Naming influences 9-month-olds' identification of discrete categories along a perceptual continuum

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Abstract

A growing body of evidence documents that naming guides 9-month-old infants as they organize their visual experiences into categories. In particular, this evidence reveals that naming highlights categories when these are visually distinct. Here we advance this work in by introducing an anticipatory looking design to assess how naming influences infants' categorization of objects that vary along a perceptual continuum. We introduced 9-month-old infants (n = 48) to continua of novel creature-like objects. During the learning phase, infants had an opportunity to observe that objects from one end of the perceptual continuum moved to the left and objects from the other end moved to the right. What varied was how the objects were named. Infants in *the one-name* condition heard the same novel noun applied to all objects along the continuum; those in the *two-name* condition heard one name for objects from one end of the continuum and a second name for objects at the other end. At test, all infants viewed new objects from the same continuum. At issue was whether infants would anticipate the side to which the test objects would move and whether their expectations varied as a function of naming condition. Infants in the *one-name* condition formed a single overarching category and therefore searched for new test objects at either location; those in the *two-name* condition discerned two categories and therefore correctly anticipated the likely location of the test objects, whether these were close to the poles or to the center of the continuum. This provides the first evidence that by 9 months, naming supports both the number of categories infants impose along a perceptual continuum and the clarity of the category boundaries.

Keywords: Word learning, categorization, lexical development, perceptual continua

1. Introduction

Although there is lively debate as to *how* and *how deeply* language exerts its influence, there is little doubt that the language(s) we speak shape our experience of the world. Perhaps the most dramatic evidence comes from cross-linguistic differences in our perception of color. Across the world's communities, sighted people experience the very same spectrum of visible light and impose discrete categories along this perceptual continuum. But the particular categories we impose bear the imprint of the language we speak. For example, speakers of English categorize wavelengths ranging from 455-492 nm as *blue* and wavelengths from 492-577 nm as *green*. But for speakers of Berinmo, an indigenous language of Papua New Guinea, *blues* and *greens* are marked with a single color term, *nol*. This cross-linguistic difference in the number of color categories we form and the boundaries we place between them influences not only the color lexicon but also our memory: Berinmo speakers are less likely to remember distinctions between wavelengths that English speakers describe as *blue* versus *green* (Kay & Regier, 2006; Roberson, Davidoff, Davies, & Shapiro, 2004; Roberson, Davidoff, Davies, & Shapiro, 2005; Roberson, Davies, & Davidoff, 2000; but also see Kay & Regier, 2009; Lindsay & Brown, 2006). But what remains unanswered is how early in development naming begins to shape the categories we impose along a perceptual continuum. Here, we consider this question by focusing on the effects of naming on 9-month-old infants' categorization of novel objects along a perceptual continuum.

There is now considerable evidence that infants successfully form object categories within the first months of life (Gliga, Mareschal, & Johnson, 2008; Quinn, 2006; Quinn & Bhatt, 2009; Quinn, Schyns, & Goldstone, 2006; Mandler, 2000, 2004; Pauen, 2002; Plunkett, Hu, & Cohen, 2008; Rakinson & Oakes, 2003; Rakison & Yevdokiya, 2010; Westermann & Mareschal, 2013). Moreover, recent evidence reveals that by well before they begin to speak, infants' categorization is affected by language. By 3 months of age, simply listening to language supports infants' ability to form object categories (Ferry, Hespos, & Waxman, 2010); within the next several months, infants begin to trace whether the *same* or *different* names are applied to a set of objects. For example, using a novelty preference paradigm, Waxman and Braun (2005) familiarized 13-month-old infants to four distinctly different objects from a single category (either ANIMALS or TOOLS). What varied across conditions was whether infants heard the same word applied consistently to all of the familiarization objects (e.g., *Look at the keeto! Look at the keeto!...*) or a different word applied to each (e.g., *Look at the keeto! Look at the bookoo!...*). At test, two novel objects were presented simultaneously in silence – one belonged to the now-familiar category (e.g., another animal) and one to a novel category (e.g., a tool). Infants who heard the same word applied consistently to all familiarization objects categorized successfully, but infants who heard a distinct word applied to each familiarization object performed at chance levels (Waxman & Braun, 2005; Ferguson, Havy, & Waxman, 2015). Consistently applying the same name to a set of distinct objects highlights commonalities among them and facilitates categorization; conversely, applying distinct names to each distinct object highlights differences among them and facilitates the process of object individuation (Dewar & Xu, 2007; Ferguson et al., 2015; Ferry et al., 2010; Fulkerson & Waxman, 2007; Gelman & Waxman, 2009; Graham, Keates, Vukatana, & Khu, 2012; Plunkett et al., 2008; Song, Baillargeon, & Fisher, 2014; Vales, & Smith, 2015; Waxman & Booth, 2001, 2003; Waxman & Braun, 2005; Xu, 2002; Xu, Carey, & Quint, 2004; Xu, Cote, & Baker, 2005).

Thus, by 9 months, infants track not only *which* objects they see (Quinn, 2006) and *which* words they hear (Byrd & Mintz, 2010), but also *how* each object is named (Ferguson et al., 2015; Waxman & Braun, 2005; see also Smith & Yu, 2008).

This link, impressive in itself, sheds light on the effect of naming on categorization. But it also raises a question: In the work described thus far, infants viewed objects from perceptually distinct categories (e.g., distinct object kinds or distinct shapes). But not all categories have such perceptually distinct boundaries. For example, there is no hint of a perceptual “break” between the adjacent wavelengths considered as *blue* versus *green* in English; nonetheless, speakers of different linguistic communities impose boundaries and treat them as categorical (Kay & Regier, 2006; Roberson et al., 2000, 2004, 2005). At issue, hence, is whether and how naming sculpts the categories infants impose along a perceptual continuum.

Landau and Shipley (2001) were the first to address this question. They created two distinctly different novel objects (Standard A and Standard B) and then morphed them successively to obtain a set of intermediate objects along the perceptual continuum bounded by the two standards. Their design was straightforward: An experimenter introduced 2- and 3-year-old children to the two standards, and asked children about the intermediate (morphed) test objects. When Standards A and B were each introduced with its own distinct name, children formed two distinct categories along the perceptual continuum (e.g., Standard A: *This is a dax;* Standard B: *This is a blicket*; Test object: *Is this a blicket?*). But when both standards received the same name, children formed a single category (e.g., Standard A: *This is a blicket;* Standard B: *This is a blicket*; Test object: *Is this a blicket?*). This documented that by two years of age, naming shapes the categories children impose along a perceptual continuum.

More recently, Althaus and Westermann (2016) sought to examine this naming effect in younger infants. Like Landau and Shipley, the authors morphed two distinctly different novel objects (Standard A and Standard B) to create a continuum. During a familiarization phase, 10-month-old infants viewed eight different objects from the continuum, selected to represent a distribution that was slightly bimodal (that is, with a gap at the center of an otherwise uniform distribution). What varied was whether the familiarization objects were presented in silence, with a single name applied to all eight objects, with two distinct names (one applied to the four objects from each end of the continuum) or with two tones (one applied to the four objects from each end of the continuum). At issue was whether infants in each condition would form a single inclusive category or two distinct ‘subcategories’, one at each end of the continuum. To test this issue, the experiments presented infants in all conditions with several different test trials, all comprised of two objects each. These trials were not counterbalanced.

In the first two test trials, infants viewed a) a new object from the center of distribution (the average of the ‘inclusive category’) and b) a new object that was the average of one of the two ‘subcategories’. Infants performed at chance on these trials; there were no reliable differences among conditions. Notice that this outcome is consistent with two possibilities: infants in all conditions either failed to form any category (inclusive or subcategory) or formed both the inclusive category and the subcategories.

