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## Listening to the calls of the wild: The role of experience in linking language and cognition in young infants

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### Abstract

Well before they understand their first words, infants have begun to link language and cognition. This link is initially broad: At 3 months, listening to both human and nonhuman primate vocalizations supports infants' object categorization, a building block of cognition. But by 6 months, the link has narrowed: Only human vocalizations support categorization. What mechanisms underlie this rapid tuning process? Here, we document the crucial role of infants' experience as infants tune this link to cognition. Merely exposing infants to nonhuman primate vocalizations permits them to preserve, rather than sever, the link between these signals and categorization. Exposing infants to backward speech—a signal that fails to support categorization in the first year of life—does not have this advantage. This new evidence illuminates the central role of early experience as infants specify *which* signals, from an initially broad set, they will continue to link to core cognitive capacities.

### Keywords

infancy; developmental tuning; language acquisition; conceptual development; language and thought

### 1. Introduction

Human language is our most powerful cultural and cognitive tool, permitting us to share our thoughts and beliefs with others in a fashion that is unparalleled elsewhere in the animal kingdom. Also unique to humans is our altricial status: Human infants are born relatively immature, even compared to other primates. This, coupled with our powerful capacity to learn, insures that human infants are exquisitely sensitive to postnatal experience. It also insures that the course of human development is shaped, for better or worse, by the physical, cultural and linguistic environments in which infants are immersed. Together, these two uniquely human signatures—our capacity for language and our remarkable early plasticity—

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make us a species tailor-made to acquire higher-order cognitive abilities and to discover the subtleties of navigating our complex social world.

This is not to say that human infants are born as ‘blank slates’. On the contrary, even neonates show perceptual preferences for certain signals, chief among them the signals of humans and our closest genealogical cousins (Vouloumanos, Hauser, Werker, & Martin, 2010; Vouloumanos & Werker, 2007). Within their first months, infants tune their earliest perceptual preferences increasingly to the signals of humans, and especially to members of their own social and linguistic communities. For example, within the visual domain, although newborns initially prefer looking at faces of human and nonhuman primates (Di Giorgio, Leo, Pascalis, & Simion, 2012), they rapidly narrow their visual preferences to human faces (Pascalis, de Haan, & Nelson, 2002), and especially faces that most resemble members of their own social community (Kelly et al., 2007; Quinn, Lee, Pascalis, & Tanaka, 2015). This process of perceptual narrowing also occurs in the acoustic domain. Newborns prefer listening to vocalizations of human and nonhuman primates (Vouloumanos et al., 2010), but they rapidly narrow their listening preferences to human vocalizations (Shultz & Vouloumanos, 2010), and in particular to the sounds of their native language (Kuhl et al., 2006; Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1991; Werker & Tees, 1984). Thus, human infants come into the world equipped with an initially broad set of perceptual preferences that encompasses the communicative signals of both humans and nonhuman primates (Lewkowicz & Ghazanfar, 2006; Pascalis, Quinn, Kandel, Tanaka, & Lee, 2014; Scott, Pascalis, & Nelson, 2007), and these preferences are then sculpted by infants’ experience. Moreover, infants’ finely gaged tuning *within* a single perceptual modality (e.g., vision or audition) may pave the way for integrating information *across* perceptual modalities (e.g., integrating faces and vocalizations; Lewkowicz & Ghazanfar, 2009). This process of perceptual narrowing insures that from birth, infants devote attention to relevant signals, homing in increasingly to those of their potential communicative partners.

Crucially, though, acquiring a human language requires more than narrowing in on the vocalizations and the faces of its speakers. The power of human language derives from its links to cognition (e.g., Berlin, Breedlove, & Raven, 1973; Brown, 1958; Gentner & Goldin-Meadow, 2003; Malt, Sloman, & Gennari, 2003; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976; Waxman & Gelman, 2009; Wolff & Malt, 2010). Recent work documents that even in their first year of life, preverbal infants are well on their way to establishing links between the language they hear and the objects and events they observe in the world. Simply listening to human language has far-reaching cognitive advantages: It promotes infants’ acquisition of fundamental psychological processes, including pattern learning (Marcus, Vijayan, Bandi Rao, & Vishton, 1999), the formation of object categories (Balaban & Waxman, 1997; Ferry, Hespos, & Waxman, 2010; Fulkerson & Waxman, 2007), the identification of communicative partners (Vouloumanos, Druhen, Hauser, & Huizink, 2009), knowledge acquisition within social interactions (Vouloumanos, Onishi, & Pogue, 2012) and the development of social cognition (for a recent review, see Vouloumanos & Waxman, 2014).

