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BRIEF ARTICLE

Grammatical Categorization in Mandarin-Chinese-Learning Infants

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In previous perceptual studies infants showed emerging grammatical categorization during the preverbal and early verbal stage. The issue has only been studied with European-language-learning infants. We inquired whether categorization is a general ability in infants regardless of language background, and whether function words in bigram distribution are sufficient for guiding grammatical category learning. In a preferential looking task, Mandarin-Chinese 12-month-olds were familiarized with two categories of novel words with preceding function words in Mandarin. Test trials presented new combinations that were grammatical versus ungrammatical. Grammaticality depended on the distributional patterns between the novel words and the function words in the familiarization. Infants discriminated the test trials, showing emerging categorization ability. We suggest that function words are special anchors for learning and that the ability to use them for grammatical categorization is fundamental and general in human infants.

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1. INTRODUCTION

A fundamental task in learning syntax is the assignment of words to grammatical categories (e.g., nouns, verbs, etc.). This task is essential because grammatical categories are the basic elements for phrasal structures. The present study examined infants' use of distributional cues for grammatical categorization at the initial stage of acquisition.

In recent studies infants showed grammatical category knowledge of their ambient language at a very early age. Using perceptual experiments, Höhle et al. (2004) found that German-learning 16-month-old infants can categorize nouns. After being familiarized with a novel word following a determiner (e.g., *ein Pronk* 'a pronk'), infants were tested with sentences containing the novel word with new contextual words that had not occurred in the familiarization, as a noun in some trials (e.g., *Das kleine Kind vergaß den Pronk dort* 'The little child forgot the pronk there'), and as a verb in other trials (e.g., *Meistens pronk er auf der großen Lichtung* 'Most of the time he pronk(ed) in the big clearing'). Infants discriminated the two types of test trials. In similar perceptual experiments, French-learning infants aged 14 months categorized novel words to nouns using French determiners (Shi & Melançon 2010). In both studies infants generalized the categories to novel words and to novel contexts, demonstrating grammatical productivity.

What are the learning mechanisms underlying infants' categorization ability? A few studies tested this question explicitly (Gerken, Wilson & Lewis 2005; Gómez & Lakusta 2004; Mintz 2006). In these studies infants first heard two categories of novel content words supported by distinct distributional patterns with function words or bound functional morphemes. The distributional paradigm was provided in this training phase. Infants were then tested on whether they could use the distributional information to generalize the categorization pattern to new combinations. Gerken, Wilson & Lewis (2005) exposed English-learning 17-month-olds to a Russian gender paradigm. The stimuli contained six lexical stems each with two feminine endings (*-oj, -u*) and six other stems with two masculine endings (*-ya, -yem*), e.g., *polkoy, polku, uchitel'ya, uchitel'yem*. A few feminine and masculine words were withheld for testing, and all the remaining words served as the training input. The logic behind the design was that after hearing multiple stems with two endings, other stems that co-occurred with one of the endings should also go with the other ending (i.e., grammatical), even though the latter was absent during training. As predicted, infants distinguished the withheld grammatical words from ungrammatical words (which were constructed to violate the gender pattern), showing that they generalized the categorization rule based on the training input. Importantly, infants required the copresence of two cues (the gender endings and the phonological marker at the end of the word root) in the training in order to learn the categorization.

Mintz (2006) used a similar design as Gerken, Wilson & Lewis (2005) to test American infants' use of distributional information for categorization. The stimuli were English sentences containing nonsense target words in noun versus verb frames. Two targets occurred in four noun frames (. . . *the gorp in* . . . ; . . . *the bist in* . . . ; . . . *your gorp*; . . . *your bist*; . . . *his gorp on* . . . ; . . . *his bist on* . . . ; . . . *a gorp of* . . . ; . . . *a bist of* . . .) and two other targets in four verb frames (. . . *to deeg it*; . . . *to lonk it*; . . . *can deeg;* . . . *can lonk*; . . . *you deeg the* . . . ; . . . *you lonk the* . . . ; *I deeg you* . . . ; *I lonk you* . . .). Twelve-month-olds were familiarized with six of the noun frame sentences and six verb frame sentences. The remaining two noun frame sentences (. . . *his bist on* . . . ; . . . *a gorp of* . . .) and two verb frame sentences (. . . *you lonk the* . . . ; *I deeg you* . . .) were withheld for testing. The training input provided distributional cues to

the generalization that words occurring in the same frame belong to an equivalent class. Besides the withheld utterances, test trials also presented the targets in frames in a way that violated the familiarization patterns (e.g., . . . *you bist the* . . . ; . . . *I gorp you* . . . ; . . . *his lonk on* . . . ; . . . *a deeg of* . . .). Infants demonstrated emerging grammatical categorization. Listening time increased when the targets that had been trained as nouns later appeared in verb frames during test trials, relative to their use as nouns in test trials.

