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Short Communication

# What the *[beep]*? Six-month-olds link novel communicative signals to meaning

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ABSTRACT

Over the first year, infants tune into the signals of their native language and begin to link them to meaning. Here, we ask whether infants, like adults, can also infer the communicative function of otherwise arbitrary signals (here, tone sequences) and link these to meaning as well. We examined 6-month-olds' object categorization in the context of sine-wave tones, a signal that fails to support categorization at any point during their first year. However, before the categorization task, we exposed infants to tones in one of two vignettes. In one, the tones were produced by an actor in a rich communicative exchange; in the other, infants heard the very same tones, but these were uncoupled from the actors' activity. Infants exposed to the communicative vignette successfully formed object categories in the subsequent test; those exposed to the non-communicative vignette failed, performing identically to infants with no prior exposure to this novel signal. This reveals in 6-month-old infants a remarkable flexibility in identifying which signals in the ambient environment are communicative and in linking these signals to core cognitive capacities including categorization.



## 1. Introduction

Over the first year of life, infants tune into the signals of their native language and begin to link them to meaning (Ferry, Hespos, & Waxman, 2010, 2013; Fulkerson & Waxman, 2007; Gervain & Mehler, 2010; Saffran, Werker, & Werner, 2007; Vouloumanos, Hauser, Werker, & Martin, 2010; Waxman & Lidz, 2006). During this same period, they also become increasingly attuned to the communicative functions of other signals, including eye-gaze and pointing (Krehm, Onishi, & Vouloumanos, 2012, 2014; Liszkowski, 2008; Senju & Csibra, 2008). This early-emerging communicative competence flourishes over development. Indeed, a hallmark of being human is the flexibility with which we infuse otherwise arbitrary signals – from billows of smoke to Morse code tones – with communicative status. Our goal in the current experiment was to ask whether this capacity to infer communicative function in arbitrary signals is available to infants, or whether this flexibility requires the scaffolding of more fully developed social or linguistic capacities.

We take as our starting point recent evidence that listening to human language engages infants' object categorization, a fundamental conceptual capacity (Ferry et al., 2010, 2013). Ferry and colleagues documented that, for infants as young as three months of age, listening to the vocalizations of either human or non-human primates promoted the formation of categories in a way that listening to well-matched sine-wave tone sequences did not. By six months, this facilitative effect on object categorization becomes tuned specifically to human vocalizations. Thus, well before infants begin to speak, they have already begun to link language and cognition, a link that will serve them well as they acquire the meanings of their first words (Brown, 1958; Medin & Rips, 2005; Murphy, 2004).

But is this link to cognition, once tuned specifically to human language, then reserved exclusively to human language? Or might a novel signal also promote categorization if 6-month-old infants could be convinced that it served a communicative function? Two emerging themes in the developmental literature support the latter possibility. First, by 6 months, infants have begun to appreciate the communicative function of speech as well as non-speech signals (Imafuku, Hakuno, Uchida-Ota, Yamamoto, & Minagawa, 2014; Lloyd-Fox, Széplaki-Köllőd, Yin, & Csibra, 2015; Parise & Csibra, 2013). For example, they expect that speech will be directed to people and not artefacts (Augusti, Melinder, & Gredebäck, 2010; Legerstee, Barna, & DiAdamo, 2000) and that speech can transmit information that non-communicative vocal sounds (e.g., coughing) cannot (Vouloumanos, Martin, & Onishi, 2014).

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By at least 8–9 months, infants also appreciate the communicative functions of eye gaze and pointing (Krehm et al., 2012, 2014; Senju & Csibra, 2008; Senju, Csibra, & Johnson, 2008). Second, at least for these older infants, these non-linguistic signals (e.g., eye gaze, pointing) may, like language, support infants' learning about objects and object categories (Csibra & Gergely, 2009; Futó, Téglás, Csibra, & Gergely, 2010; Wu, Gopnik, Richardson, & Kirkham, 2011; Wu, Tummeltshammer, Gliga, & Kirkham, 2014; Yoon, Johnson, & Csibra, 2008).