In the next four test trials, infants viewed a new novel object drawn from an entirely different continuum. This same object was presented repeatedly, pitted each time against one of the objects infants had seen on the first two test trials: the average of the ‘inclusive category’ vs the average of one of the two ‘subcategories’. The authors conducted a series of comparisons within each condition. These suggested that in the *single name* condition, the *two-tone* condition and the *silent* condition, infants may have formed a single inclusive category; in these conditions, infants preferred the object from outside the original distribution over the average of the ‘inclusive category’. But in the *two-name* condition, infants may have formed two subcategories; they prefered the object from outside the distribution over the subcategory average.

Although this pattern is consistent with prior evidence documenting that hearing two distinct names guides infants to form two categories, but that hearing a single name guides them to form a single inclusive category (Ferguson et al., 2015; Ferry et al., 2010; Fulkerson & Waxman, 2007; Graham et al., 2012; Landau & Shipley, 2001; Plunkett et al., 2008; Waxman & Braun, 2005), there are several reasons to interpret this with caution. First, there was no evidence to this effect on the first two test trials. Infants in all conditions performed at chance levels, with no differences between them. Second, because test trial order was not counterbalanced, the latter test trials all included at least one, and often two, objects that infants had already seen. This makes it difficult to interpret analyses based on infants' 'novelty' preferences. Third, these latter trials were analyzed using within condition comparisons to chance, leaving it unclear whether there were any reliable differences across the conditions (see Gelman & Stern, 2006 for a discussion of why a difference between 'significant' and 'not significant' condition does not mean that the difference between the conditions itself is statistically different). Finally, it is uncertain about whether infants formed strong category-based expectations about the location of category boundaries or whether category judgment was more continuous. Together, then, these results, although suggestive, do not provide sufficiently clear answers to whether and how naming influences infants' categorization of objects along a continuum.

In the current experiments, we address this question directly. To do so, we move beyond the novelty preference design to trace the role of naming on infants' categorization of objects along a perceptual continuum. We focus on 9-month-old infants because although they do not yet produce category names on their own, there is evidence that they are sensitive to the distinct conceptual consequences of naming objects with the same vs different names (Althaus & Westerman, 2016; Dewar & Xu, 2007; Ferguson & Waxman, 2016; Waxman & Braun, 2005). We ask whether naming influences not only the number of object categories infants form along the continuum, but also, whether category membership is perceived as discrete or as a more continuous factor.

To address these questions, we designed a new paradigm, building upon recent advances in using anticipatory looking as an index of infant cognition (Addyman & Mareschal, 2010; Ambrosini et al., 2013; Brandone, Horwitz, Aslin, & Wellman, 2013; Kovács & Mehler, 2009; McMurray & Aslin, 2004; Ruffman, Slade, & Redman, 2005). Here, we developed an anticipatory looking paradigm that would permit us to move beyond the interpretive limitations of novelty preference tasks and to test the precision of the category boundaries that infants impose.

We began by creating two pairs of novel images (Standards A and B) and morphing them to create two perceptual continua (see Figure 1). In our design, we first introduced infants to the two standards. Next, during a learning phase, the standards and a series of intermediate exemplars appeared in a door at the center of a colorful house. After a few seconds, exemplars from one end of the perceptual continuum moved in one direction (either to a door at the left or right side of a little house) and exemplars from the other end of the continuum went the other way. To identify the role of naming, we varied the way in which Standards A and B were named. In the *one-name* condition, the same name was applied to all exemplars during the learning phase (e.g., *A /guv/! This is a /guv/!; A /guv/! This is a /guv/!*). In the *two-name* condition, infants heard two different names, one for each end of the perceptual continuum (e.g., *A /guv/! This is a /guv/!*; *An /etS/! This is an /etS/!*). At test, new exemplars appeared, one at a time, at the center door in silence, and then disappeared. Once they disappeared, we measured infants’ anticipatory looking to each side of the house. Two of the test exemplars were relatively close to the Standards and two were closer to the midpoint. This manipulation permitted us to evaluate infants’ expectations about the placement of category boundaries.

At issue, then, was whether and how infants’ treatment of the test exemplars was influenced by the way in which exemplars in the learning phase had been named. We reasoned as follows: If infants formed two distinct categories during the learning phase, each linked to one (or the other) pole of the underlying distribution, then infants would detect that members of one category move to the right doors and members of the other category to the left. Thus, if infants formed two categories during the learning phase, they should correctly anticipate the likely side at which the new test objects would appear. In contrast, if infants formed a single category encompassing the entire distribution during the learning phase, then they would have learned that objects from this single category moved freely to either one side or the other. Thus, if infants formed a single category during the learning phase, then they should fail to anticipate the side at which the test objects would re-appear; instead their performance should be at the chance level.

This logic permitted us to assess the influence of naming. If naming sculpts the categories infants impose along a perceptual continuum, then infants in the *two-name* condition should be more likely than infants in the *one-name* condition to form two distinct categories and thus to anticipate correctly the side at which new test objects would appear. Importantly, infants' performance will also shed light, for the first time, on whether and how naming affects infants' expectations about the location of the category boundaries. If infants' decisions are indeed category-based, as they are in color perception for example, then infants' expectations about the test exemplars should be equally strong, regardless of their perceptual difficulty (near the poles vs near the center of the continuum). If category membership is more continuous, then we predict more variability in infants' responses for test objects near the center of the continuum than test objects near the poles.

2. Experiment 1

The goal was to assess the influence of naming on the categories 9-month-old infants impose along a perceptual continuum of objects, using their predictions about an object's likely movement as an index of categorization.

2.1. Method

2.1.1. Participants

Thirty-two healthy, full-term 9-month-old infants from monolingual English-speaking families participated. Infants came primarily from White, middle-class backgrounds. Infants were assigned randomly to either the *one-name* (8 males; *M* = 9 months, 25 days; *range* = 9 months, 00 days – 10 months, 29 days) or *two-name* condition (8 males; *M* = 9 months, 22 days; *range* = 9 months, 2 days – 10 months, 29 days). There were no differences between groups in mean age or mean receptive vocabulary size (MacArthur-Bates Short Form Vocabulary Checklist: Level I, Fenson, Pethick, Renda, Cox, Dale, & Reznick, 2000), (*one-name: M* = 7.75 words, *SD* = 8.75; *two-name: M* = 7.63 words, *SD* = 5.49; $t < 1$). An additional 18 infants were replaced due to fussiness (11) or track loss (7); attrition rate did not vary as function of either condition (*one-* vs *two-name*) or gender (both *t's* < 1).

2.1.2. Materials

2.1.2.1. Visual stimuli

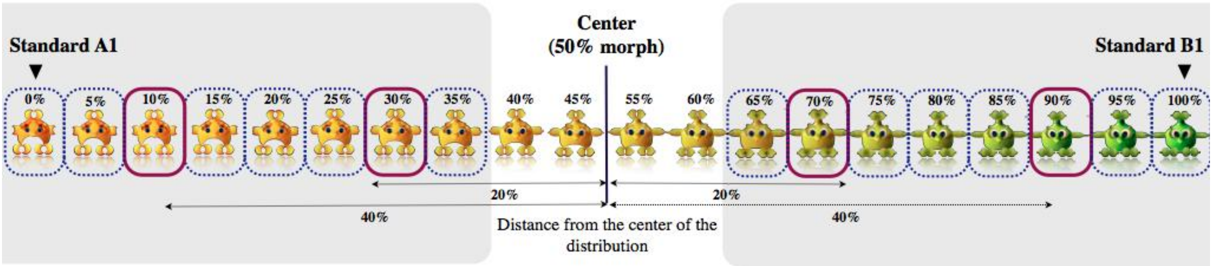
2.1.2.1.1. Objects

See Figure 1. First, we created two pairs of novel colorful creature-like objects. Using each member of a pair as the “standard” (or pole), we created two continua (Set 1, Set 2) using a morphing program (Norrkross MorphX, version 2.9.5). We selected 12 objects from each continuum for presentation during the introduction phase (n = 2, the standards: 0%, 100%) and the learning phase (n = 12 including the standards: 0%, 5%, 15%, 20%, 25%, 35%, 65%, 75%, 80%, 85%, 95%, 100%), and 4 new objects for presentation during test: two were relatively close to the Standards (10%, 90%) and two were closer to the midpoint (30%, 70%).

