two other; Fisher's exact $p = .04$).

[3] It should be noted that Experiment 1 and 3 were administrated at different times with different groups of participants, so there may be limitations inherent in comparing sample across these two experiments.

*F*s (1, 76) < 2.1, *ns*. Children were more likely to sort by color in the shake-last condition than in the shake-first condition.

Age differences in shaking actions. On average, 3-year-olds in Experiment 4 shook as many barrels as 4-year-olds did in Experiment 1, $M_{\text{3-year-olds}} = 5.81$, $M_{\text{4-year-olds}} = 5.35$, $t(78) = 0.63$, *ns*. However, when we compare trials in which children did not sort objects by sound (i.e., when they sorted by color or in other ways), 3-year-olds shook significantly more objects than 4-year-olds in these trials, $M_{\text{3-year-olds}} = 2.63$, $M_{\text{4-year-olds}} = 1.96$, $t(112) = 1.95$, $p = .05$. To confirm that age was a significant predictor of children's shaking actions, we combined data across all experiments and performed a regression analysis on the number of barrels children shook for each trial, predicted by age group (3 vs. 4), condition (shake-first vs. shake-last), generalization (original set of objects vs. new set of objects), label (with label vs. without label), and the sorting strategy children used on that trial (sound vs. color vs. other). Results (see Table 2) showed significant effects of age group: 3-year-olds shook more barrels than 4-year-olds ($\beta = -0.13$, $p = .02$), after controlling for how categorization was demonstrated and how they eventually categorized the objects.

Discussion

In line with previous studies (e.g., Nazzi & Gopnik, 2000), the majority of 3-year-olds in our experiment categorized objects by their surface features when surface features conflicted with the nonobvious property. Importantly, however, 3-year-olds in the shake-first condition were more likely to categorize by the nonobvious property than their peers in the shake-last condition. Thus, just like 4-year-olds, 3-year-olds were influenced by the timing of actions revealing the nonobvious property of objects relative to categorization.

Although 3-year-olds were influenced by the sequence of actions, they were equally likely to perform the shaking actions in both shake-first and shake-last conditions. Compared with 4-year-olds, they were more likely to perform these actions overall, controlling for other variables. This suggests possible interesting developmental differences in influence of particular social demonstrations on object *exploration* as well as categorization.

Table 2
Regression Analysis of Children's Shaking Response

Predictor	*B*	*SE*	β	*t*	*p*
Age group	–.49	.22	–.13	–2.26	.02
Condition	–.19	.19	–.06	–1.04	.30
Generalization	.29	.22	.07	1.32	.19
Label	–.15	.21	–.04	–.73	.47
Sound	1.10	.37	.32	2.99	<.01
Color	–.88	.36	–.26	–2.41	.02

Note. $N = 300$. Dependent variable is the number of barrels children shook for each trial. Values of each independent variable (predictor) are assigned as the following. Age group: 3-year-old = 0, 4-year-old = 1; Condition: Shake first = 0, Shake last = 1; Generalization: original trial = 0, generalization trial = 1; Label: without label = 0, with label = 1. Sorting strategy was dummy coded into two predictors—Sound: sort by sound = 1, sort by color or other = 0; Color: sort by color = 1, sort by sound or other = 0.

General Discussion

This study explores whether preschoolers can use the sequence of demonstrated actions and events to infer the relevance of a nonobvious property toward the object's category membership. Results showed that they are indeed able to do so: The bias toward categorizing by surface feature was absent when the nonobvious property was intentionally revealed before sorting, but that bias was present when the nonobvious property was intentionally revealed after sorting (Experiment 1). This difference cannot be fully explained by attention and interest toward the demonstrator's intentional actions to reveal the nonobvious property, because the majority of children repeated these actions at least sometimes in each condition, regardless of how they categorized the objects. This difference also cannot be explained by differences in pedagogical cues (eye-contact, child-directed speech), as these cues were identical across conditions.

In Experiment 2, children sorted based on the same feature for the demonstrated set of objects and for a new set of objects. Moreover, many of them continued to use that feature during their own free play. These results suggest that children are learning a categorization *strategy* from the demonstrated action sequence, which is both generalizable and transferable to some extent. These results parallel results from inductive learning studies that show infants' and children's capacity to form *second-order generalizations*, or *overhypothesis*, across categories (Dewar & Xu, 2010; Macario, Shipley, & Billman, 1990; Walker & Gopnik, 2014).

The sequence of actions also affected children's categorization when objects were both labeled and sorted (Experiment 3). Labels are shown to promote categorization based on nonobvious properties, possibly because the act of labeling leads children to assume the existence of deeper similarities among the labeled objects that go beyond perceptual similarities (Gelman & Meyer, 2011). Our results suggest that children made an appropriate inference about which property, sound or color, was relevant to assigning the label, based on the time the nonobvious property was revealed relative to both sorting and labeling. These results are consistent with other work showing that social cognition plays an important role in how children interpret labeling events, and in word-learning more generally (Baldwin et al., 1996; Baldwin & Moses, 2001; Frank & Goodman, 2012).

The results of Experiment 4 reveal the emergence of the ability to use sequence as a social cue to categorize in children as young as 3 years of age. Though children faced an ambiguous categorization task, they were more likely to ignore the surface feature of the object in favor of the sound when the sound was revealed at the right time. Our results suggest that a properly timed sequence of actions could have a facilitative effect on 3-year-olds' categorization by nonobvious properties, helping them override their tendency to sort by surface similarity. Our results may therefore have implications for category learning in pedagogical contexts: When teaching children about how nonobvious properties determine objects' category membership, it may be important to reveal these properties at the right time.