Gómez & Lakusta (2004) also investigated the mechanism of grammatical categorization using an artificial language. American 12-month-olds were familiarized with two categories of content words each following artificial function words. One content-word category consisted of monosyllabic nonsense words (X_1, X_2, etc.), and each word co-occurred with two function words (a_1, a_2), e.g., a_1X_1, a_2X_1, a_1X_2, a_2X_2. The other content-word category consisted of bisyllabic nonsense words (Y_1, Y2, etc.), each co-occurring with two other function words (b_1, b_2), e.g., b_1Y_1, b_2Y_1, b_1Y_2, b_2Y_2. Following training, grammatical test trials presented new monosyllabic words following *a*, and new bisyllabic words following *b*, consistent with the pattern of the training input. Ungrammatical test trials presented utterances that violated the training pattern (i.e., monosyllabic words following *b*, and bisyllabic words following *a*). Infants discriminated the two test trial types, indicating that they generalized the phonological features and linked them to their distribution with corresponding function words. They used these combined cues to categorize new content words. Lany & Saffran (2010) subsequently found that categorization based on these combined cues enabled infants to map semantic features to content words.

In sum, these studies showed that infants begin to categorize words to grammatical classes from about 12 months of age. The categorization is abstract, in that infants generalized the category assignment to novel target words in contexts that had never occurred with those targets. Infants used the distribution of functional items to categorize content words. The use of functors is logical given that many cues support the basic distinction of content and function words in speech input (e.g., Cutler 1993; Monaghan, Christiansen & Chater 2007; Shi, Morgan & Allopenna 1998) and that infants before 12 months of age already track and represent functional morphemes (Gervain et al. 2008; Hallé, Durand & Boysson-Bardies 2008; Höhle & Weissenborn 2003; Marquis & Shi 2012; Shafer et al. 1998; Shi & Lepage 2008; Shi et al. 2006; Shi, Werker & Cutler 2006).

Moreover, in several studies redundant cues were needed for learning grammatical categories, such as conjoined phonological and distributional cues (Gómez & Lakusta 2004; Lany & Saffran 2010) or copresence of two contextual elements (Gerken, Wilson & Lewis 2005; Mintz 2006). The training phrase in Gómez and Lakusta (2004) and Valian and Coulson (1988) included artificial functors surrounding artificial content words (e.g., *a* and *b* words surrounding X words in aXbY phrases), and the copresence pattern of the functors may have guided their learners' grammatical category learning. Mintz (2002, 2006) proposed that frequent frames (i.e., preceding and following function words) support categorization, whereas bigrams would not be sufficient. In Gerken, Wilson & Lewis (2005), infants learned the categories only when training input contained double contextual cues.

The goal of the present study was to extend the existing work to infants in a different language environment, Mandarin. The few studies that tested categorization mechanisms were all with English-learning infants. We inquired whether the distributional mechanism for learning grammatical categories shown previously is general in infants regardless of language environment.

Specifically, we asked whether infants can succeed in grammatical category learning with one single cue rather than redundant cues. In particular, we tested whether function word distribution

in the preceding context alone (i.e., a kind of bigrams) was sufficient for category learning. We reasoned that function words, a small set that are highly frequent in natural languages, may be special for learning. Consistent with this idea, infants aged 8–11 months used function words to segment adjacent words, and the unit of the segmentation analysis was bigrams, each including one function word (Shi et al. 2006; Shi & Lepage 2008). We hypothesized that functional items in bigrams may be sufficient for grammatical category learning. It is possible that the infants in Gerken, Wilson & Lewis (2005) failed to learn the categories of the novel language based on one cue alone because the cue (grammatical gender suffixes) did not occur frequently enough during training, leading infants to perceive them *not* as functional morphemes. In this sense, function words in infants' native language are privileged for supporting learning. The distributional cues in Mintz (2002, 2006), which led to successful learning, were native language function words, although the studies did not test whether category learning would succeed or fail in the context of bigrams. The present study therefore tested whether Mandarin-learning infants perceive function words in bigrams and use the information to learn grammatical categories.