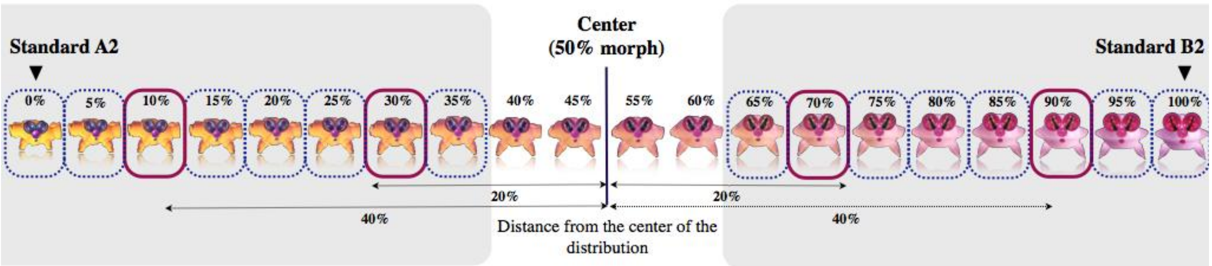
Figure 1. Exemplars presented during the introduction, learning, and test phases for Experiment 1 (bimodal underlying distribution) and Experiment 2 (unimodal underlying distribution).

> Experiment 1

Set 1

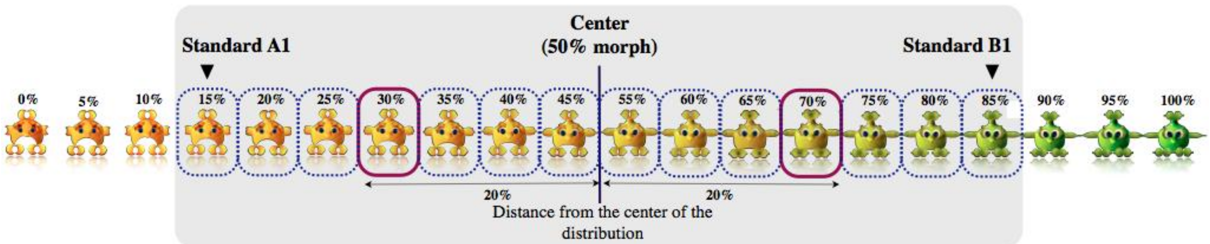


Set 2

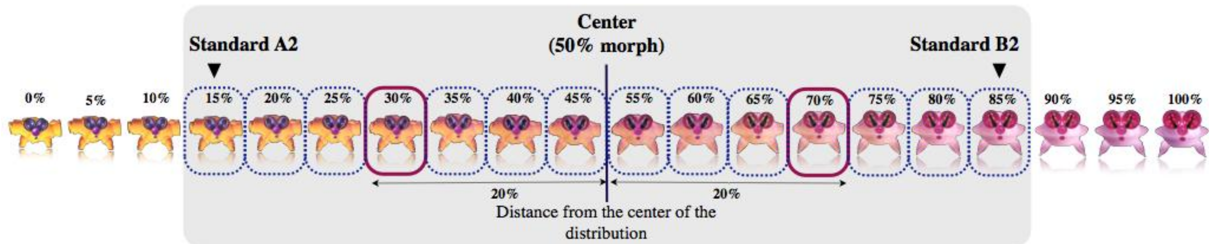


> Experiment 2

Set 1



Set 2



We used a free image comparison script (resemblejs, version 2.2.0, 2015) to provide an index of the perceptual distance among objects in each of our sets. See Table 1. This provides assurances that Set 1 and Set 2 were comparable in their perceptual variabilty, and that in both sets, the test objects closer to the poles were indeed more different than those near the center. In addition, this index reveals that our continua were perceptually tighter than those in Althaus and Westermann (2016)' study[1], suggesting that they were likely more difficult to split into two subcategories.

Table 1.

Perceptual distance among objects presented in our study (based on a free image comparison script: resemblejs, version 2.2.0, 2015).

Study	Set	At the poles	At the center
Experiment 1	1	16.37%	11.18%
	2	17.40%	11.74%
Experiment 2	1	13.89%	07.42%
	2	14.26%	08.71%

2.1.2.1.2. House

See Figure 2. To provide an engaging backdrop for the anticipatory task (described below), we designed an image of colorful house with 5 doors, one at the center and one in each quadrant. Objects from one portion of the visual continuum moved to doors on the left side; objects from the other portion moved to the right.

[1] Althaus and Westermann (2016)' stimuli received values of 21.18% and 18.93% for the exemplars at the poles and near the center of the continuum respectively.

Figure 2. Experimental apparatus. House used at learning and test: for attention purpose, random use of the doors at the top versus the lower quadrant of the house.

2.1.2.2. Auditory stimuli

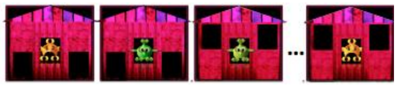
We created two pairs of phonetically distinct pseudo-words. To highlight the phonetic distinction between pseudo-words in each pair, they varied systematically in syllabic structure (one was a CVC token and the other a VCV token) and in phonetic distance (all phonetic segments of the pseudo-words differed by at least one phonetic feature) (pair 1: /guv/-/etS/, pair 2: /tiS/-/orv/). These pseudo-words, recorded by a native English-speaking female, were comparable in duration (*M* = 770 ms, *range* = 708-833 ms).

2.1.3. Procedure

Once they were comfortable in the lab, infants and caregivers were welcomed into the testing room where infants were seated on their caretakers' laps, 2 ft in front of a 19-inch screen equipped with a Tobii T60XL corneal-reflection eye-tracker. The eye tracker, which had a sampling rate of 60 Hz, was calibrated for each participant using a 5-point procedure. Calibration, stimulus presentation, and data recording were performed with the Tobii Studio Analysis software. After calibration, the experiment proper began. The design included three phases: introduction, learning and test. See Figure 3. Sessions lasted approximately 15 mins. Infants were assigned randomly to one of two conditions (*one-name* condition versus *two-*

name condition). Within each, the order in which trials were presented, the order in which objects were presented within a trial, and the left/right movement of the objects during the learning phase were counterbalanced.

Figure 3. Structure of a trial.

Introduction phase	Learning phase	Test phase
Visual information		
 Standard A Standard B	 Standard A Standard B B (85%) ... A (5%)	 A (10%) B (90%) B (70%) A (30%)
Two standards *Each visible for 4.75 s*	Standards A, B and 10 other exemplars *Each appeared first at center door for 3.75 s and then moved to appear in a door either on the left or right for 3 s*	Four new exemplars *Each visible for 3.75 s at center door before disappearing*
Auditory information		
One-name condition		
Hi baby! A ***guv***. This is a ***guv***. A ***guv***. This is a ***guv***.	A ***guv***. This is a ***guv***. A ***guv***. This is a ***guv***. A ***guv***. A ***guv***.	*Silence*
Two-name condition		
Hi baby! A ***guv***. This is a ***guv***. An ***etch*** This is an ***etch***.	A ***guv***. This is a ***guv***. An ***etch***. This is an ***etch***. An ***etch***. A ***guv***.	*Silence*

2.1.3.1. Introduction phase

To engage infants' attention, a female face appeared at the center of the screen, saying, 'Hi baby! Hi! Look!'. Next, each of the Standards (Standard A and B) appeared for 4750 ms, one at a time, in random order on alternate sides of the screen respectively. As each object appeared, the female speaker labeled it twice. Infants in the *one-name* condition heard the same pseudo-word applied to both objects (e.g., *A /guv/. This is a /guv/.*). Infants in the *two-*

name condition heard a different pseudo-word applied to each object (e.g., Standard A: *A /guv/. This is a /guv/.*, Standard B: *An /etS/. This is an /etS/.*).

