Communication and Categorization: New Insights into the Relation Between Speech, Labels and Concepts for Infants

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Abstract

Almost two decades of research has demonstrated that labels facilitate infants' categorization of novel objects. Some interpret this as evidence of an early link between infants' linguistic and conceptual systems. Others suggest that these effects stem exclusively from lower-level processing mechanisms in cross-modal perception, and that words promote categorization only because they are more familiar to infants than non-linguistic acoustic stimuli and therefore easier to process. Here we address these discrepant interpretations using a novel approach. We expose infants to unfamiliar non-linguistic stimuli (sine-wave tone sequences), manipulating the exposure conditions. For 6-month-olds, if the novel acoustic stimuli were embedded within a communicative episode, they subsequently facilitated categorization (Experiment 1), but if they were presented in a non-communicative episode, they had no such effect (Experiment 2). We propose a developmental model that takes infants' burgeoning perceptual and conceptual capacities into account in identifying how communication and words are linked to concepts.

Keywords: language development; words; concepts; categorization; auditory overshadowing; infancy

Introduction

The nature of word learning has been the focus of a noteworthy debate in recent years. At stake is the relationship between words and concepts: Are words merely associated with objects by infants, as any percept might be associated with another (e.g., Sloutsky & Fisher, 2012)? Or might even the youngest word learners appreciate words as symbols that refer to concepts (e.g., Waxman & Gelman, 2009)? Further, if there is a privileged link between words and concepts in infancy, how is it established?

Evidence for this latter position, positing an early and unique link between words and concepts, comes from numerous studies demonstrating that infants integrate domain-specific knowledge about words when they map novel words to objects (Fennell & Waxman, 2010; Namy & Waxman, 2000; Woodward & Hoyne, 1999), generalize words to object concepts (Booth & Waxman, 2009; Booth, Waxman, & Huang, 2005), make inferences about hidden properties of named objects (Diesendruck & Graham, 2010; Gelman & Heyman, 1999; Graham, Booth, & Waxman, 2012), and individuate named objects (Dewar & Xu, 2007; 2009).

There is also evidence for a developmental cascade underlying infants' establishment of a link between words and concepts. Initially, infants appear to hold a broad expectation that words refer to commonalities amongst objects (Waxman, 2003). With development, they refine this broad expectation to link particular types of words (e.g., nouns, adjectives) to particular types of categories (e.g., object categories, property categories) (Booth & Waxman, 2009). This increasingly precise relation between words and concepts can be observed over the first year in object categorization tasks. Infants hearing human language successfully form categories, but other matched acoustic stimuli (e.g., sine-wave tone sequences) do not (Balaban & Waxman, 1997; Fulkerson & Haaf, 2003; Fulkerson & Waxman, 2007; Waxman & Markow, 1995). More recent evidence reveals that infants as young as 3- and 4-months (who do not yet segment distinct words from fluent speech) form object categories in the context of human speech, but not in the context of sine-wave tones (Ferry, Hespos & Waxman, 2010). Thus over the first year, infants' response to words may be a refinement of a broader and earlier response to communicative signals.

Some researchers have argued that the influence of language in these studies reflects cross-modal perceptual processing alone (Robinson & Sloutsky, 2007; Sloutsky & Robinson, 2008). Their claims are clear: (1) object categorization tasks with paired acoustic stimuli recruit infants' cross-modal processing abilities, (2) unfamiliar auditory stimuli impede visual processing through "auditory overshadowing", and (3) verbal labels are more familiar to infants than the acoustic stimuli (e.g., tone sequences) to which they are typically compared (Sloutsky & Robinson, 2008). On this account, words benefit category formation only insofar as they are acoustically familiar.

Here we take a novel empirical approach to tease apart these two accounts. In each experiment, infants participated in a standard object categorization task. But instead of pitting human language *against* unfamiliar sounds, *all* infants heard the same unfamiliar sounds: sine-wave tone sequences. Crucially, we introduced infants to these novel sounds in a video before they were presented within an object categorization task. This gave us full control over infants' prior exposure to these novel stimuli, which in turn permits us to ascertain the precise exposure conditions that enable an auditory stimulus to facilitate visual categorization. In Experiment 1, we ask whether embedding

tone sequences in a communicative episode will allow them to subsequently facilitate object categorization. In Experiment 2, we document that this effect cannot be accounted for by appealing to familiarity alone.