But what remains unanswered is whether infants, like older children and adults, are flexible enough to identify a new communicative signal and relate it to meaning, as they do with language. To address this question, we examined 6-month-olds' ability to form object categories while listening to a novel sound (a sine-wave tone sequence). We selected tone sequences because previous work documents that, unlike language, this sound fails to promote object categorization at any point within the first year (Balaban & Waxman, 1997; Ferry et al., 2010; Fulkerson & Haaf, 2006; Fulkerson & Waxman, 2007). This provided us with an opportunity to discover whether there were conditions under which infants would infuse this otherwise inert non-linguistic sound with communicative status and relate it to categorization.

Our design is straightforward: We first exposed infants to sine-wave tone sequences within the context of a brief videotaped vignette. Each vignette featured two female actors, engaged happily with one another in a joint social activity. Importantly, we developed two vignettes that differed in the way in which the tones were embedded in the actors' interchange (see Fig. 1). In the *Communicative* condition, the tones were embedded within a rich social communicative exchange in which one actor spoke and the other "beeped." In the *Non-communicative* condition, infants heard the very same tone sequences, but these were uncoupled from the dialogue; they were no longer embedded in their communicative exchange. After this exposure period, all infants participated in the same object categorization task (Ferry et al., 2010, 2013; Fulkerson & Waxman, 2007).

This design permitted us to explore infants' categorization in the context of a novel communicative signal in two ways. First, by varying the way in which tone sequences were embedded in the exposure vignette, we could identify whether communicative experience with the tones permitted infants to link them to object categories. Second, by exposing all infants to precisely the same set of sine-wave tone sequences, we could assess claims that signal familiarity alone can account for the influence of auditory stimuli on visual categorization (e.g., Robinson & Sloutsky, 2007a, 2007b; Sloutsky & Robinson, 2008).

## 2. Methods

### 2.1. Participants

Twenty-four healthy, full-term 6-month-olds ($M$ = 5.91 months, *range* = 5.52–6.44, 13 F) participated. An additional 7 infants were tested but replaced due to looking less than 25% of the time (i.e., accumulating, on average, less than 5 s of looking during either familiarization or test; $N$ = 6) or fussing out of the task before the test trials ($N$ = 1). One other infant, who was identified as an outlier (>2.5 MADs and >2 SDs from the condition mean), was replaced.

### 2.2. Apparatus

Infants sat on their caregivers' laps approximately 110 cm from the center of a white projector screen. The projected image was 125 cm (width) by 79 cm (height), although only the dialogue video used the full area of the projection. Auditory stimuli were played on two Audioengine A5 speakers placed beneath the screen 82 cm apart. The speakers and other equipment were concealed with black fabric. Sessions were recorded with a videocamera through a 3 cm hole in the fabric beneath the screen.