2.1.3.2. Learning phase

On each trial, an object appeared in the center door (3750 ms) and was labeled. To establish a clear referential link, labels were embedded in a naming phrase on the first two trials of the learning phase (e.g., *A /guv/. This is a /guv/.*) (Fennell & Waxman, 2010); thereafter, labels were presented in isolation (e.g., */guv/.*). Next, the object moved silently to a door either at the left or right side of the house, where it remained visible for another 3000 ms. Exemplars from one end of the visual continuum (e.g., 0%, 5%, 15%, 20%, 25%, 35%) moved to one side and exemplars from the other end (e.g., 65%, 75%, 80%, 85%, 95%, 100%) moved to the other. Following McMurray and Aslin (2004), we varied a) the speed with which each object moved (750 ms – 3000 ms) and b) the portion of the movement trajectory that was visible (0 ms – 1750 ms) in an effort to foster anticipatory looking (Table 1).

All infants viewed the very same sequences of objects and events; what varied was the way in which objects were named when they appeared in the center door. In the *one-name* condition, all exemplars in a given trial received the same name (e.g., */guv/*); in the *two-name* condition, exemplars closest to Standard A received one name (e.g., */guv/* for morphs from 0% to 35%) and those closest to Standard B a different name (e.g., */etS/* for morphs from 65% to 100%).

2.1.3.3. Test phase

At test, infants viewed four new exemplars (two close to the poles: 10%, 90%; two close to the center: 30%, 70%). These were presented in silence, one at a time, in random order. Each appeared at the center door, remained visible for 3750 ms and then disappeared. At issue was whether infants would anticipate the location at which each test object would reappear. Notice that because test objects were presented in silence, infants' anticipatory responses at test could not be mediated by hearing a name; instead, it had to be mediated by the effect of naming on the categories infants formed in the learning phase.

Table 2. Stimulus characteristics (representative set). For each phase of the procedure (introduction, learning, test), characteristics of the objects (% morphing) and their visibility at center and side door and during motion (duration, visible, invisible).

Phase	Trial	Exemplars	At center (ms)	Motion (ms)			At side (ms)
		% morphing	Visible	Total Duration	Visible	Invisible	Visible
Introduction phase	1	Standard A	-	-	-	-	4750
	2	Standard B	-	-	-	-	4750
Learning phase	3	Standard A	3750	1500	1500	0	3000
	4	Standard B	3750	1750	1750	0	3000
	5	B (85%)	3750	1250	1250	0	3000
	6	A (20%)	3750	1000	1000	0	3000
	7	B (95%)	3750	1000	500	500	3000
	8	A (15%)	3750	1250	625	625	3000
	9	B (80%)	3750	1750	875	875	3000
	10	A (35%)	3750	1500	500	1000	3000
	11	A (25%)	3750	750	250	500	3000
	12	B (65%)	3750	1000	0	1000	3000
	13	A (5%)	3750	1250	0	1250	3000
	14	B (75%)	3750	1750	0	1750	3000
Test phase	15	A (10%)	3750	3000	0	3000	-
	16	B (90%)	3750	3000	0	3000	-
	17	B (70%)	3750	3000	0	3000	-
	18	A (30%)	3750	3000	0	3000	-

2.1.4. Coding and analysis

We measured infants' looking to each (empty) door at test to ascertain whether they correctly anticipated the side at which each object would appear. Because infants tend to exhibit anticipatory looking within a one-to-two-second period (Ambrosini et al., 2013; Brandone et al., 2013; Kovács & Mehler, 2009; McMurray & Aslin, 2004; Ruffman et al., 2005), we focused our analyses on a 2 s anticipation window, beginning from the moment the object disappeared from the center door (Figure 5). We trimmed from analysis any test trials (out of a possible 8) on which an infant failed to look at either door. The mean number of included trials was 5.15; this did not vary as function of either condition (*one*- vs *two-name*) or gender ($t < 1$). For each infant and in each time window, we calculated an 'anticipation score' (Looking time to Correct door/(Looking to Correct and Incorrect doors combined)). Anticipation scores were transformed (arcsine root) for parametric analysis to stabilize variance at the extremes of the proportion measures (DeCoster, 2001).

To assess the timecourse of infants' anticipatory responses, data from each condition was aggregated into a series of 200 ms bins. Bins were compared sequentially using ANOVAs to identify any stable period during which infants' looking in the two conditions diverged.

2.1.5. Predictions

We reasoned that if infants formed two categories during the learning phase, then they should anticipate the side at which an object would likely re-appear at test, but that if infants formed a single overarching category, they would not. We predicted that the way in which objects were named during the learning phase would shape infants' anticipatory looking at test. More specifically,we predicted that infants in the *two-name* condition would form two categories during learning, and should therefore anticipate the side at which the unnamed test objects would re-appear. In contrast, we predicted that infants in the *one-name* condition would form a single category encompassing the entire continuum during learning, and should therefore fail to anticipate the side at which the unnamed test objects would re-appear.

We also reasoned that if category membership is discrete, then infants' judgments about location should be the same for objects near the pole and near the center of the continuum. If instead, category membership is continuous and moderated by the perceptual features of the objects, then we predict more variability in infants' responses for test objects near the center of continuum than near the poles.

2.2. Results and discussion

An analysis of infants' anticipatory looking reveals that their categorization along a perceptual contiuum was shaped by the way in which the individual objects were named. As predicted, infants in the *two-name* condition were more likely than those in the *one-name* condition to anticipate correctly the location at which the test objects would re-appear.

Consider first infants' performance across the entire 2 s window. See Figure 4. We submitted infants' aggregated anticipatory scores to an ANOVA using condition (*two-name* versus *one-name*) as a between-participants factor and perceptual difficulty (*near-the-pole* versus *near-the-center*) as a within-participants factor. This revealed a main effect of condition ($F(1, 30) = 4.35$, $p = .046$, $\eta^2 = .13$). As predicted, infants in the *two-name* condition successfully anticipated the likely location of new exemplars at test ($M = 71.76\%$, $SD = 20.26\%$, $t(15) = 4.30$, $p < .001$, $d = 2.22$), suggesting that they had indeed discerned two visual categories during training and held principled expectations about the side at which new members, presented at test, would likely appear. In sharp contrast, infants hearing a single label for the entire visual distribution performed at chance ($M = 51.67\%$, $SD = 32.81\%$, $t < 1$). This outcome is consistent with the prediction that infants hearing a single name for the entire distribution would identify a single underlying visual category and, as a result, would hold no principled expectations about the side at which new objects from this single category would likely appear. There were no other main effects or interactions (all *Fs* < 1). Table 3.

A series of subsequent analyses provided additional support. For example, infants in the *two-name* condition were just as likely to correctly anticipate the location of test objects that were close to the center of the distribution (*two-name*: M = 67.63%, SD = 30.12%, $t(15) = 2.34$, $p = .03$, $d = 1.21$; *one-name*: M = 50.79%, SD = 40.19%, $t < 1$) as those close to the poles (*two-name*: M = 75.89%, SD = 24.52%, $t(15) = 4.22$, $p < .001$, $d = 2.18$; *one-name*: M = 52.55%, SD = 36.52%, $t < 1$). This suggests that infants formed discrete categories: their performance was comparable regardless of how close the objects were to the center of the distribution. In addition, analyses of individual infants' performance revealed that the mean differences observed in the two naming conditions was characteristic of the behavior of most individual infants. We tallied the number of infants in each condition who correctly anticipated the test objects' location (anticipatory scores > .5), Table 3. As predicted, more infants in the *two-name* condition anticipated correctly (n = 14/16, $\chi^2(1, N = 16) = 10.49$, $p = .001$) than did infants in the *one-name* condition (n = 7/16, $\chi^2(1, N = 16) = .53$, $p = .47$).

Table 3. Experiment 1 and 2. Parametric and non-parametric results in each condition.