Existing research on the acquisition of function words in Mandarin has focused only on production, showing that function words emerge in children's speech from about 2 years of age (e.g., Kong & Chen 1999; Peng 2004; Xu & Min 1992), as for children who learn European languages. Whereas European-language-learning infants have been shown to perceive function words before age 1 (e.g., Hallé, Durand & Boysson-Bardies 2008; Höhle & Weissenborn 2003; Shi, Werker & Cutler 2006), no study has examined Mandarin-learning infants' perception and use of function words.

In our study we familiarized and tested Mandarin-learning 12-month-old infants with novel content words following frequent function words in Mandarin. We provided a distributional paradigm during the familiarization phase while withholding a few utterances for testing, as in Mintz (2006) and Gerken, Wilson & Lewis (2005). Our stimuli were well controlled to contain no phonological or acoustical cues, an aspect different from Gómez and Lakusta (2004), who used both distributional and phonological cues. Our design hence allowed us to assess if infants can form initial grammatical categories based solely on one distributional cue in the training input: the preceding function word context.

2. METHOD

2.1. Participants

Sixteen monolingual Mandarin-Chinese-learning infants residing in Beijing completed this experiment (seven boys, nine girls, mean age: 0;12,19; range: 0;11,27–0;14,19). Another five infants were tested, but their data were excluded from the analysis due to the following reasons: fussiness (two infants), looking time too short (2 seconds or less per trial for the initial six trials; one infant), researcher operation errors (two infants).

2.2. Stimuli

The target words for categorization were six words in Mandarin Chinese that can be used as either nouns or verbs, i.e., *yanjiu* 'research' (noun), 'to research' (verb); *faming* 'discovery' (noun),

'to discover' (verb); *jianyan* 'evaluation' (noun), 'to evaluate' (verb); *diaocha* 'investigation' (noun), 'to investigate' (verb); *tongji* 'statistics' (noun), 'to do statistics' (verb); *bianlun* 'debate' (noun), 'to debate' (verb). These are not the kind of words that one would typically use when addressing a child.

The six target words were each paired with four preceding contexts, two noun contexts, i.e., *wode* 'my,' *zhege* 'this,' and two verb contexts, i.e., *woye* 'I also,' *nibie*'you don't (imperative). These contexts all contained function words. The combinations yielded a total of 24 utterances (6 x 4 = 24), e.g., *wode yanjiu* 'my research,' *zhege yanjiu* 'this research,' *woye yanjiu* 'I also do research,' *nibie yanjiu* 'you shouldn't do research,' *wode faming* 'my discovery,' etc.

A female Mandarin-Chinese speaker recorded the 24 utterances in an acoustic chamber, using infant-directed speech style. The sampling frequency of the recording was 44.1 KHz, and the bit rate was 16 bits. The utterances were recorded multiple times. We chose one exemplar for each utterance with the aim of balancing the prosodic cues of the targets as nouns versus as verbs. This control was necessary since our goal was to test whether infants were able to perform categorization based on the distributional links between function words and target content words. Statistical tests showed that the two categories were indeed produced with comparable prosody. In particular, the two categories of target word production did not significantly differ in duration, in mean pitch, or in mean intensity. These measures are shown in the appendix.

Auditory stimuli also included water bubble sounds, used for the pretest trial and the posttest trial. A black-and-white checkerboard and a colorful checkerboard served as visual stimuli. In addition, an animation of a bouncing ball accompanied by cricket sounds served as the attention-getter, which was used between trials.

2.3. Design

We randomly divided infants into two groups according to the category assignment of the target words during the familiarization phase, as shown in Table 1. For the first group (group A), three of the target words (i.e., *yanjiu, jianyan, faming*), followed the function words *wode* 'my,' *zhege* 'this,' thus supporting the targets as nouns. Of the six possible co-occurrences, one was withheld from familiarization and was reserved for the test phase, *zhege faming.* The other three target words (i.e., *diaocha, tongji, bianlun*) were preceded by *woye* 'I also' and *nibie* 'you don't'—imperative), which supported the targets as verbs. Again, one of the six possible co-occurrences (*nibie bianlun*) was withheld from familiarization and was used for the test phase.