The early link between language and object categorization, a core cognitive process, was recently documented in a novelty preference paradigm designed to accommodate young

infants (Ferry et al. 2010; Fig. 1b). During a Familiarization Phase, all infants viewed images of a series of distinct objects (e.g., dinosaurs) presented sequentially. For half of the infants, each image was presented in conjunction with human language; for the others, each image was accompanied by a sine wave tone sequence. During a Test Phase, all infants viewed two new images in silence: One a new member of the now-familiar category (e.g., another dinosaur) and the other a member of a novel category (e.g., a fish). In this paradigm, infants' looking time served as an index of categorization. If infants detected the category-based commonalities among the familiarization objects, then they should distinguish the novel from the familiar test image. If infants failed to detect these category-based commonalities, then they should perform at chance (Aslin, 2007; Colombo, 2002; Golinkoff, Hirsh-Pasek, Cauley, & Gordon, 1987).

The results were surprising: Even before understanding their first words, simply listening to human language had a powerful effect on infant cognition. At 3, 4 and 6 months of age, infants listening to human language showed clear preferences at test, suggesting that they had successfully formed the object category (Ferry et al., 2010; Fulkerson & Waxman, 2007). In sharp contrast, infants listening to sine wave tone sequences performed at chance, suggesting that they had failed to form the object category. Perhaps more surprising still, for infants as young as 3 and 4 months, human vocalizations were not the only signals that initially engendered this advantageous cognitive effect; listening to vocalizations of nonhuman primates (Madagascar, blue-eyed lemur: *Eulemur macaco flavifrons*) conferred precisely the same cognitive advantage as human vocalizations (Ferry, Hespos, & Waxman, 2013). Yet by 6 months of age, infants had tuned this initially broad link specifically to human vocalizations; lemur vocalizations no longer exert an advantageous effect on infant categorization (Ferry et al., 2013).

Here we ask: What guides infants to specify *which* signals, from the broad initially privileged set, they will continue to link to cognition and which they will tune out? We focus specifically on the role of exposure. We know that exposure is instrumental as infants tune to the *perceptual* signals in their ambient environment (Doupe & Kuhl, 1999; Fair, Flom, Jones, & Martin, 2012; Friendly, Rendall, & Trainor, 2013; Kuhl et al., 1991; Werker & Tees, 1984). Might exposure also be a guiding force as infants tune the *link* between language and object categorization? Perhaps infants' rich and consistent exposure to human vocalizations (and their paucity of exposure to lemur vocalizations) guides the maintenance of the link to human language, as well as the dissolution of the initial link to lemur vocalizations.

Certainly we cannot address this question by manipulating infants' exposure to human language. Instead, we adopt a different strategy: We systematically manipulate infants' exposure to lemur vocalizations. To ascertain whether and how infants' exposure to this initially privileged signal affects its link to cognition, we focus on infants at 6 and 7 months of age—infants who, in the absence of exposure, would have tuned out the link between lemur vocalizations and categorization (Ferry et al., 2013).

The logic of our designs, described below, is inspired by two recent lines of elegant work documenting that although infants tune out some perceptual signals from a broader, initially privileged set, these signals can nonetheless be either *reinstated* or *maintained* if infants are

given exposure to them. For example, providing 12-month-old infants with *brief* (less than one minute) exposure to monkey faces enabled them to *reinstate* their developmentally prior ability to discriminate among novel monkey faces, even months after their face perception had been tuned specifically to human (and no longer monkey) faces (Fair et al., 2012; for parallel work in music perception, see Hannon & Trehub, 2005; Trehub & Hannon, 2006). In addition, providing infants with *persistent* exposure—from 6 months (when infants still discriminate among monkey faces) until 9 months (when they would otherwise have tuned specifically to human faces)—enabled infants to *maintain* their perceptual discrimination of monkey faces (Pascalis et al., 2005; Scott & Monesson, 2009; for parallel work in other-race face perception, see Heron-Delaney, Wirth, & Pascalis, 2011). Combined, this evidence showcases infants' perceptual plasticity and the powerful effects of exposure.