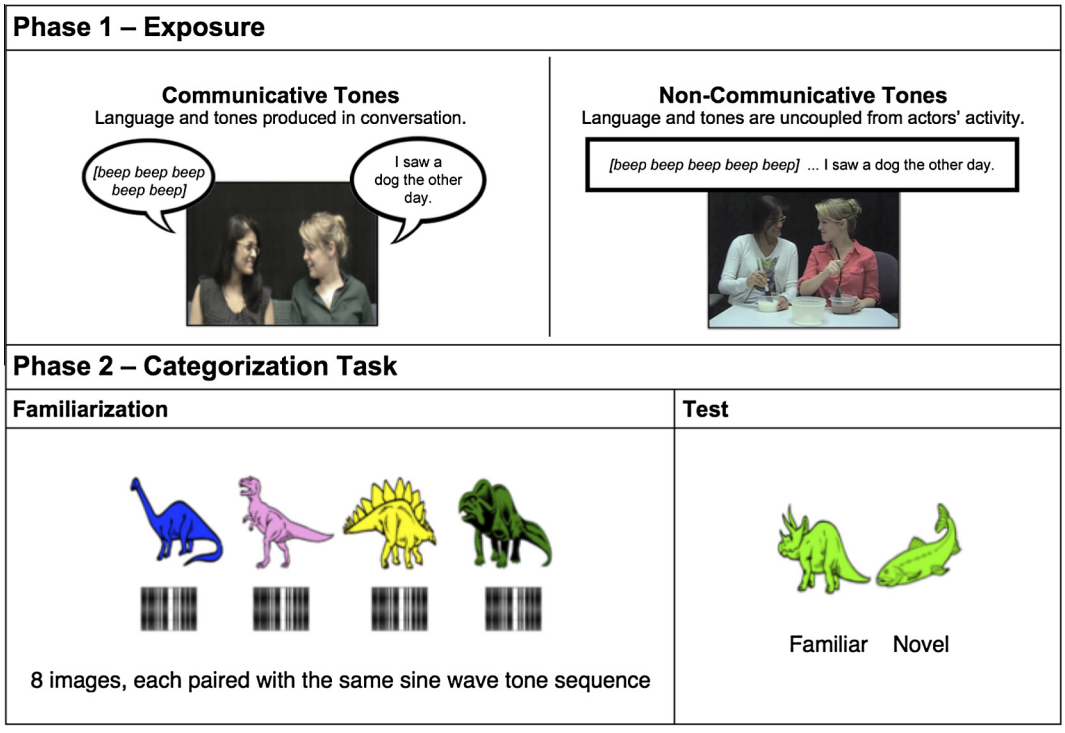


**Fig. 1.** A representation of the procedure. Infants were first exposed to the novel sound stimulus (sine-wave tones) in the context of either a Communicative or Non-communicative vignette. Next, they participated in an object categorization task while listening to tones.

### 2.3. Procedure and materials

The experiment included three phases: exposure, familiarization, and test (see Fig. 1). In the exposure phase, infants viewed one of two 2-min videotaped vignettes, each featuring two women sitting next to each other while engaged in joint activity. In the Communicative condition, they were engaged in a communicative exchange. The "speaker" spoke in infant-directed speech and the "beeper" responded in sine-wave tones that had been dubbed in and synchronized with her mouth movements. This "conversation" included several cues to communicative status of the tone sequences. For example, the speaker and beeper made eye contact, smiled, and waved to each other (and to the infant). In the Non-communicative condition, several cues from the Communicative condition were preserved: the women made frequent eye contact, and engaged one another (and the infant) by smiling and waving, and infants heard the very same auditory signals (both the tone-sequences and infant-directed utterances). Crucially, however, in the Non-communicative condition, the sound track was uncoupled entirely from the women's activity. In this vignette, the women did not engage in a conversation, but instead cooperated silently in a shared task (mixing ingredients as if they were baking together) while the audio played in the background (as if they were listening to the radio or a CD). We designed the vignettes to insure that the amount and intensity of movement in which the actors were engaged were roughly comparable in the Communicative and Non-communicative vignettes. In both, the actors remained seated; they waved and smiled at one another and at the infant, laughed, turned their heads and nudged one another with their arms. In the Non-communicative vignette, each actor gently stirred liquid in a transparent bowl; they stirred continuously to align the amount of activity well with the continuous conversation in the Communicative condition. Finally, the order in which the beeper's and speaker's utterances were presented was shuffled (between-utterances) in the Non-communicative condition; the phrases from the Communicative condition remained intact but the shuffling eliminated the sense of conversational turn-taking.

After the exposure phase, infants in all condition were treated identically. They participated in a categorization task patterned closely after previous studies (Ferry et al., 2010, 2013; Fulkerson & Waxman, 2007). During familiarization, infants saw 8 line-drawn, colored images, all members of a single object category (either dinosaurs or fish, counterbalanced). Each image appeared for 20 s and was paired with a single tone sequence (2.2 s in duration), presented at image onset and repeated 10 s later. This tone sequence differed in both rhythm and pitch (400 Hz) from those presented in the exposure phase. At test, we presented a spinning colorful wheel at the center of the screen to focus infants' attention. Next, two new images appeared: a new member of the now-familiar category (e.g., another dinosaur) and a member of a novel category (e.g., a fish). Test images were presented side-by-side, in silence, for 20 s. The left/right position of the novel image was counterbalanced across participants.

### 2.4. Analysis

Infants' eye gaze directions were coded frame-by-frame by trained coders blind to the hypotheses, and 50% from each condition were recoded by a second coder to assess reliability ($r(10) = .98$, 95% CI [.93, .99], $p < .001$). As in previous work with this paradigm (e.g., Ferry et al., 2010, 2013; Fulkerson & Waxman, 2007), a novelty preference score was calculated for each infant (accumulated time looking toward the novel test object/accumulated time looking toward both the novel and familiar test objects) based on infants' first 10 s of looking during test. (Analyses based on the entire test phase yielded the same pattern of results and $p$-values.) All statistical tests used arcsine root transformations. This transformation permits us to analyze bounded proportional data using linear models that assume an unbounded dependent measure. In describing the results in text, we report raw summary statistics for clarity. Because a preliminary ANOVA revealed no reliable effects of test image position, familiarization category, or participant gender (all $p$'s > .31), further analyses collapsed across these factors.