The second group (group B) was designed to counterbalance the first group. The three targets (*yanjiu, jianyan,* and *faming*) followed *woye* 'I also' and *nibie* 'you don't' (imperative), which supported the targets as verbs. The other three targets (*diaocha, tongji* and *bianlun*) were preceded by *wode* 'my,' *zhege* 'this,' which supported the targets as nouns. All possible co-occurrences for the two categories were applied accordingly for the familiarization stimuli, except that two utterances (*nibie faming* and *zhege bianlun*) were withheld from the familiarization and reserved for the test phase.

Infants of both familiarization groups heard the same test stimuli, i.e., the four withheld utterances from the familiarization. Each trial presented two utterances, either *zhege faming* and *nibie bianlun* or *nibie faming* and *zhege bianlun*. Within a trial, the two utterances were presented repetitively in a random order. Thus, there were two types of test trials: grammatical versus

TABLE 1
Familiarization Groups (Groups A & B) and Test Groups (Subgroups 1 & 2)

FAMILIARIZATION—GROUP A
zhege yanjiu, wode yanjiu, zhege jianyan, wode jianyan, wode faming
woye diaocha, nibie diaocha, woye tongji, nibie tongji, woye bianlun

FAMILIARIZATION—GROUP B
woye yanjiu, nibieyanjiu, woye jianyan, nibie jianyan, woye faming
zhege diaocha, wode diaocha, zhege tongji, wode tongji, wode bianlun

	Test	
	Subgroup 1	*Subgroup 2*
Trial	*zhege faming* *nibie bianlun* (grammatical-A, ungrammatical-B)	*nibie faming* *zhege bianlun* (ungrammatical-A, grammatical-B)
Trial	*nibie faming* *zhege bianlun* (ungrammatical-A, grammatical-B)	*zhege faming* *nibie bianlun* (grammatical-A, ungrammatical-B)

Note. Table 1 contains different familiarization stimuli presented to two groups of infants (Groups A & B). The same test stimuli were presented to both familiarization groups, but the grammaticality of test materials is reversed (i.e., grammatical trials for Group A are ungrammatical for Group B) because of the different pairings between content words and the preceding function words during the familiarization. The subgroups of the test conditions represent the counterbalancing of the first test trial (grammatical first versus ungrammatical first) within each familiarization group, i.e., subgroups 1 and 2.

ungrammatical. Because of the counterbalancing of the two familiarization groups, trials presenting *zhege faming* and *nibie bianlun* were grammatical for group A but ungrammatical for group B, and those presenting *zhege bianlun* and *nibie faming* were grammatical for group B but ungrammatical for group A. Grammatical and ungrammatical trials were presented in alternation. The first test trial was either a grammatical trial or an ungrammatical trial, counterbalanced across infants.

2.4. Procedure

Infants were individually tested in a preferential looking procedure. The infant sat on the parent's lap in front of a 42-inch monitor in a dimly lit acoustic chamber. Auditory stimuli were played simultaneously from loudspeakers on each side of the monitor. Prior to the study, the parent was instructed to avoid interfering with the infant's responses during the experiment. The parent heard masking music through headphones. The researcher, blind to the stimuli presentation, observed the infant in an adjacent room through a monitor and pressed down a computer key whenever the infant looked at the central screen. The experiment was run by an experimental program, which presented each trial and recorded all looking times online. Between any two trials, an attention-getting animation (of a bouncing ball and cricket sounds) was presented, and it disappeared when a trial was initiated by the infant's look toward the monitor.