Another developmental change suggested by our results concerns the amount of exploratory actions on the objects. Whereas 4-year-olds shook significantly fewer objects in the shake-last condition, 3-year-olds shook high numbers of objects regardless of condition and regardless of the way they sorted the objects in the end. One possible explanation is that 3-year-olds are more imitative than 4-year-olds, and faithfully copied the demonstrator's shaking behavior without understanding its relevance to the task at hand. However, recent research on "overimitation" suggest that 4-year-olds are more likely to faithfully imitate irrelevant actions than younger children (e.g., Yu & Kushnir, 2014), so it is unlikely that the tendency to imitate caused the age difference in shaking behavior. A more likely possibility is that 3-year-olds are more exploratory than 4-year-olds in our task. Previous research has shown that preschoolers perform more exploratory actions when they have prior expectations about category members and those expectations are violated (Schulz et al., 2008), and when their exploration supports causal learning and discovery (Schulz & Bonawitz, 2007). It is possible that in our task, 3-year-olds had a stronger expectation that similar-looking objects should make similar sounds (e.g., Markson & Spelke, 2006), and thus they explored more (Legare, 2012). By Age 4, children understand that appearance and insides can, and often do, mismatch (Sobel et al., 2007). Thus, their weakened expectations could have resulted in a reduction of exploratory behavior.

Taken together with prior work (e.g., Butler & Markman, 2012, 2014), our study raises interesting questions about how social information, labels, and particular nonobvious properties of objects interact in children's categorization. As discussed previously, when labels were the only cue to categorization, Butler and Markman (2014) found that 4-year-olds categorized by nonobvious functions of objects demonstrated pedagogically *after* labeling. In our experiment, however, being presented with labels in addition to active "sorting" did not lead children to preferentially sort by the nonobvious property. Therefore, it is possible that children make a stronger assumption that sorting, compared with labeling, can only be based on properties that have been revealed in advance. On the other hand, the difference may also be related to the fact that Butler and Markman focused on how social cues lead children to categorize artifacts by *function* (what they are for), whereas we focused on categorization by *hidden properties* (what they do). Children understand that artifacts are created and labeled for specific functions, and they extend labels to those with the same function even when function is pitted against surface features (Diesendruck, Markson, & Bloom, 2003; Kemler Nelson, 1995; Kemler Nelson et al., 2000). It could be, then, that the connections between labels and functions are robust enough to override the effect of action sequence. Indeed, Butler and Markman (Experiment 3) found that when the nonobvious properties are not functional properties (when they were visible features revealed after labeling), children no longer sorted by these nonobvious properties.

Our four experiments suggest that children's attention to the sequences of actions might be a powerful way to shape their category formation. The underlying mechanism, we suggest, is that children infer the *relevance* of the hidden property to categorization by tracking the order of actions in the demonstration. The exact nature of the inference is still an open question: Children might have inferred the experimenter's intention to sort a particular way, and children might have inferred the experimenter's intention to teach a particular sorting strategy. Although we do not know which for sure, we favor the second interpretation, in part because the results of our generalization experiment (Experiment 2) suggest that children learned a sorting strategy, not just that a particular person had a specific intent, and in part because of the free-play results (also Experiment 2), in which children continued to sort even after the experimenter turned away. Future research is needed to confirm whether action sequence alone is enough to convey relevance (i.e., without additional pedagogical cues). We also speculate that children's inferences relied on understanding that the whole action sequence was performed to achieve one coherent goal of the demonstrator. If the action sequences lacked such a coherent goal (e.g., one person shake the objects and a different person sorts them), we expect this to change children's inferences about the relevance of the nonobvious property to categorization.

Our results are consistent with the general idea that children infer pedagogical intent from certain demonstrations, and that there are various pedagogical cues that lead young children to infer that they are being shown or taught some generalizable information about the world (Csibra & Gergely, 2009; Egyed et al., 2013; Gelman & Meyer, 2011; Vredenburgh et al., 2014). Action sequence, in our study, may be a type of pedagogical cue on this formulation. Children used it to categorize (Experiments 1 and 4), to generalize (Experiment 2), and to label (Experiment 3). Moreover, children (especially 3-year-olds) often shook the objects no matter whether they used the sound to categorize them, suggesting that they understood that some properties of objects are interesting (and fun to do) but not relevant to their category membership. This consistency between our results and past research (including Butler & Markman, 2012, 2014) suggests that, beyond the most commonly studied pedagogical cues (such as joint attention, child-direct speech, and generic language), there might be one more, and maybe even others. This opens up possibilities for new research.

This study also raises interesting questions about how often, and in what contexts, children might see such meaningful "sequences" in their everyday lives. Research on infant-directed actions showed that mothers routinely use action sequences that highlight meaningful information (termed "motionese") when demonstrating object properties to infants (Brand, Baldwin, & Ashburn, 2002). Perhaps one aspect of "motionese" involves intentionally highlighting events by presenting them in a certain sequence. If this is indeed the case, then it combines with children's ability to infer relevance from properly timed actions, and offers further evidence that the structure of social interactions supports early learning.

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