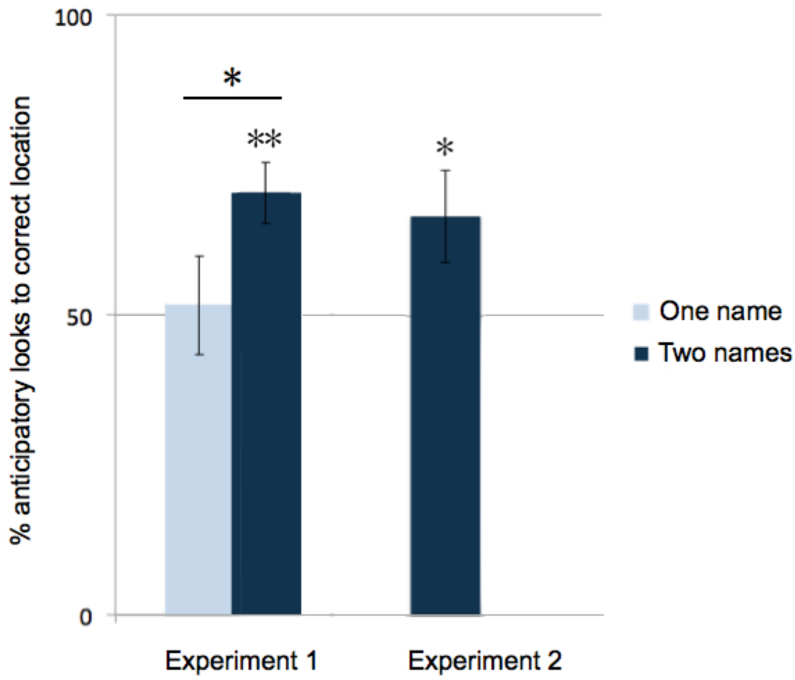
One-name condition

	Mean anticipatory score	SD	T-test	N with correct anticipatory looks	Chi-square
Overall	51.67%	32.81%	$t < 1$	7/16	$\chi^2(1, N = 16) = .53$, $p = .47$
Near the poles	52.55%	36.52%	$t < 1$	8/16	$\chi^2(1, N = 16) = 1.17$, $p = .28$
Near the center	50.79%	40.19%	$t < 1$	7/16	$\chi^2(1, N = 16) = .53$, $p = .47$

Two-name condition

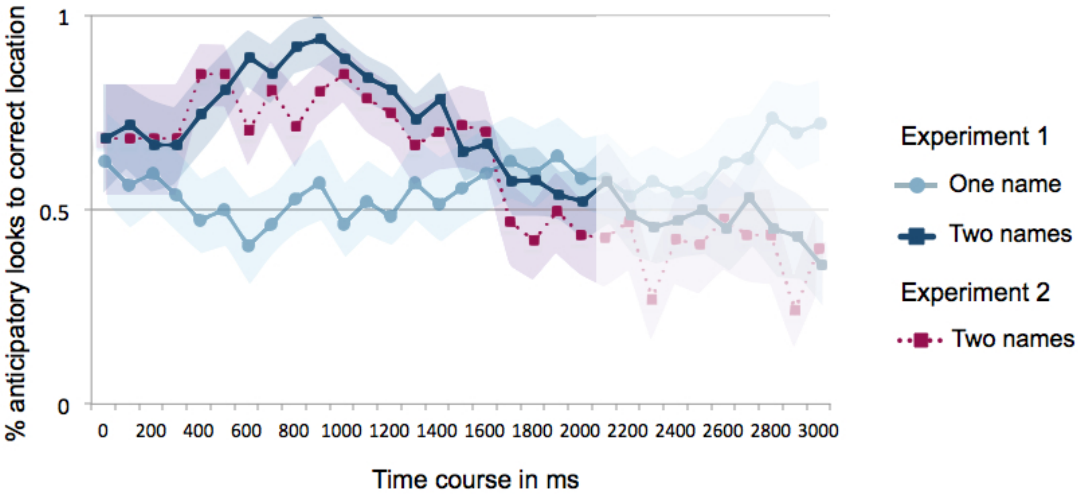
	Mean anticipatory score	SD	T-test	N with correct anticipatory looks	Chi-square
Experiment 1					
Overall	71.76%	20.26%	$t(15) = 4.30$, $p < .001$, $d = 2.22$	14/16	$\chi^2(1, N = 16) = 10.49$, $p = .001$
Near the poles	75.89%	24.52%	$t(15) = 4.22$, $p < .001$, $d = 2.18$	13/16	$\chi^2(1, N = 16) = 8.13$, $p = .004$
Near the center	67.63%	30.12%	$t(15) = 2.34$, $p = .03$, $d = 1.21$	12/16	$\chi^2(1, N = 16) = 6.15$, $p = .013$
Experiment 2					
Overall	66.72%	30.84%	$t(15) = 2.17$, $p = .047$, $d = 1.12$	11/16	$\chi^2(1, N = 16) = 4.50$, $p = .03$
Near the center	66.72%	30.84%	$t(15) = 2.17$, $p = .047$, $d = 1.12$	11/16	$\chi^2(1, N = 16) = 4.50$, $p = .03$

Figure 4. Mean anticipatory looking to the correct door in each condition.



Consider next the continuous timecourse underlying infants' looking (Figure 5). To identify the point at which performance in the conditions diverged, we compared infants' looking in each consecutive 200 ms bin as a function of condition. An ANOVA with condition as a between-participants factor and bin (1-16) as a within-participants factor revealed that looking in the two conditions diverged reliably from 600 ms to 1400 ms (bins 4-8), ($F(1, 30) = 10.70$, $p = .003$, $\eta^2 = .26$). This timing converges well with evidence from infants in other anticipatory looking paradigms (Ambrosini et al., 2013; Brandone et al., 2013; Kovács & Mehler, 2009; McMurray & Aslin, 2004; Ruffman et al., 2005).

Figure 5. Test Phase. Continuous time-course of anticipatory looking in each naming condition, aggregated over infants and trials. Error bars (shaded) correspond to standard errors.



Together, these analyses identify a clear effect of naming on infants' construal of a perceptual continuum. If exemplars along the continuum are all labeled with the same name, infants tend to treat them as members of a single category; in this case, whether an object moves to the left or to the right cannot be predicted by its category membership. But if the very same exemplars along this continuum are labeled with two distinct names, with those closer to Standard A getting one name and those closer to Standard B getting another, then infants identify two distinct categories; in this case, the location to which an exemplar moves can indeed be predicted by its category membership.

Moreover, the effect of naming was sufficiently powerful to direct infants' anticipatory looking for new unnamed test objects, even those near the center of the continuum. This suggests that naming supports the number of categories infants impose along a continuum, and evokes clear expectations about the category boundaries.

In Experiment 2, we put the effects of naming to an even stronger test.

3. Experiment 2

In Experiment 1, our distribution included more exemplars close to the poles than to the midpoint during the learning phase. Thus, although the underlying distribution was continuous, it had a slightly bimodal distribution, with two slight peaks near the poles and a relative depression at its center. Might this have provided infants with a perceptual landmark that signaled a category distinction? Notice that if it did, infants in the *one-name* condition ignored it. But perhaps for infants in the *two-name* condition, this subtle perceptual feature helped to divide the continuum into two categories. In Experiment 2, we address this possibility directly by eliminating any hint of bimodality. This permitted us to ask whether infants can successfully form two categories even when there is no hint of a “perceptual break” in the underlying distribution. To do so, we present infants with a classic unimodal distribution, one with more exemplars near the midpoint of the continuum than at its extremes. If naming the objects with two distinct labels is sufficiently powerful to support the creation of two distinct categories along this continuum, then infants in Experiment 2, like those in Experiment 1’s *two-name* condition, should form two categories and, as a result, should correctly anticipate the location of new unnamed test objects.

3.1. Method

3.1.1. Participants

Sixteen healthy, full-term 9-month-old infants from monolingual English-speaking families participated (8 males; *M* = 9 months, 21 days; *range* = 9 months, 01 days – 10 months, 21 days). Infants came primarily from White, middle-class backgrounds and had a mean receptive vocabulary size of 8.36 words (*SD* = 4.74) (MacArthur-Bates Short Form Vocabulary Checklist: Level I, Fenson et al., 2000). An additional 7 infants were replaced due to fussiness (2) or track loss (5); attrition rate did not vary as function of either condition (*one-* vs *two-name*) or gender ($t < 1$).