At the beginning of the experiment the pretest trial (15 seconds), which presented water bubble sounds together with a black-and-white checkerboard, served to acquaint the infant with the equipment. Subsequently, the familiarization trial began. It presented the familiarization utterances (10 for each group of infants) three times in one trial, which lasted 77 seconds. During this trial the speech and visual stimuli were presented for the full trial length regardless of whether the infants looked or not. After familiarization, two contingency training trials were presented, for the purpose of teaching the infant the "full infant control" feature, which was applied in all subsequent trials. That is, in addition to being able to initiate a trial (by looking at the monitor), the infant could now terminate a trial (by looking away from the monitor). The stimuli were water bubble sounds together with a colorful checkerboard. Following the contingency trials, test trials followed. Grammatical and ungrammatical test trials were presented in alternation, for a total of eight trials (four for each type). The colorful checkerboard served as the visual stimulus for the test trials. As soon as the infant looked away within a trial, speech stimuli stopped. A trial would terminate if the infant looked away for at least 2 seconds or if the maximum trial length (15 seconds) was reached. The silence interval between any two utterances during the familiarization and test phases was approximately 1 second. A posttest trial consisting of the same auditory and visual stimuli as the pretest trial was presented at the end of the experiment. The posttest trial allowed the researcher to later determine if an infant was still doing the task toward the end of the test phase. Looking time during the posttest trial should increase relative to the last test trial if the infant was on task. In our study the infants who completed the experiment all yielded longer looking time for the posttest trial than for the last test trial.

2.5. Predictions

Our design was similar to those of Gerken, Wilson & Lewis (2005) and Mintz (2006) in that the familiarization exposure provided full distributional cues (of functional items) to two categories of target words. For example, multiple target words of one category were preceded by two function-word contexts, thus indicating that the targets belonged to an equivalent grammatical class. Another target word co-occurred with one of those function-word contexts during familiarization, and its co-occurrence with the other function-word context was withheld as the test utterance. We predicted that if infants learned the categories during the familiarization, they should perceive the withheld test utterances as grammatical and that looking times to grammatical versus ungrammatical trials should differ. The ungrammatical test trials were the mis-pairings of the target words with function-word contexts of the other category from familiarization.

Based on the findings of previous studies, we expected our infants to only show emerging categorization abilities. Our infants were relatively young (on average 12 months of age), and our stimuli were quite complex since each infant was familiarized with two content-word categories, and they were supported only by the preceding contexts. In Gerken, Wilson & Lewis (2005), infants only succeeded in learning when the categories were supported by double cues, and the discrimination of grammatical versus ungrammatical test stimuli was more robust late in the test phase, suggesting that infants needed time to process the test stimuli before being able to determine their grammaticality. Such slow processing has also been reported in word-form recognition studies with young infants (e.g.,Vihman et al. 2004). We therefore predicted that in our experiment the discrimination of grammatical versus ungrammatical test trials may only be solid late in the test phase.

3. RESULTS

We analyzed infants' looking times during test trials in a 2 x 2 ANOVA, with Grammaticality as one within-subject factor (grammatical vs. ungrammatical), and Block (block 1 vs. block 2) as the other within-subject factor. Average looking time per trial for grammatical trials and that for ungrammatical trials were calculated for each block. Block 1 consisted of the initial four test trials, two grammatical and two ungrammatical. Block 2 consisted of the subsequent four test trials, two grammatical and two ungrammatical. There was no significant main effect of Block, $F(1, 15) = 1.94$, $p = .184$ and no significant main effect of Grammaticality, $F(1, 15) = 1.097$, $p = .312$. However, the interaction of Grammaticality and Block was significant, $F(1, 15) = 6.018$, $p = .027$. A subsequent paired t-test was performed to compare grammatical and ungrammatical trials in each block. The two types of trials were not significant in block 1 (grammatical: $M = 10.492$ seconds; $SE = 1.092$ seconds; ungrammatical: $M = 9.575$ seconds, $SE = .874$ seconds), $t(15) = 0.949$, $p = .358$, Cohen's $d = 0.232$. They were significantly different in block 2 (grammatical: $M = 7.816$ seconds; $SE = 1.108$ seconds; ungrammatical: $M = 10.375$ seconds, $SE = 1.157$ seconds), $t(15) = –2.245$, $p = .04$, Cohen's $d = –0.565$. Both t-tests were two-tailed. Ten out of the 16 infants looked longer at the ungrammatical trials in block 2, whereas 7 of the 16 infants looked longer at the ungrammatical trials in block 1. The results are shown in Figure 1.