But does exposure also affect the development tuning of infants' links between signals and conceptual content? Does exposure to a signal that was part of infants' broad initially privileged set—in this case, lemur vocalizations—permit infants to either *reinstate* or *maintain*<sup>1</sup> the link between this signal and object categorization? In Experiment 1, we ask whether brief exposure to lemur vocalizations at 7 months, one month after the link between lemur vocalizations and object categorization would otherwise have been severed, permits infants to *reinstate* the link. In Experiment 2, we ask whether brief exposure to backward speech—a signal that consistently fails to support object categorization at any age (Ferry et al., 2013)—permits infants to create a link. In Experiment 3, we ask whether prolonged exposure to lemur vocalizations, from 4 months of age (when lemur vocalizations still promote object categorization) until 6 months of age (when the link between lemur vocalizations and object categorization would otherwise have been severed), permits infants to *maintain* this link.

## 2. Experiment 1

Does brief exposure to a signal within infants' initially privileged set—here, lemur vocalizations—at an age *after* which infants have tuned out its link to cognition, enable them to *reinstate* the developmentally prior link between this signal and object categorization?

### 2.1. Method

**2.1.1. Participants**—Fourteen fullterm infants participated (9 female,  $M_{age} = 7$  months, 15 days;  $SD_{age} = 12$  days).<sup>2</sup> Another nine participated but were excluded from analyses due to insufficient attention during familiarization (7), caregiver interference (1), or a test score more than 2.5 standard deviations from the mean (1).

<sup>1</sup>We adopted these terms to parallel the documented effects of exposure in reinstating and maintaining infants' discrimination of unfamiliar (nonhuman and other-race) faces and voices.

<sup>2</sup>Across experiments, we selected our sample size based on effect sizes reported in previous studies involving the categorization task and signals (lemur vocalizations and backward speech) used here, with infants in this age range (Ferry et al., 2013; Fulkerson & Waxman, 2007). In addition, participants across experiments were raised in environments with less than 25% exposure to a second language, and we included for analysis only those infants who looked at the images on the screen for at least 40% of the Familiarization Phase. We selected 40% rather than 50% looking during familiarization (as in Ferry, Hespos and Waxman, 2010; 2013) as our inclusion criterion because 6- and 7-month-old infants in this task tend to look less than do 3- and 4-month-old infants, and because these older infants (in experiments 1 and 3) showed reliable decreases in looking time over the course of familiarization (an indicator of learning), therefore accruing less looking time, overall.

**2.1.2. Procedure**—All infants participated in the standard categorization task with familiarization images accompanied by lemur vocalizations (Ferry et al., 2013; Fig. 1b), with one critical modification: Immediately before participating in this task, infants were exposed to lemur vocalizations (Fig. 1a). We created a 10-minute soundtrack of classical music (a Mozart piano concerto), interspersed at irregular intervals with 8 distinct lemur vocalizations, each repeated 4 times (2 minutes total duration).<sup>3</sup> During the Exposure Phase, lemur vocalizations were not linked to a communicative exchange of any kind; instead, they were simply part of infants' ambient acoustic environment.

**2.1.3. Coding and analysis**—Infants' looking time served as our dependent measure. Infants' left-right eye gaze directions were coded frame-by-frame by trained coders, blind to the hypotheses.<sup>4</sup> For the Familiarization Phase, we coded infants' looking time for each individual trial. We then calculated their mean looking time across all 8 familiarization trials, as well as their mean looking time for familiarization trials 1-4 and 5-8 (see Table 1). For the Test Phase, we coded infants' first 10 seconds of looking to the test images,<sup>5</sup> and then calculated a Preference Score (looking time to novel test image / looking time to both test images combined) (see Table 1). A preliminary analysis revealed that infants' Preference Scores at test were not related to their gender, age, or looking time during familiarization. In addition, there was no change in infants' looking over the first and last 4 familiarization trials,  $t(13) = 1.31, p = .213$  (see Table 1).

## 2.2. Results

This exposure manipulation had a dramatic effect: Infants revealed a robust preference for the novel test image,  $M = .57, SD = .09; t(13) = 3.12, p = .008, d = .78$ , indicating that they successfully formed an object category (Fig. 2). Their success stands in sharp contrast to infants' failure with no such exposure, at an age after which they had tuned out lemur vocalizations (Ferry et al., 2013). Thus, mere exposure to lemur vocalizations, even briefly, is sufficient to permit infants to reinstate a developmentally prior link between this signal and object categorization.