3.1.2. Materials

3.1.2.1. Visual stimuli

See Figure 1b. Using the same house and continua as in Experiment 1, we selected 12 exemplars to represent a unimodal disribution. These were presented during the introduction phase ($n = 2$; 15%, 85%) and the learning phase ($n = 12$; 15%, 20%, 25%, 35%, 40%, 45%, 55%, 60%, 65%, 75%, 80%, 85%). At test, two new exemplars, close to the center of the distribution (30%, 70%) were presented twice. See Table 1. A measure of overall object differences (resemblejs, version 2.2.0, 2015) at the poles of the continuum indicated that the distribution was tighter than in Experiment 1.

3.1.2.2. Auditory stimuli

Identical to those in Experiment 1's *two-name* condition.

3.1.3. Procedure

Identical to Experiment 1.

3.1.4. Coding and analysis

Identical to Experiment 1. We trimmed from analysis any test trials (out of a possible 8) on which an infant failed to look at either door. The mean number of included trials was 5.7/8; this did not vary as function of either condition (*one-* vs *two-name*) or gender ($t < 1$). We then calculated for each infant an 'anticipatory score' over a 2 s time window.

3.2. Results and discussion

Even when presented with a unimodal distibution, infants listening to two distinct names for exemplars at each end of the continuum formed two distinct categories. Consider first performance on the full 2 s window of analysis: Infants successfully anticipated the likely re-appearance of the test exemplars (*M* = 66.72%, *SD* = 30.84%, $t(15) = 2.17$, $p = .047$, $d = 1.12$), This suggests that they had indeed formed two categories during the learning phase, Figure 4. Moreover, this pattern characterized the behavior of most infants; 11 out of the 16 infants correctly anticipated the test objects' location (anticipatory scores > .5), $\chi^2(1, N = 16) = 4.50$, $p = .03$). Finally, to assess whether infants' precision in establishing the category boundary varied as function of the visual distribution they observed during learning, we conducted a post-hoc analysis, using experiment as a between-subjects (Experiment 1 (*two-name* condition) vs Experiment 2) and infants' treatment of the test exemplars closest to the center of the continuum (30%, 70%) as a dependent measure. An ANOVA revealed no effect of experiment ($F < 1$). Thus, even when presented with a strongly unimodal distribution, infants in the *two-name* condition not only established two categories, but also identified clear boundaries, permitting them to correctly anticipate the location of new unnamed exemplars even those close to the category boundary.

Analysis of the timecourse (Figure 5) provided additional support for this conclusion: An ANOVA with condition as a between-participants factor and bin (1-16) as a within-participants factor revealed that the timecourse underlying infants' anticipatory looking in the *two-name* condition was identical in Experiments 1 and 2 ($F < 1$).

These results illuminate the power of naming as infants organize their visual experiences of a perceptual continuum into categories; naming supports the formation of two categories even when a category boundary is not 'given' in the distribution.

4. General discussion

These results constitute the first evidence that for infants as young as 9 months of age, naming not only shapes the number of categories they impose along a perceptual continuum but also highlights the joints or boundaries between them. In two experiments, 9-month-old infants were introduced to novel creature-like objects that fell along a perceptual continuum, created by morphing two distinct objects (the Standards). In both experiments, during the learning phase, infants observed that exemplars from one half of the continuum moved in one direction, but that exemplars from the other half of the continuum moved in the other direction. At test, we asked whether infants could correctly anticipate the direction in which new exemplars would move. The results were clear: Infants in the *two-name* condition, who heard one name applied to exemplars from one side of the continuum and a different name applied to exemplars from the other side of the continuum during the learning phase, established two distinct categories and used these to make inferences about where to search for new exemplars, presented at test. In sharp contrast, infants in the *one-name* condition, who heard a single name applied to all exemplars along the entire distribution during the learning phase, formed a single underlying category and searched randomly, at either location.

Thus, by 9 months, naming not only highlights categories that are perceptually discontinuous (like dogs vs dinosaurs), but also sculpts categories from a continuous distribution with no clear perceptual landmarks. This reveals that even before infants begin to produce words on their own, naming serves as a strong supervisory signal for category learning, supporting infants as they impose boundaries along a continuum and highlighting the categories' joints. This new evidence, coupled with evidence from older children (Althaus & Westermann, 2016; Graham, Booth, & Waxman, 2012; Graham, Kilbreath, & Welder, 2004; Johanson & Papafragou, 2011; Landau & Shipley, 2001), suggests that there is considerable developmental continuity in the effects of naming from infancy.

Our results are consistent with the view that infants are sensitive to the principle of *acquired equivalence* (Hall, 1991; Miller & Dollard, 1941) – that two distinct objects that share a name also share other category-based commonalities (Althaus & Mareschal, 2014; Ferguson, et al., 2015; Ferry et al., 2010; Fulkerson & Waxman, 2007; Graham et al., 2012; Plunkett et al., 2008; Waxman & Booth, 2001, 2003; Waxman & Braun, 2005; Waxman & Gelman, 2009) and the principle of *acquired distinctiveness* (Hall, 1991; Miller & Dollard, 1941) – that two objects that have a distinct name belong to two different categories (Dewar & Xu, 2007; Waxman & Braun, 2005; Xu, 2002; Xu et al., 2004, 2005; Yeung, Chen, & Werker, 2014; Yeung & Werker, 2009). Note that our continua were perceptually tighter than the distribution used in Althaus and Westermann (2016). Because in Althaus and Westermann (2016) the underlying distribution was perceived as a broad category in *silence*, *one name* and *two-tone* conditions, we can speculate that in our task, infants should be at least as likely to fail to form two categories in such conditions. If so, this would be suggestive of a stronger contribution of the principle of *acquired distinctiveness*, which further studies will have to determine.

This new evidence, which underscores the power of naming on object categorization even in infants who have not yet begun to speak, challenges three claims. First, this work calls into serious question the argument that naming fails to support category learning in young infants (Deng & Sloutsky, 2015). On this argument, infants should have had difficulty imposing two distinct categories, especially when presented with two novel words. That is, infants should have performed identically in the *one-name* and *two-name* conditions. Clearly, this was not the case.

Second, the evidence reported here challenges the claim that at 8-to-12-months of age, listening to novel words *overshadows* infants' visual processing of novel objects and hinders category learning. On the overshadowing account, it should have been especially difficult for infants in the *two-name* condition to detect two categories (Robinson, & Sloutsky, 2004, 2007a; Sloutsky, & Robinson, 2008). The current data provide no support for this account. Indeed, even when listening to two names, infants were not overshadowed by naming. Instead, they used the two names to establish two distinct categories.

Third, our results question the possibility that names are merely additional features that enter into infants' assessment of a similarity-based comparison of the objects (Sloutsky, 2010; Sloutsky & Fisher, 2004, 2011; Sloutsky, Kloos, & Fisher, 2007; Sloutsky & Lo, 1999). If this were the case, then infants' judgment should have been more variable for objects near the center than near the poles of the continuum. Yet, infants' expectations were equally strong, regardless of perceptual difficulty (near the poles vs near the center of the continuum).

Critically, our results document naming effects with a new anticipatory looking design. This design permitted us to move beyond the limitative interpretations of novelty preference tasks and assess clarity of category boundaries. Yet, infants may have developed two kinds of expectations. Infants may have simply learned to associate a category with a location (Addyman & Mareschal, 2010; Ambrosini et al., 2013; Brandone et al., 2013; Kovács & Mehler, 2009; McMurray & Aslin, 2004; Ruffman et al., 2005; Zamuner, Fais, & Werker, 2014); infants may have reasoned beyond and treated object location as a category feature on its own in the *two-name* condition and as mere within-category variation in the *one-name* condition. This latter possibility is consistent with evidence showing that as young as 13 months of age (Graham, Kilbreath, & Welder, 2004), infants use naming to support inductive inferences about the hidden properties and the likely behavior of the objects (e.g., when Standard A is shaken, it produces a mooing sound, Graham, Keates, Vukatana, & Khu, 2012; Graham & Kilbreath, 2007; Graham et al., 2004; Welder & Graham, 2001).