4. DISCUSSION

In our experiment Mandarin-Chinese 12-month-olds were briefly familiarized with a paradigm in which contextual function words supported novel content words that fell into two grammatical categories. Infants showed emerging ability of categorization learning, similar to the findings in English-learning infants (Gerken, Wilson & Lewis 2005; Gómez & Lakusta 2004; Mintz 2006),

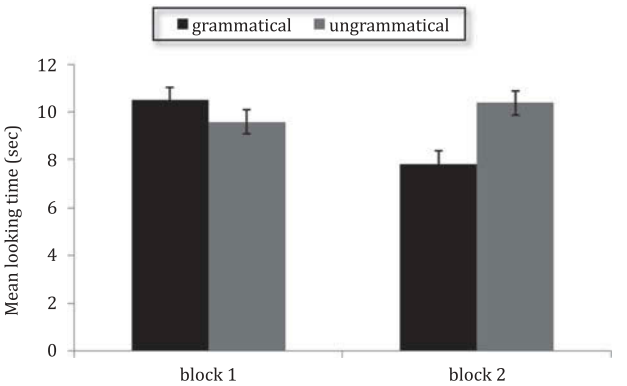

FIGURE 1 Twelve-month-old infants' average looking (listening) times (means and standard errors) for the two test trial types (grammatical vs. ungrammatical) in the two blocks of the test phase. Infants discriminated the two trial types in block 2.

indicating that the use of distributional cues for grammatical category learning is general for human infants regardless of the ambient languages.

With respect to the exact learning mechanism, our study specifically tested the use of one single cue in bigram distribution, i.e., a function word in the preceding context. This aspect thus differs from studies that presented redundant cues (Gómez & Lakusta 2004; Mintz 2006; Valian & Coulson 1988). Whereas Gerken, Wilson & Lewis (2005) tested the contribution of one single cue and found that it failed to enable category learning, our infants succeeded in the learning task using one cue, consistent with the findings of Shi & Melançon (2010). We suggest that this success was due to infants' familiarity with frequent function words and their distribution in their native language. Infants in Gerken, Wilson & Lewis (2005), who heard a foreign language in the study, may not have perceived the distributional elements in the training set as functor-like because they did not occur as frequently as functors would in natural environment.

The general ability to use function-word distributional cues for grammatical learning is plausible in light of the literature showing distinctive properties of functional items in the input across languages as well as the perception and representation of functors in infants during the first year of life. It has been shown in various languages, including Mandarin, that a massive number of open-class words (i.e., content words) co-occur with a small set of functional items, which have distinct acoustic and phonological characteristics and are extremely frequent relative to open-class words (Cutler 1993; Gervain et al. 2008; Monaghan, Christiansen & Chater 2007; Shi, Morgan & Allopenna 1998). Infants recruit these cues from the input to distinguish function words from content words, even at birth (Shi, Werker & Morgan 1999). The fact that a small number of functional items occur frequently in structurally specific positions (e.g., determiner at the edge of noun phrases) makes these items important for bootstrapping early learning. Indeed, in previous studies the high-frequency property of function words allows them to serve as anchors for infants to segment adjacent open-class words (Shi & Lepage 2008; Shi et al. 2006); importantly, function words that assisted the learning in those studies were in bigrams, suggesting that these items play a crucial role for learning. Those results are consistent with the finding of the present study, indicating that infants can use the single cue of function word distribution in bigrams to learn initial grammatical categories.

The prosodic characteristics of our target words in the two categories were deliberately balanced. We carefully chose our recorded stimuli so that target productions for the two categories were equivalent. This manipulation was designed to test exclusively function-word-driven grammatical categorization without the assistance of prosodic cues. We note that prosodic cues may in fact assist category learning (a part of their contributions for bootstrapping various aspects of syntax, as discussed in previous literature, e.g., Christophe, Guasti & Nespor 1997; Shi, Morgan & Allopenna 1998). For example, prosodic and phonological cues may bootstrap initial grammatical categorization, by enabling infants to link open-class content words (such as nouns or verbs) that possess certain phonological or prosodic cues with specific contextual function words (e.g., determiners, auxiliaries).