## 3. Experiment 2

But does exposure to *any* novel signal boost infants' subsequent categorization in the context of listening to that signal? Or is this 'boost' reserved for signals that were part of infants' initial template? To address this, we used precisely the same paradigm as in Experiment 1, but replaced the lemur vocalizations (presented during Exposure and Familiarization) with segments of backward speech—a signal that fails to facilitate object categorization at any point in the first year (Ferry et al., 2013). If exposure to *any* auditory signal boosts infants' subsequent ability to form categories while listening to that signal, then infants in Experiment 2, like those exposed to lemur vocalizations in Experiment 1, should successfully form object categories in the subsequent categorization task.

<sup>3</sup>This duration is comparable to the exposure provided in other paradigms (e.g., Fair et al., 2012; Hannon & Trehub, 2005).

<sup>4</sup>Across all three experiments reported here, a 2<sup>nd</sup> independent observer re-coded 36% of infants. Reliability between observers was high (Pearson's  $r = .97, p < .0001$ ).

<sup>5</sup>Our analysis of the first 10 seconds of accumulated looking during test trials directly follows the analyses in Ferry, Hespos and Waxman (2010; 2013).

### 3.1. Methods

**3.1.1. Participants**—Fourteen fullterm infants participated (7 female;  $M_{age} = 7$  months, 16 days;  $SD_{age} = 12$  days). Another four participated but were excluded due to insufficient attention during familiarization.

**3.1.2. Procedure**—We retained the design of Experiment 1, but replaced the lemur vocalizations during the Exposure and Familiarization Phases with segments of backward speech.

**3.1.3. Coding and analysis**—Identical to Experiment 1. As in Experiment 1, preliminary analyses revealed that infants' Preference Scores at test were not related to their gender, age, or mean looking time during familiarization. Also as in Experiment 1, there was no change in infants' looking over the first and last 4 familiarization trials,  $t(13) = .155$ ,  $p = .879$  (see Table 1).

### 3.2. Results

Infants exposed to backward speech failed to form object categories, performing at chance levels,  $M = .47$ ,  $SD = .11$ ;  $t(13) = -.98$ ,  $p = .34$ ,  $d = .27$  (Fig. 2). This null effect, which mirrors the chance-level performance of infants who receive no such exposure (Ferry et al., 2013), contrasts sharply with infants' successful categorization after the very same amount and kind of exposure to lemur vocalizations (Experiment 1),  $t(26) = -2.70$ ,  $p = .012$ . Moreover, infants' successful categorization in Experiment 1 and failure in Experiment 2 cannot be attributed to differences in their engagement with the two signals. If lemur vocalizations happened to have been more engaging for infants than backward speech, then infants listening to lemur vocalizations (Experiment 1) should have been more visually attentive during familiarization (when the signals were played) than those listening to backward speech (Experiment 2). This was not the case: There were no differences in infants' mean accumulated looking times during familiarization in the two experiments,  $t(26) = 1.5$ ,  $p = 0.14$ . Instead, the differences between infants' performance at test underscore the very different cognitive consequences of exposure to signals that were once part of infants' initially broad template (lemur vocalizations; Experiment 1) versus those that were not (backward speech; Experiment 2).

Together, Experiments 1 and 2 make two contributions. First, they reveal that experience is instrumental not only for perceptual tuning, but also for tuning infants' links between vocalizations and cognition. Second, this new evidence converges well with evidence that experience-based tuning operates over some signals (e.g., nonhuman primate vocalizations), but not all signals (e.g., backward speech) (Werker & Tees, 1984).

## 4. Experiment 3

In Experiment 3, our goal was to submit the effects of exposure to lemur vocalizations to an even more stringent test. Experiment 1 revealed that brief exposure to lemur vocalizations has advantageous consequences for infants' subsequent object categorization, moments later. But what are the limits of this effect? Is this a fleeting phenomenon, one that permits infants

to reinstate the developmentally prior link between lemur calls and cognition for only a few moments? And is this effect tightly tied to time or place (experience in the laboratory)? Or might exposure to lemur vocalizations have a longer-lasting effect?

## 4.1. Methods

**4.1.1. Participants**—Fourteen fullterm infants participated in a rigorous 6-week exposure paradigm (8 female). Exposure began at 4.5 months ( $M_{age} = 4$  months, 18 days;  $SD_{age} = 13$  days), when lemur vocalizations still promote object categorization, and ended 6 weeks later, when this signal would otherwise have been tuned out (Ferry et al., 2013). Infants were tested at 6 months ( $M_{age} = 6$  months, 6 days;  $SD_{age} = 8$  days). Another two infants participated but were excluded due to insufficient attention during familiarization. Three others were excluded because their caregivers failed to follow the strict at-home exposure protocol precisely.