Importantly, infants were able to form category predictions within a smaller time window (1-2s), than the one usually considered in the literature (10s). While infants' responses may change over time, category decision is time constrained (see Plunkett et al., 2008; for a relatively high drop-out rate with time windows larger than 6 s), especially in anticipatory looking designs where there is no visual information to maintain infants' visual interest (Addyman & Mareschal, 2010; Ambrosini et al., 2013; Brandone et al., 2013; Kovács & Mehler, 2009; McMurray & Aslin, 2004; Ruffman et al., 2005).

Our results also set the foundation for new investigations. First, in future work, it will be important to consider a broader range of visual stimuli. Here, we presented continua that were comprised of creature-like stimuli. There are reasons to suspect that naming effects might be strongest with animate kinds: At 9 months, infants show greater interest for animate over inanimate entities (Ferguson, Graf, & Waxman, 2014; Legerstee, 1994; Sanefuji et al., 2011). Infants are especially attentive to animate-like features (Farroni et al., 2005; Gelman & Opfer, 2002; Molina, Van de Walle, Condry, & Spelke, 2004; Pauen, 2002; Poulin-Dubois, Crivello, & Wright, 2015; Rakison & Poulin-Dubois, 2001; Simion, Macchi Cassia, Turati, & Valenza, 2001; Träuble, Pauen, & Poulin-Dubois, 2014) and already form social categories (Kim, Johnson, & Johnson, 2015; Kinzler, Shutts, & Correll, 2010; Kinzler & Spelke, 2011; Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002; Shutts, Kinzler, McKee, & Spelke, 2009; Waxman, 2013; Waxman & Grace, 2012). Therefore, in future work, it will be important to assess whether the effects observed here would hold up if the objects resembled artifacts, rather than animate objects. Along with this, it would be interesting to evaluate whether the boundaries between animate and inanimate entities can be united by naming (e.g., animates vs inanimates) or whether some distinctions are conceptually (or perceptually) too strong to be overridden by naming.

Another, perhaps more challenging, avenue is discovering whether the naming effects we have documented here provide the foundation for categorization along abstract conceptual continua, including concepts of time and space. Among adults, there is cross-linguistic variation in lexicalization of time and space (e.g., future lies ahead of us in English, behind us in Aymara, below us in Mandarin, or in east of a cardinal space in Kuuk thaayorre, (Boroditsky, 2011; Fulga, 2012). Only with additional research will it be possible to trace when infants become sensitive to the ways that time, space and other abstract continua are lexicalized in their language.

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Figure Captions

Figure 1. Exemplars presented during the introduction, learning, and test phases for Experiment 1 (bimodal underlying distribution) and Experiment 2 (unimodal underlying distribution).

Figure 2. Experimental apparatus. House used at learning and test: for attention purpose, random use of the doors at the top versus the lower quadrant of the house.

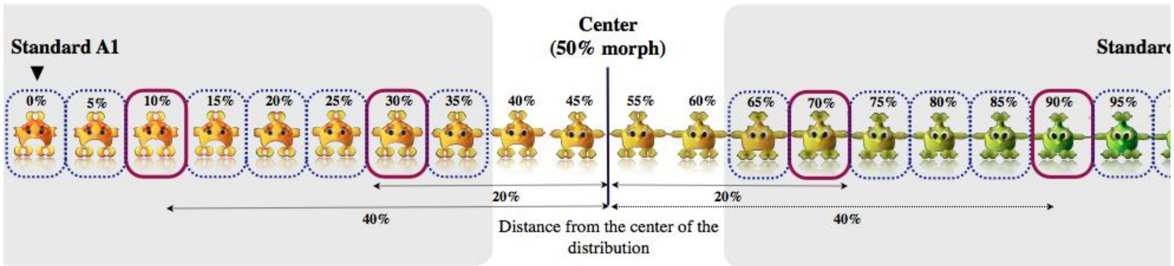
Figure 3. Structure of a trial.

Figure 4. Mean anticipatory looking to the correct door in each condition.

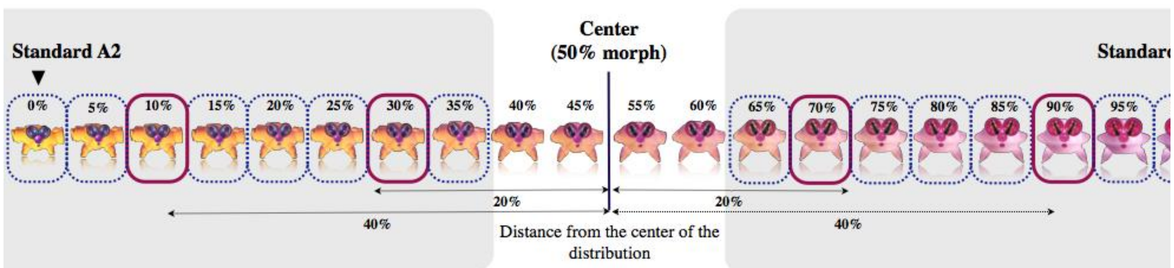
Figure 5. Test Phase. Continuous time-course of anticipatory looking in each naming condition, aggregated over infants and trials. Error bars (shaded) correspond to standard errors.

> Experiment 1

Set 1

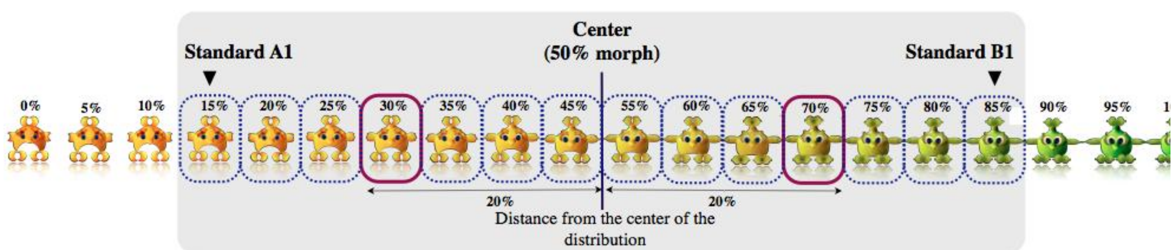


Set 2



> Experiment 2

Set 1



Set 2

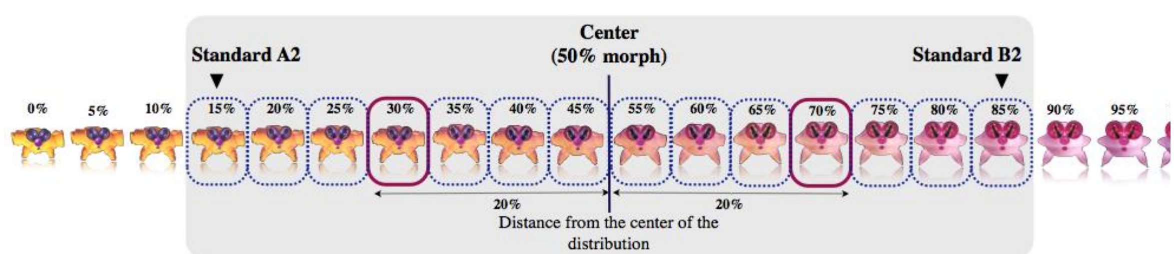


Figure 1.

Figure 2.