Our study is relevant to theories of early grammatical learning. Exemplar-based theories maintain that abstract grammatical representations are absent at the early stages of acquisition and are gradually established after many exemplars are stored (around 2–3 years of age) (e.g., Pine & Lieven 1997). Other researchers argue that children's early language contains abstract grammatical representations (Valian 2009; Yang 2013). Our stimuli involved target words that do not or rarely occur in infants' input. Thus, infants could not rely on previously stored exemplars to

perform our task. Furthermore, our infants were very young. They were at the transitional stage between no production and single-word production, an age that should not have any abstract grammatical categories, according to exemplar-based theories. Our results demonstrate that the ability to learn grammatical categories is early and sophisticated. Infants in our study assigned words to abstract equivalent classes and generalized the categorization to new phrases that did not appear during training, demonstrating grammatical productivity.

Being able to perform grammatical categorization early in development may impact other linguistic tasks. For instance, basic categories are needed in order to fully acquire larger syntactic constituents. Knowledge of syntactic representations can guide the learning of meaning, as proposed in the Syntactic Bootstrapping theory (e.g., Gleitman 1990). Our study on Mandarin-learning infants corroborates previous categorization studies on European-language-learning infants, suggesting that the ability to use distributional cues to learn grammatical categories is universally present early in acquisition.

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REFERENCES

Christophe, Anne, Teresa Guasti & Marina Nespor. 1997. Reflections on phonological bootstrapping: Its role for lexical and syntactic acquisition. *Language and Cognitive Processes* 12(5/6). 585–612. doi:10.1080/016909697386637

Cutler, Anne. 1993. Phonological cues to open- and closed-class words in the processing of spoken sentences. *Journal of Psycholinguistic Research* 22(2). 109–131. doi:10.1007/BF01067827

Gerken, Louann, Rachel Wilson & William Lewis. 2005. Infants can use distributional cues to form syntactic categories. *Journal of Child Language* 32(2). 249–268. doi:10.1017/S0305000904006786

Gervain, Judit, Marina Nespor, Reiko Mazuka, Ryota Horie & Jacques Mehler. 2008. Bootstrapping word order in prelexical infants: A Japanese-Italian cross-linguistic study. *Cognitive Psychology* 57(1). 56–74. doi:10.1016/j.cogpsych.2007.12.001

Gleitman, Lila. 1990. The structural sources of verb meaning. *Language Acquisition* 1(1). 3–55. doi:10.2307/20011341

Gómez, Rebecca L. & Laura Lakusta. 2004. A first step in form-based category abstraction by 12-month-old infants. *Developmental Science* 7(5). 567–580. doi:10.1111/j.14677687.2004.00381.x

Hallé, Pierre A., Catherine Durand & Bénédicte de Boysson-Bardies. 2008. Do 11-month-old French infants process articles? *Language and Speech* 51. 23–44. doi:10.1177/00238309080510010301

Höhle, Barbara & Jürgen Weissenborn. 2003. German-learning infants' ability to detect unstressed closed-class elements in continuous speech. *Developmental Science* 6(2). 122–127. doi:10.1111/1467-7687.00261

Höhle, Barbara, Jürgen Weissenborn, Dorothea Kiefer, Antje Schulz & Michaela Schmitz. 2004. Functional elements in infants' speech processing: The role of determiners in the syntactic categorization of lexical elements. *Infancy* 5(3). 341–353. doi:10.1207/s15327078in0503_5

Kong, Lingda & Changhui Chen. 1999. A theoretical interpretation of the order of pronoun acquisition in child language. *Applied Linguistics* (*YUYAN WENZI YINGYONG)* 2. 41–46.

Lany, Jill & Jenny R. Saffran. 2010. From statistics to meanings: Infants' acquisition of lexical categories. *Psychological Science* 21(2). 284–291. doi:10.1177/0956797609358570

Marquis, Alexandra & Rushen Shi. 2012. Initial morphological learning in preverbal infants. *Cognition* 122(1). 61–66. doi:10.1016/j.cognition.2011.07.004

Mintz, Toben H. 2002. Category induction from distributional cues in an artificial language. *Memory & Cognition* 30(5). 678–686. doi:10.3758/BF03196424

Mintz, Toben H. 2006. Finding the verbs: Distributional cues to categories available to young learners. In Kathy Hirsh-Pasek & Roberta M. Golinkoff (eds.), *Action meets word: How children learn verbs*, 31–63. Oxford: Oxford University Press. doi:10.1093/acprof:oso/9780195170009.003.0002

Monaghan, Padraic, Morten H. Christiansen & Nick Chater. 2007. The phonological-distributional coherence hypothesis: Cross-linguistic evidence in language acquisition. *Cognitive Psychology* 55(4). 259–305. doi:10.1016/j.cogpsych.2006.12.001

Peng, Xiaohong. 2004. Mandarin-speaking children's acquisition of pronouns—A case study of a girl of 2 years and 2 months. *Journal of Zhuzhou Institute of Technology* 18(4). 146–147.