Experiment 1

We introduced 6- and 12-month-old infants to novel acoustic stimuli (sine-wave tone sequences), embedding it in a clearly communicative episode. Next, we presented new tone sequences, this time within the context of the standard object categorization task. We asked whether tone sequences would now (like speech) facilitate categorization. If infants interpreted the novel tone sequences presented in the video as communicative, then tones may now promote categorization in the standard task. However, if infants do not privilege this novel signal with communicative status, or if they resist relating it to object categories, they should not form object categories in the standard task.

We expected the consequences of our manipulation to differ as a function of infants' age. At 6 months, we expected that embedding tones in a rich communicative episode would be sufficient to facilitate categorization but that, by 12 months, infants would require more specific evidence that the signal is referential. This is consistent with evidence that by 12 months, infants distinguish referential from non-referential communicative utterances and only interpret the former as referring to object categories (Fennell & Waxman, 2010; Hollich, Hirsh-Pasek, & Golinkoff, 2000; Waxman & Braun, 2005).

Methods

Participants Twenty-four healthy, full-term infants participated. Participants included twelve 6-month-olds (6 males, M = 5.94 months) and twelve 12-month-olds (6 males, M = 12.08 months). Another 13 infants (seven 6-month-olds, six 12-month-olds) were excluded due to looking for less than 25% of the familiarization or test phases (8), fussiness (3), or parental interference (2).

Stimuli The design included three phases: exposure, familiarization, and test (see Figure 1). In the exposure phase, infants saw a 2-minute video of two undergraduate women sitting next to each other engaged in a communicative exchange. The "beeper" appeared to produce sine wave tones that had been dubbed over her mouth movements. The "speaker" responded in infant-directed English. Both interlocutors alternated between looking and speaking towards each other and the infant.

In the familiarization phase, infants saw 8 images of members of a single object category (either dinosaurs or fish, counterbalanced). Each image was presented for 20s with 4s between images. Images were line-drawn and filled with unique solid colours. Each image was paired with a single sine-wave tone sequence, presented at image onset and 10s post-onset. This sequence (2.2s), which differed in pitch from the sequences presented in the dialogue, was matched for pause-length and duration to the labeling phrases used in previous studies (e.g., Ferry et al., 2010).

In the test phase, infants saw two new images in silence for 20s. One image was another member of the familiar category (e.g., another fish), and the other a member of a novel category (e.g., a dinosaur). The left/right position of the novel image was counterbalanced.

Procedure Infants sat on their caregivers' laps approximately 110cm from the centre of a screen. Auditory stimuli were played through two speakers placed 85cm apart beneath the screen.

Coding Infants' left-right eye gaze directions were coded frame-by-frame by trained coders blind to the hypotheses. A second coder re-coded the videos to assess reliability (Pearson's r = .97, p < .0001).