**4.1.2. Procedure**—All infants were exposed repeatedly to lemur vocalizations (2 minutes, within the same 10-minute soundtrack used in Experiment 1) for an average of 6 weeks. Caregivers played this soundtrack at home to their infants on a precise tapering schedule (Heron-Delaney, Wirth, & Pascalis, 2011; Pascalis et al., 2005; Scott & Monesson, 2009). Infants listened to the soundtrack everyday in Week 1, every other day in Week 2, and three times per week thereafter. Next, infants (who were by now 6 months of age) visited the laboratory. Unlike infants in Experiment 1, these infants did not listen to the soundtrack upon arrival at the laboratory. Instead, we engaged them directly in the object categorization task.

**4.1.3. Coding and analysis**—Identical to Experiments 1 and 2. Preliminary analyses revealed that infants' preferences at test were not related to gender, age, or mean looking time during familiarization. In contrast to Experiments 1 and 2, however, infants in Experiment 3 showed a significant decrease in looking from the first to the last 4 familiarization trials,  $t(13) = 2.79$ ,  $p = .008$  (see Table 1). We suspect that infants' extensive exposure (6 weeks) permitted them to process these signals more efficiently than their counterparts in Experiments 1 and 2, who received considerably less exposure (2 minutes).

**4.2. Results**—The results were striking: Although infants in this experiment had not heard a lemur vocalization for days ( $M = 2$  days,  $SD = 2$  days), they nonetheless successfully formed object categories,  $M = .59$ ,  $SD = .14$ ,  $t(13) = 2.52$ ,  $p = .026$ ,  $d = .64$  (Fig. 2). Indeed, their successful categorization at test mirrored that of infants who had listened to lemur vocalizations only moments before the categorization task (Experiment 1),  $t(22.1) = .44$ ,  $p = .66$ . Infants' performance at test, moreover, was unrelated to the number of days that had transpired since they had last heard a lemur call at home ( $p = .970$ ). In addition, infants in this experiment accumulated the same mean looking time during familiarization as their counterparts in Experiment 1 ( $t(26) = 0.21$ ,  $p = .83$ ) and Experiment 2 ( $t(26) = 1.13$ ,  $p = .27$ ) (See Table 1).

Clearly, then, the cognitive advantage conferred by exposing infants to lemur vocalizations is more than a fleeting phenomenon. Exposure permitted infants to *maintain* an initial link

between lemur vocalizations and categorization throughout the developmental window during which it would otherwise have been tuned out, and this effect persisted for at least a period of several days post exposure.

## 5. General Discussion

Together, these experiments provide the first evidence that experience plays a vital role as infants specify which signals, from a broad initial set of possibilities, they will harness to core conceptual processes that ultimately provide the foundations of meaning. These findings advance our understanding of developmental tuning beyond considerations of perceptual sensitivities alone, documenting the role of experience as infants tune the link between perceptual signals and *conceptual* processes. Additionally, this work, which underscores the importance of language exposure in the first months of life, has far-reaching implications for early language and cognitive development. It provides a unique vantage point from which to consider the intricate interface between capacities inherent in the human infant and the shaping force of experience. Although experience may play little role, if any, in picking out the broad set of signals that infants first link to cognition (Ferry et al., 2013), here we show that experience is essential in guiding infants, with increasing precision, to single out which signals from the initially privileged set they will *continue* to link to meaning and which they will *tune out*.

We have demonstrated that at 6 and 7 months, when the link between lemur vocalizations and object categorization would otherwise have been severed (Ferry et al., 2013), merely exposing infants to this signal has a dramatic effect, permitting infants either to *reinstate* or *maintain* this developmentally prior link (Experiments 1, 3). We have also identified principled limits on the *kinds* of signals that may be mediated by exposure alone: For signals that are not included in infants' initial endowment (e.g., backward speech), experience alone appears to be insufficient for creating, *de novo*, a link to cognition (Experiment 2). By addressing directly the interplay between infants' initial template and the effects of exposure, these studies contribute to a larger goal—one central to the cognitive and developmental sciences—of refining our understanding of the interplay between “nature and nurture.”