## 3. Results

Infants' categorization performance varied reliably as a function of the vignette to which they had been exposed, $t(22) = 2.15$, $p = .043$, Cohen's $d = .88$ (see Fig. 2). Infants in the Communicative condition revealed a robust preference for the novel object, indicating that they had successfully formed an object category ($M = .61$, $SD = .15$; comparison to chance: $t(11) = 2.50$, $p = .029$). In fact, this preference was statistically indistinguishable from their 6-month-old counterparts listening to speech ($M = .63$, $SD = .19$), $t(42) = -.32$, $p = .75$ (Fulkerson & Waxman, 2007). In sharp contrast, infants in the Non-communicative condition who were exposed to the very same tone sequences, uncoupled from the communicative exchange, failed to form object categories ($M = .48$, $SD = .15$; $t(11) = -.45$, $p = .66$). Performance in this condition mirrored the chance level performance of their counterparts listening to tones in the absence of any prior exposure ($M = .54$, $SD = .20$), $t(42) = -.87$, $p = .39$ (Fulkerson & Waxman, 2007). Thus, merely exposing infants to tones did not affect their object categorization in this task. Instead, what was required was that the tones be introduced within a communicative context.

Importantly, this difference between the Communicative and Non-communicative conditions at test cannot be attributed to differences in infants' attention during the exposure or familiarization phases. There were no differences between these conditions in the proportion of time that infants attended either to the exposure vignettes (Communicative: $M = .85$, $SD = .20$; Non-communic ative: $M = .83$, $SD = .11$), $t(22) = .73$, $p = .47$, or to the familiarization objects (Communicative: $M = .43$, $SD = .15$; Non-communicative: $M = .47$, $SD = .15$), $t(22) = -0.60$, $p = .55$.

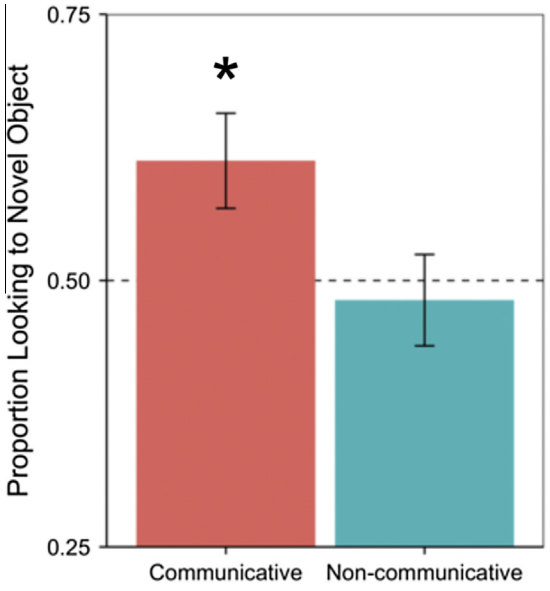


**Fig. 2.** Infants' proportion of looking to the novel object at test by condition. Nine of 12 infants in the Communicative condition preferred the novel object, as compared to 6 of 12 in the Non-communicative condition. *Note:* * $p < .05$.

## 4. Discussion

This work provides new insights into infants' early communicative capacity and its links to cognition. First, it offers the first evidence that infants as young as six months of age can successfully elevate novel, otherwise inert sounds to communicative status. This extends recent evidence that by six months, infants have begun to appreciate the distinct functions of several familiar communicative signals (Augusti et al., 2010; Legerstee et al., 2000; Lloyd-Fox et al., 2015; Parise & Csibra, 2013; Senju & Csibra, 2008; Vouloumanos et al., 2014) and goes further to document that 6-month-olds also have the capacity to identify *novel* signals as communicative if those signals have been embedded in a rich communicative exchange. Second, we show that once a novel signal has been identified as communicative, it can then promote object categorization – mirroring the facilitative effects engendered by listening to language (Ferry et al., 2010, 2013; Fulkerson & Waxman, 2007).