Analyses We analyzed the first 10s of looking to either

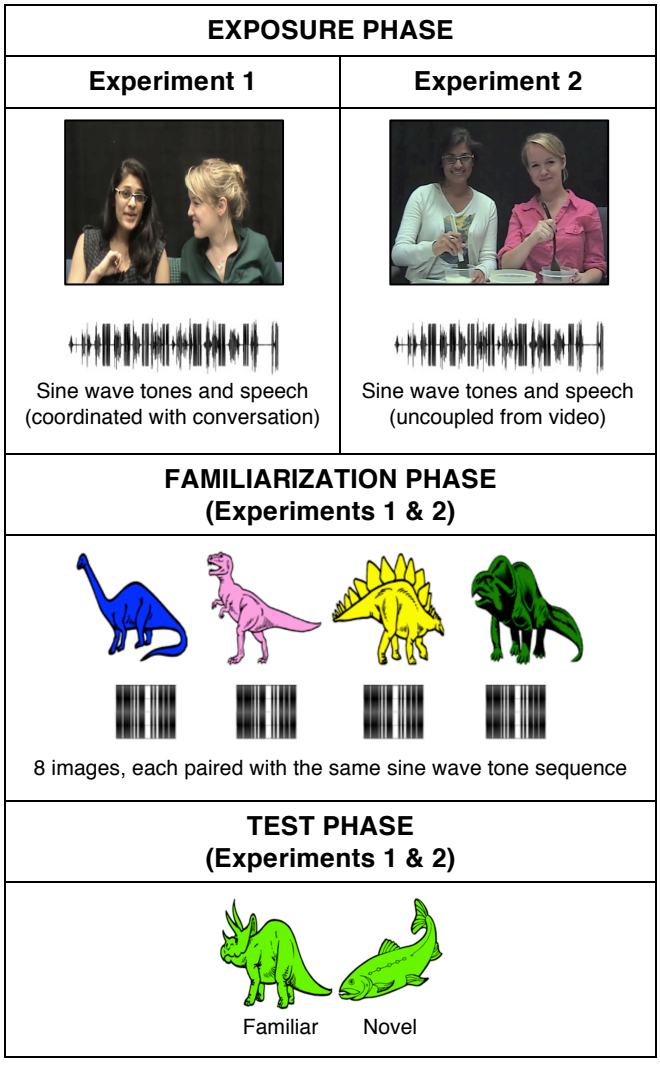

Figure 1: Experimental design of Experiments 1 and 2. Procedure for Exposure, Familiarization and Test Phases, with a sample of representative stimuli.

object in the test phase, as in prior research. (An analysis of the complete test trial yielded the same pattern of results in both experiments.) For each infant, a novelty preference score was calculated as the proportion of looking towards the novel category member. All analyses used arcsin-root transformed proportions.

Results

As predicted, 6-month-olds (M = .61, SD = .15) had significantly higher novelty preference scores than 12-month-olds (M = .49, SD = .19), $t(22) = 1.72$, one-tailed $p < .05$. Planned comparisons to chance showed a clear novelty preference (evidence of categorization) for the 6-month-olds ($t(11) = 2.51$, $p < .03$) but not the 12-month-olds ($t(11) = -.19$, *n.s.*).

There were no age differences in looking towards the familiarization images ($M_{6\text{-months}}$ = .43, SD = .15; $M_{12\text{-months}}$ = .53, SD = .13), $t(22) = 1.71$, $p = .10$, and no effects of familiarized category, novel object side at test, familiarization looking time, or gender on novelty preference scores (all p's > .3). All analyses collapsed across these factors.

Discussion

When infants were introduced to sine-wave tones during a brief communicative episode (dialogue phase), tone sequences then facilitated object categorization (test phase) for 6-month-olds, but not 12-month-olds.

This age difference is striking. We suggest that at both 6- and 12-months, infants flexibly identify the candidate communicative signals in their environment. At 6 months, infants hold a broad expectation linking communicative signals to object categories. But by 12 months, infants recognize the distinct functions of different communicative signals (e.g., speech versus gesture; Martin, Onishi, & Vouloumanos, 2012; and naming an object versus merely indicating it (e.g., "wow"); Fennell & Werker, 2003; Namy & Waxman, 2000). Therefore, at 12-months, evidence of communicative status alone is insufficient: Infants require more precise evidence that a novel signal is one that refers to objects and object categories.

But could an appeal to signal familiarity alone account for these results? There are two hints that it cannot. First, the particular pattern/pitch of the tones paired with each category member at test were novel (i.e., not presented during the dialogue phase). Second, although 6- and 12-month-olds' exposure to tone sequences was identical, only the 6-month-olds showed evidence of categorization, as we predicted

However, to further tease apart the two accounts, in Experiment 2 we pursue this issue with another group of 6-month-olds.

Experiment 2

In this experiment, we exposed infants to the very same sine-wave tone sequences (exposure phase) as in Experiment 1, but this time uncoupled them from the communicative context. During the exposure phase, infants listened to the same auditory signals as in Experiment 1, and saw a video with the same two women, but this time the women cooperated in a joint task in silence. Crucially, infants' exposure to the tones was held constant across both experiments, but in Experiment 2, there was no indication that the tones were part of a communicative interchange. If 6-month-olds' successful categorization in Experiment 1 reflects nothing more than their familiarity with tone sequences, then infants in Experiment 2 should also categorize successfully.

Methods

Participants Twelve healthy, full-term, 6-month-old infants participated (M = 5.87 months). Another 4 infants were tested but excluded due to looking for less than 25% of the familiarization or test phases.

Stimuli The new exposure video showed two women silently engaged in a cooperative task (mixing ingredients and pouring them, as if making brownies together). They smiled to each other and the infant (as in Experiment 1), but did not communicate verbally. The audio stream included exactly the same "utterances" (tone sequences, English speech) as in Experiment 1, but these were randomly shuffled. (The goal was to remove the prosodic pattern of turn-taking in the spoken utterances that might lead infants to infer that the tone sequences were part of a conversation and therefore communicative). Familiarization and test stimuli were identical to Experiment 1.