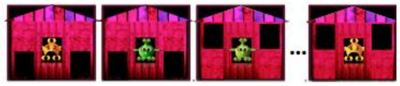
Introduction phase	Learning phase	Test phase
Visual information		
		
Standard A Standard B	Standard A Standard B B (85%) … A (5%)	A (10%) B (90%) B (70%) A (30%)
Two standards *Each visible for 4.75 s*	Standards A, B and 10 other exemplars *Each appeared first at center door for 3.75 s and then moved to appear in a door either on the left or right for 3 s*	Four new exemplars *Each visible for 3.75 s at center door before disappearing*
Auditory information		
***One-name* condition**		
Hi baby! A ***guv***. This is a ***guv***. A ***guv***. This is a ***guv***.	A ***guv***. This is a ***guv***. A ***guv***. This is a ***guv***. A ***guv***. A ***guv***.	*Silence*
***Two-name* condition**		
Hi baby! A ***guv***. This is a ***guv***. An ***etch*** This is an ***etch***.	A ***guv***. This is a ***guv***. An ***etch***. This is an ***etch***. An ***etch***. A ***guv***.	*Silence*

Figure 3.

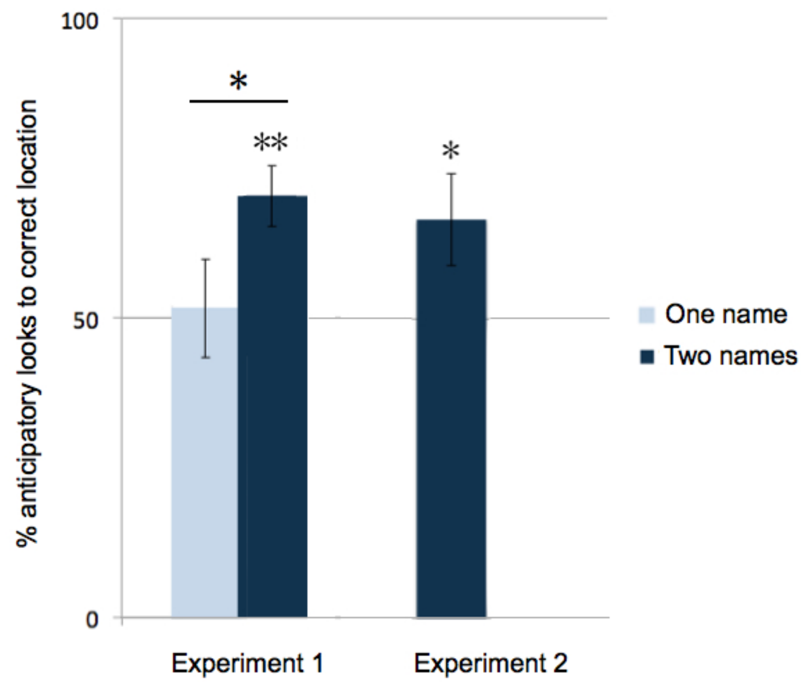

100
50
0
% anticipatory looks to correct location
*
**
*
Experiment 1
Experiment 2
One name
Two names

Figure 4.

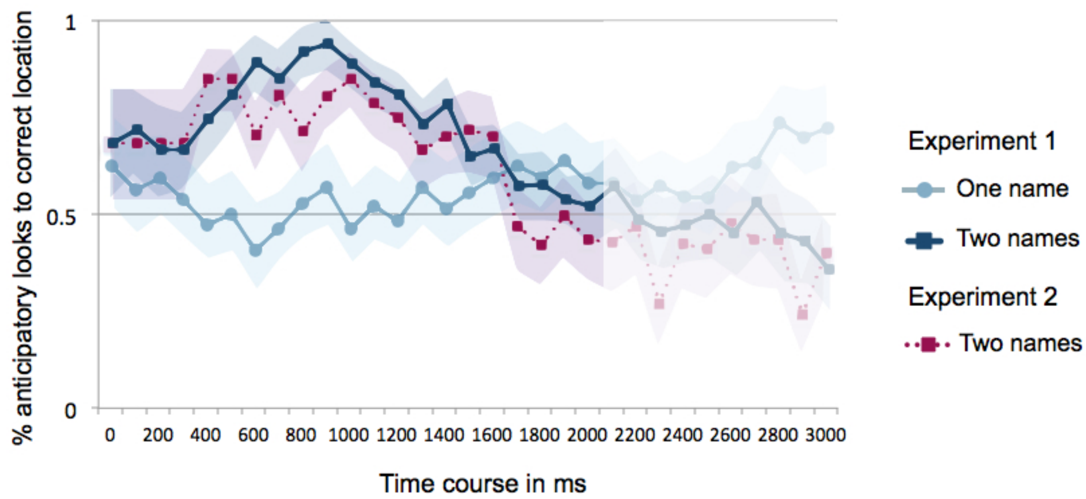

% anticipatory looks to correct location
1
0.5
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
3000
Time course in ms
Experiment 1
One name
Two names
Experiment 2
Two names

Figure 5.

Table 1.

Perceptual distance among objects presented in our study (based on a free image comparison script: resemblejs, version 2.2.0, 2015).

Study	Set	At the poles	At the center
Experiment 1	1	16.37%	11.18%
	2	17.40%	11.74%
Experiment 2	1	13.89%	07.42%
	2	14.26%	08.71%

Table 2. Stimulus characteristics (representative set). For each phase of the procedure (introduction, learning, test), characteristics of the objects (% morphing) and their visibility at center and side door and during motion (duration, visible, invisible).

Phase	Trial	Exemplars	At center (ms)	Motion (ms)			At side (ms)
		% morphing	Visible	Total Duration	Visible	Invisible	Visible
Introduction phase	1	Standard A	-	-	-	-	4750
	2	Standard B	-	-	-	-	4750
Learning phase	3	Standard A	3750	1500	1500	0	3000
	4	Standard B	3750	1750	1750	0	3000
	5	B (85%)	3750	1250	1250	0	3000
	6	A (20%)	3750	1000	1000	0	3000
	7	B (95%)	3750	1000	500	500	3000
	8	A (15%)	3750	1250	625	625	3000
	9	B (80%)	3750	1750	875	875	3000
	10	A (35%)	3750	1500	500	1000	3000
	11	A (25%)	3750	750	250	500	3000
	12	B (65%)	3750	1000	0	1000	3000
	13	A (5%)	3750	1250	0	1250	3000
	14	B (75%)	3750	1750	0	1750	3000
Test phase	15	A (10%)	3750	3000	0	3000	-
	16	B (90%)	3750	3000	0	3000	-
	17	B (70%)	3750	3000	0	3000	-
	18	A (30%)	3750	3000	0	3000	-

Table 3. Experiment 1 and 2. Parametric and non-parametric results in each condition.

	One-name condition				
	Mean anticipatory score	SD	T-test	N with correct anticipatory looks	Chi-square
Overall	51.67%	32.81%	*t < 1*	7/16	χ^2 (1, *N* = 16) = .53, *p* = .47
Near the poles	52.55%	36.52%	*t < 1*	8/16	χ^2 (1, *N* = 16) = 1.17, *p* = .28
Near the center	50.79%	40.19%	*t < 1*	7/16	χ^2 (1, *N* = 16) = .53, *p* = .47

	Two-name condition				
	Mean anticipatory score	SD	T-test	N with correct anticipatory looks	Chi-square
Experiment 1					
Overall	71.76%	20.26%	*t*(15) = 4.30, *p* < .001, *d* = 2.22	14/16	χ^2 (1, *N* = 16) = 10.49, *p* = .001
Near the poles	75.89%	24.52%	*t*(15) = 4.22, *p* < .001, *d* = 2.18	13/16	χ^2 (1, *N* = 16) = 8.13, *p* = .004
Near the center	67.63%	30.12%	*t*(15) = 2.34, *p* = .03, *d* = 1.21	12/16	χ^2 (1, *N* = 16) = 6.15, *p* = .013
Experiment 2					
Overall	66.72%	30.84%	*t*(15) = 2.17, *p* = .047, *d* = 1.12	11/16	χ^2 (1, *N* = 16) = 4.50, *p* = .03
Near the center	66.72%	30.84%	*t*(15) = 2.17, *p* = .047, *d* = 1.12	11/16	χ^2 (1, *N* = 16) = 4.50, *p* = .03

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