These results, important in their own right, raise intriguing new questions. Chief among them are questions concerning the timing parameters underlying the exposure effects documented here. In future work, it will be important to identify more precisely how *much* exposure to lemur vocalizations is required, how *long* the benefits of exposure persist, and whether these timing parameters vary as a function of *development*. We suspect that there may be sensitive periods for maintaining this link—periods during which exposure alone will exert a dramatic effect

Interestingly, this work also raises an apparent paradox: If in the first six months of life, infants become increasingly precise, linking their core cognitive capacities (here, object categorization) specifically to *human* vocalizations, then how is it that adults exhibit such remarkable flexibility in appropriating *otherwise arbitrary* non-linguistic signals in the service of communication (e.g., the tone sequences of Morse code, the letter characters of

written text)? This observation suggests that there must be another route—beyond exposure alone—by which humans come to link otherwise arbitrary signals to conceptual content.

Recent developmental evidence has identified one such route (Ferguson & Waxman, 2016). Using the same categorization task as we used here, Ferguson and Waxman (2016) focused on 6-month-old infants' responses to sine wave tone sequences. Sine wave tone sequences, like backward speech, are an otherwise arbitrary signal; indeed, they consistently fail to promote object categorization at any point in the first year of life (Ferry et al., 2010; Fulkerson & Waxman, 2007). As in the experiments reported here, Ferguson and Waxman (2016) included an exposure phase during which infants listened to tone sequences before participating in the categorization task itself. But in sharp contrast to the current experiments, during the exposure phase the tone sequences were incorporated into a rich social communicative context. Infants viewed brief videotaped episodes involving two young women engaged in a lively conversational exchange in which one woman spoke and the other responded in (dubbed) sine wave tone sequences. Embedding the tones in this rich communicative exchange had a dramatic effect on infants' subsequent object categorization: 6-month-olds successfully formed object categories while listening to tone sequences. Yet if the very same tone sequences were uncoupled from the communicative exchange and presented instead as part of the ambient acoustic environment, infants failed to establish this link. Notice that this outcome converges well with the evidence reported here for backward speech (Experiment 2): When infants were exposed to backward speech as part of the ambient acoustic environment, they failed to link backward speech with object categorization. Strikingly, when tone sequences were embedded within a rich social communicative interchange, infants responded to them quite differently.

The evidence from Ferguson and Waxman (2016), considered in conjunction with the new evidence reported here, suggests that there may be (at least) two routes by which infants establish links between signals and meaning. For signals that are part of infants' initial template (e.g., human and nonhuman primate vocalizations), exposure alone appears to be sufficient to maintain or reinstate the link at 6 or 7 months of age. In contrast, for signals that fall outside of infants' initial template (e.g., tones, backward speech), a different route is required: Infants will link otherwise arbitrary signals to meaning *only* if they have been embedded within a social communicative exchange (Ferguson & Waxman, 2016; May & Werker, 2014; Namy & Waxman, 1998; Woodward & Hoyne, 1999). This leads to a clear prediction: Even prolonged exposure to such signals (either tone sequences or backward speech) is unlikely to lead infants to link them to cognition *unless* the signals are introduced within a rich social, communicative context. This prediction is currently under investigation.

This work also heralds a new set of questions: What does it mean to be a “privileged signal?” Here, we have adopted a descriptive approach, identifying any signal that initially supports infants' earliest cognitive capacities as an “initially privileged” one. Thus far, this set includes human and nonhuman primate vocalizations and excludes sine wave tone sequences and backward speech (Ferry et al., 2010, 2013). A goal for future work will be to broaden this description, identifying the boundary conditions on the *kinds* of signals that initially promote object categorization. For example, examining infants' responses to vocalizations of nonprimates (mammals, birds) will permit us to discover whether all

naturally produced vocalizations offer the same early advantageous effect on infant cognition or if this effect is reserved for our nearest genealogical cousins. Another goal will be to pursue detailed acoustic analyses to identify which perceptual features distinguish the set of signals that initially support infants' object categorization from those that do not. Supplementing this work, an additional key avenue will be to ascertain which other cognitive capacities, if any, are supported by these signals.