The current results challenge the view that appealing to signal familiarity alone can account for the influences of auditory input on infants' categorization. Some researchers have argued that infants' successful categorization in the context of hearing words (but not non-linguistic signals like tones) is attributable entirely to signal familiarity (e.g., Robinson & Sloutsky, 2007a, 2007b; Sloutsky & Robinson, 2008). The claim is that familiar sounds (like speech) interfere less with infants' processing of visual materials than do unfamiliar sounds (like tone sequences). Notice however that this argument cannot account for the results reported here. After all, we held familiarity with sine-wave tones constant; all infants heard precisely the same tone sequences within a brief vignette. If infants' success in forming object categories rested on their familiarity with the tone sequences alone, then infants in both conditions should have performed identically. Yet this was not the case. Instead, infants' performance varied as a function of the communicative context in which the tones were introduced. Thus, the current results underscore the inadequacy of appealing to signal familiarity alone to account for the facilitative effect of language on categorization (see also Althaus & Plunkett, 2015; Booth & Waxman, 2009; Ferry et al., 2013; Gliga, Volein, & Csibra, 2010; Noles & Gelman, 2012; Plunkett, 2008).

These intriguing findings also open several paths for future research. First, it will be important to identify which features of the vignette (separately or in unison) permit 6-month-olds to link an otherwise non-communicative signal to a cognitive process like categorization. Several features, present in the Communicative but absent in the other condition, are likely candidates. For example, the cooperative, turn-taking between tones and speech may be instrumental (Johnson, 2003; Watson, 1972). This would be consistent with evidence that if an entirely novel object "converses" by beeping, then 9- to 12-month-old infants expect that that object is a communicative agent; in contrast, they have no such expectations for novel objects that beep, but do so inconsistently (Beier & Carey, 2013; Johnson, Slaughter, & Carey, 1998). It will also be interesting to ascertain whether turn-taking itself is sufficient, or whether a novel signal must take its conversational turns with speech (Vouloumanos et al., 2014; see also Csibra, 2010). By manipulating these features and others (e.g., audio-visual synchrony, human versus non-human actors) in the exposure paradigm that we have designed here, it will be possible to specify more clearly what is required for infants to identify a novel signal as communicative and to relate it to the objects and events in their world.

A second challenge will be to identify the mechanism underlying the cognitive consequences of listening to communicative signals (e.g., "communicative" tones, language). For example, it could be that communicative signals direct infants' attention specifically toward information that is category-relevant. This proposal, which is consistent with the theory of natural pedagogy (Csibra & Gergely, 2006, 2009), predicts the advantageous effect of communicative signals promote categorization, a fundamental processes underlying generalization (Ferry et al., 2010, 2013; Fulkerson & Waxman, 2007; see also Futó et al., 2010; Hernik & Csibra, 2015; Yoon et al., 2008). Alternatively, communicative signals might have a more general cognitive effect, heightening infants' attention more broadly to the objects and events that surround them (Ferry et al., 2010; Kuhl, 2007). This proposal predicts that communicative signals will also enhance cognitive and attentional capacities beyond object categorization, a possibility that is consistent with several recent observations (Kuhl, Tsao, & Liu, 2003; Marcus, Fernandes, & Johnson, 2007; Thiessen, Hill, & Saffran, 2005; Vouloumanos & Waxman, 2014; Wu et al., 2011, 2014). To further adjudicate between these alternatives, it will be important to identify which other cognitive capacities (if any) are supported in the context of novel communicative signals (e.g., Ferguson & Lew-Williams, 2014; see also Vouloumanos & Waxman, 2014), and whether the underlying mechanisms that link linguistic signals (e.g., speech, manual gestures) to meaning differ from those linking non-linguistic signals (e.g., communicative tones).

In closing, we have shown that six-month-old infants are remarkably flexible in identifying which signals in the ambient environment are communicative and in linking these signals to core cognitive capacities including categorization. This outcome sets the stage for asking whether infants learn, in their first months, that speech is communicative or whether they are endowed at birth with this expectation (cf. Ferry et al., 2013). Pursuing this question will bring us closer to identifying the developmental origin of infants' expectations about the communicative power of language and its links to cognition.

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## Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2015.09.020.

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