Procedure, Coding & Analyses Identical to Experiment 1.

Results

As predicted, 6-month-olds performed differently here than in Experiment 1 ($t(22) = 2.16$, $p < .05$). In contrast to Experiment 1, where 6-month-olds averaged a .61 novelty preference at test, those in Experiment 2 performed at the chance level (M = .48, $t(11) = -0.45$, *n.s.*).

There were no effects of familiarized category, novel object side at test, familiarization looking time, or gender on novelty preference scores (all p's > .4). All analyses collapsed across these factors.

Discussion

These results reveal that mere familiarity with sine-wave tone sequences cannot account for their facilitative effect on object categorization in Experiment 1. Six-month-olds who received the same exposure to these sequences, uncoupled from the communicative episode, show no evidence of categorization.

General Discussion

In these experiments, we introduce a novel approach for investigating classic questions about the nature of word learning: Are words perceptual features associated with

objects? Or is there a more nuanced link between words and concepts? And, if so, how is it established?

Waxman and colleagues (Balaban & Waxman, 1997; Booth & Waxman, 2003; Fulkerson & Waxman, 2007; Waxman, 2003; Waxman & Markow, 1995) have long argued for the latter position, and cite evidence that providing a consistent name for distinct members of an object category highlights the commonalities among them and promotes object categorization. On this account, language exerts its influence because infants link language to core conceptual capacities, including object categorization. In contrast, others have suggested that language facilitates categorization only insofar as it is a familiar acoustic stimulus (Robinson & Sloutsky, 2007a; Sloutsky & Robinson, 2008). On this account, any adequately familiar stimulus should show facilitative effects: the facilitative effect of an acoustic signal will vary as a function of its familiarity.

In Experiment 1, we asked whether an otherwise inert acoustic stimulus (sine wave tones), introduced within the context of a communicative episode, might facilitate categorization. Six-month-olds showed evidence of categorization, while 12-month-olds did not. In Experiment 2, we asked whether the 6-month-olds' successful categorization could be attributed to their mere exposure to the tone sequences. We provided the same amount of exposure to the sine wave tones, but uncoupled them from the communicative episode. The results were straightforward: infants in Experiment 2 revealed no evidence of categorization in the subsequent task. Stimulus familiarity alone cannot capture these results.

Auditory overshadowing

Auditory overshadowing is a precise claim about low-level cross-modal processing, and it is relevant to many studies in infant cognitive development including object categorization (Robinson & Sloutsky, 2007a) and individuation (Robinson & Sloutsky, 2008). The general processing model invoked is uncontroversial: infants have limited cognitive resources and any stimulus that exhausts these resources will have consequences on subsequent processing.

Thus we do not ask whether auditory overshadowing could, in principle, influence infants' learning (about categories or otherwise), but whether it alone can account for infants' clear patterns of behaviour. The results here join a host of others in demonstrating that in addition to perceptual underpinnings, there are conceptual and social-communicative factors that determine whether a paired acoustic stimulus can facilitate object categorization.

Consider, for example, infants' developing knowledge of grammatical categories and its influence on categorization. By 14 months, novel nouns highlight object categories, but adjectives do not (Booth & Waxman, 2009; Waxman & Booth, 2001). Adopting an auditory overshadowing interpretation, Sloutsky and colleagues (Robinson & Sloutsky, 2007a, 2008) argue that nouns are a more familiar stimulus than adjectives, and thus interfere less with visual processing (Sloutsky & Fisher, 2012). However, this explanation cannot account for the performance of younger infants (9 to 12 months), whose categorization improves when both adjectives and nouns are paired with category exemplars (Waxman & Booth, 2003; Waxman & Markow, 1995). Familiarity alone can neither explain this developmental change nor the results of the present studies.

Communication, cognition, and "natural pedagogy"

Previous claims about the influence of language on categorization have focused primarily on the effect of words presented as labels for object categories (Waxman, 2003). More recent evidence suggests that, for younger infants, human speech more generally can facilitate categorization (Ferry et al., 2010). Three- and 4-month-olds show an increased ability to categorize in the context of human speech despite their inability to reliably segment the speech stream into discrete words (Jusczyk & Aslin, 1995). The present results go further to suggest that for young infants, speech may be just one of a number of communicative signals that facilitate categorization. Infants in the present studies had no prior exposure to the sine wave tone sequences we presented, and yet merely introducing them as a human communicative signal had a powerful effect on their contribution to infants' subsequent categorization.