Finally, infants' neural responses to acoustic signals like the ones we have considered here may shed light on compelling questions about what counts as an initially privileged signal. We know that the neonate brain responds differentially to forward and backward human speech (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002). But what remains unknown is how infants respond neurally to lemur vocalizations, and whether this changes over the first 6 months. At 3 and 4 months, when human and lemur vocalizations confer the same cognitive advantage in categorization (a behavioral measure), do these two signals also elicit the same neural signatures? Does infants' neural response to lemur vocalizations change between 4 and 6 months, as infants tune out its link to cognition (see Grossmann, Missana, Friederici, and Ghazanfar, 2012)? Perhaps lemur vocalizations leave a "neural trace" (Rivera-Gaxiola, Silva-Pereyra, & Kuhl, 2005; Scott, Shannon, & Nelson, 2006) of their earlier privileged status, after the link to cognition has been severed. If so, this trace may provide the footing upon which exposure to this signal reinstates a developmentally prior link to cognition.

In closing, the current results provide new insight into the crucial role of language exposure in the first months of life. They represent an important first step in identifying how exposure to signals in the ambient environment guide infants to home in on precisely which signals, from their initially broad set, will carry meaning. This work illuminates the cascading interactions between infants' innate endowments and the powerful shaping role of their early experiences.

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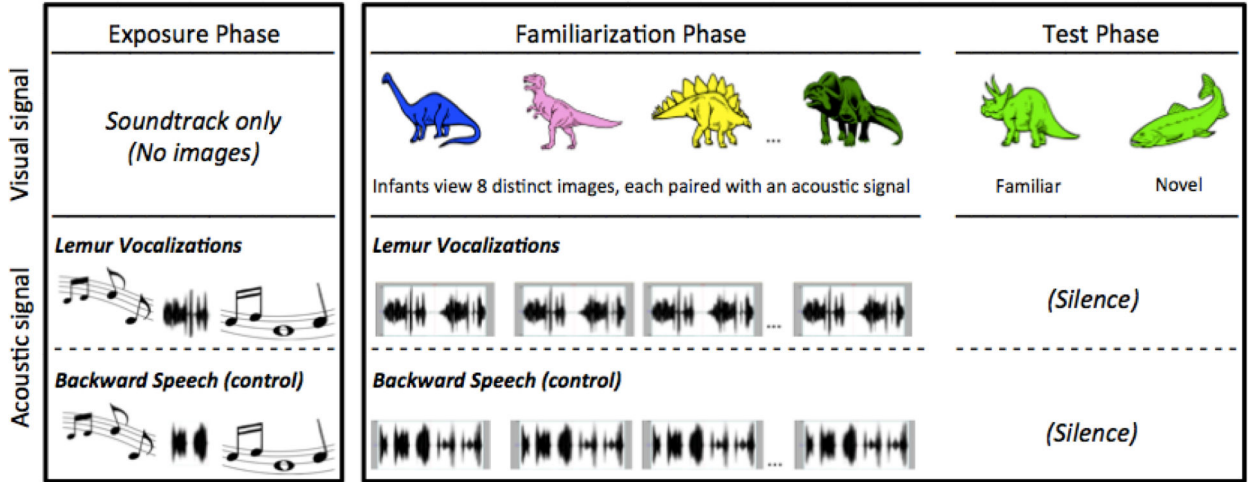
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A. Exposure