Why might communicative signals link to concepts? One recent proposal is that ostensive human communication is "naturally pedagogical" for infants, biasing them to interpret new information as category-relevant and generalizable (Csibra & Gergely, 2009; Gergely & Csibra, 2012). A recent study by Yoon, Johnson, and Csibra (2008) demonstrated the effect of communicative signals on cognition in 9-month-olds: in the context of a communicative gesture (pointing), infants most accurately encoded the shape of the object. In a non-communicative (grasping) context, infants most accurately encoded its location. Another study with 9-month-olds reported object categorization benefits from eye gaze (Wu, Gopnik, Richardson, & Kirkham, 2010). There is also evidence that communicative object labels enhance object recognition by augmenting core visual processes during encoding (Gliga, Volein, & Csibra, 2010).

If one posits that the sine wave tone sequences in Experiment 1 were part of an ostensive communicative exchange with the infant (see Csibra, 2010, for a discussion of how infants recognize ostensive signals), the 6-month-olds' results align with the theory of natural pedagogy: the presence of the communicative signal facilitated the discovery of category-relevant information.

Tuning the perceptual and conceptual systems

Natural pedagogy cannot, however, explain the full developmental picture. For example, it cannot account for the results of the 12-month-olds in Experiment 1. Neither can it explain why, for example, young infants accept gestural labels (like words) to refer to object categories but

older hearing infants do not (Namy & Waxman, 1998; Suanda & Namy, 2012), or why young infants map both nouns and adjectives to object categories but older infants are more precise, mapping nouns, and not adjectives, to object categories (Booth & Waxman, 2009). We therefore suggest a more detailed developmental account. .

Our account builds on a substantial literature suggesting that infants begin life with broad perceptual sensitivities in a variety of social domains (e.g., faces, speech sounds, and hand gestures) but rapidly tune these to make functionally relevant distinctions (Grossmann, Missana, Friederici, & Ghazanfar, 2012; Palmer, Fais, Golinkoff, & Werker, 2012; Vouloumanos, Hauser, Werker, & Martin, 2010; Werker & Tees, 1984). In language development, this process of perceptual tuning is a critical step, for example, in focusing infants' attention on the signals that are potentially communicative (e.g., human speech) and tuning out those that are not (e.g., non-human primate vocalizations).

We suggest that infants also engage in a process of referential tuning in which they tease apart the particular functions of distinct communicative signals. For example, 12-month-olds expect that human speech, but not non-communicative vocalizations (e.g., coughing) can refer (Martin et al., 2012). And within human speech, infants gradually distinguish between distinct types of words (nouns and adjectives) and map them accordingly to distinct types of meaning (e.g., to object categories and properties, respectively) (Waxman & Booth, 2009; Waxman & Gelman, 2009). In this ongoing, constructive process, infants recruit several knowledge systems (social, linguistic, and conceptual) to infer the intended reference and meaning of communicative signals. When a communicative signal is interpreted as intending to refer to an object category, it can serve to highlight that category and facilitate learning in young infants.

One prediction of the present account is that 12-month-olds' object categorization abilities should benefit from a novel communicative signal if they are given sufficient cues (i.e., beyond mere communicativeness) that the signal is meant to refer to an object or object category. We are currently testing this prediction.

Several other questions remain to be explored. First, this account posits an early expectation that communicative signals in general will relate to meaning in the world. This is consistent with natural pedagogy (Csibra & Gergely, 2009). However, whether this expectation is innate or acquired prior to 6 months is presently unclear. Second, other studies that explore the influence of social cues in learning do not find a consistent benefit for social cues over non-social cues (e.g., Moore, Angelopoulos, Bennett, 1999; Theuring, Gredebäck, & Hauf, 2007). Unlike the present experiments, these studies pit social cues against non-social cues in tasks with distractor and target events. Thus their failure to show benefits from social cues may reflect younger infants' limited capacities for inhibitory control and attention deployment. Future research in complex environments can examine this hypothesis and the constraints of learning in communicative contexts. Finally, it is important to explore the range of conditions under which infants interpret a novel stimulus as communicative.

The present research integrates social, conceptual, and linguistic development for a rich description of infants' early communicative development. We suggest with others (e.g., Noles & Gelman, 2012; Waxman & Gelman, 2009) that words are not merely perceptual features that associate with objects, but are communicative symbols, and the products of early perceptual and conceptual tuning.

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