B. Categorization Task



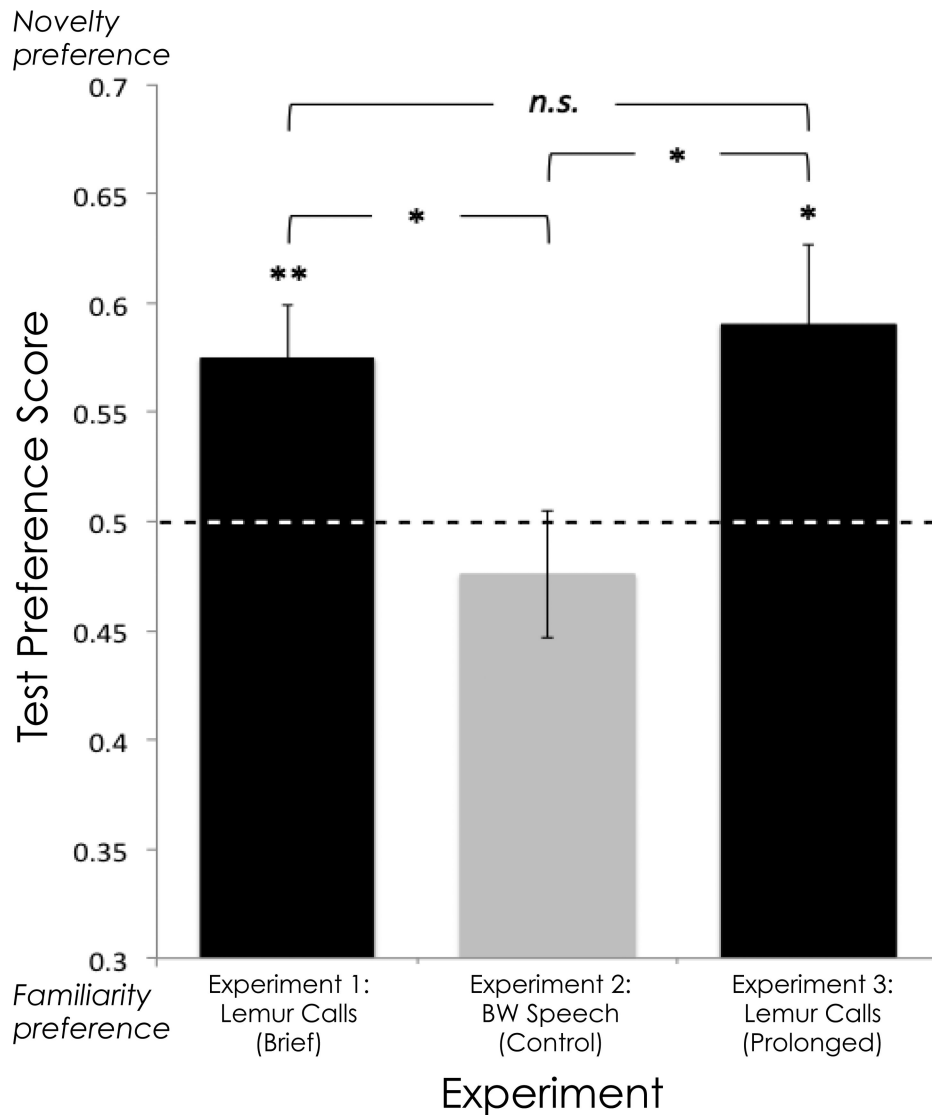
**Fig. 1.** Experimental design. In the Exposure Phase (A), each infant listened to a 10-minute soundtrack of classical music (a Mozart piano concerto), interspersed at irregular intervals with 8 distinct lemur vocalizations (Experiments 1 and 3) or, in the control condition (Experiment 2), with 8 different segments of backward speech. Each signal was repeated 4 times, for a total of 2 minutes accumulated duration. Signals presented during exposure differed from those presented in the Categorization Task. After Exposure, infants participated in the Categorization Task from Ferry et al., 2013. (B). During Familiarization, each infant viewed 8 distinct visual images (20 seconds each), presented sequentially, in conjunction with a lemur vocalization (or, in the control condition, a segment of backward speech). The same lemur vocalization (or backward speech segment, for Experiment 2) was presented twice during each familiarization trial. At test (20 seconds), each infant viewed 2 images, a new member of the now-familiar category and a member of a novel category; these were presented simultaneously, in silence.

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**Fig. 2.** Infants' Preference Scores at test across experiments. Infants exposed to lemur vocalizations (Experiments 1 and 3) revealed a robust preference for the novel test image, indicating that they had formed the object category. Infants exposed to backward speech (Experiment 2) failed to form the object category. This suggests that the 'boost' conferred by exposure may be restricted to signals that were included in infants' initially broad template. Error bars represent  $\pm 1$  SEM. Significant differences between Preference Score and chance performance (0.50) and between test conditions are marked by a single asterisk ( $p < 0.05$ ) or double asterisk ( $p < 0.01$ ).

**Table 1**

Experiments 1-3. Summary of results for Familiarization and Test Phases.

Experiment	Familiarization		Test
	All Trials (1-8): Mean looking (SD)	Trials 1-4 vs. Trials 5-8: Mean looking (SD)	Preference Score (SD)
1. Lemur calls (brief)	12.48 s (2.23 s)	12.96 s (2.65 s) vs. 12.00 s (2.59 s)	<i>.57 (.09)**</i>
2. BW speech (control)	11.30 s (1.94 s)	11.37 s (1.82 s) vs. 11.22 s (3.26 s)	.47 (.11)
3. Lemur calls (prolonged)	12.28 s (2.66 s)	<i>13.23 s (2.34 s) vs. 11.33 s (3.45 s)**</i>	<i>.59 (.14)*</i>

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