Pine, Julian M. & Elena V. M. Lieven. 1997. Slot and frame patterns in the development of the determiner category. *Applied Psycholinguistics* 18(2). 123–138. doi:10.1017/S0142716400009930

Shafer, Valerie L., David W. Shucard, Janet L. Shucard & LouAnn Gerken. 1998. An electrophysiological study of infants' sensitivity to the sound patterns of English speech. *Journal of Speech, Language, and Hearing Research* 41(4). 874–886.

Shi, Rushen, Anne Cutler, Janet Werker & Marisa Cruickshank. 2006. Frequency and form as determinants of functor sensitivity in English-acquiring infants. *Journal of the Acoustical Society of America* 119(6). EL61–EL67. doi:10.1121/1.2198947

Shi, Rushen & Mélanie Lepage. 2008. The effect of functional morphemes on word segmentation in preverbal infants. *Developmental Science* 11(3). 407–413. doi:10.1111/j.1467-7687.2008.00685.x

Shi, Rushen & Andréane Melançon. 2010. Syntactic categorization in French-learning infants. *Infancy* 15(5). 517–533. doi:10.1111/j.1532-7078.2009.00022.x

Shi, Rushen, James L. Morgan & Paul Allopenna. 1998. Phonological and acoustic bases for earliest grammatical category assignment: A cross-linguistic perspective. *Journal of Child Language* 25(1). 169–201. doi:10.1017/S0305000997003395

Shi, Rushen, Janet Werker & Anne Cutler. 2006. Recognition and representation of function words in English-learning infants. *Infancy* 10(2). 187–198. doi:10.1207/s15327078in1002_5

Shi, Rushen, Janet Werker & James L. Morgan. 1999. Newborn infants' sensitivity to perceptual cues to lexical and grammatical words. *Cognition* 72(2). B11–21. doi:10.1016/S0010-0277(99)-00047-5

Valian, Virginia. 2009. Abstract linguistic representations and innateness: The development of determiners. In William D. Lewis, Simin Karimi, Heidi Harley & Scott O. Farrar. (eds.), *Time and again: Theoretical perspectives on formal linguistics in honor of D. Terence Langendoen*, 189–206. Amsterdam: John Benjamins.

Valian, Virginia & Seana Coulson. 1988. Anchor points in language learning: The role of marker frequency. *Journal of Memory and Language* 27. 71–86. doi:10.1016/0749-596X(88)90049-6

Vihman, Marilyn M., Satsuki Nakai, Rory A DePaolis & Pierre Hallé. 2004. The role of accentual pattern in early lexical representation. *Journal of Memory and Language* 50(3). 336–353. doi:10.1016/j.jml.2003.11.004

Xu, Zhengyuan & Ruifang Min. 1992. A study on the acquisition of personal pronouns by Chinese-speaking children. *Acta Psychologica Sinica* 24(4). 337–345.

Yang, Charles. 2013. Ontogeny and phylogeny of language. *Proceedings of the National Academy of Sciences* 110(16). 6324–6327. doi:10.1073/pnas.1216803110

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APPENDIX: ACOUSTIC VALUES (MEANS AND STANDARD DEVIATIONS) OF THE TARGET WORDS

Acoustic Measure	*Category 1 (Nouns)*	*Category 2 (Verbs)*	*Independent t-Test*
First syllable of Target words; duration (sec)	0.356 (0.071)	0.361 (0.072)	$t(22) = 0.865;\ p > .05$
Second syllable of Target words; duration (sec)	0.589 (0.031)	0.568 (0.041)	$t(22) = 0.185;\ p > .05$
First syllable of Target words; average pitch (Hz)	296.221 (59.673)	292.205 (48.818)	$t(22) = 0.853;\ p > .05$
Second syllable of Target words; average pitch (Hz)	288.736 (30.528)	272.319 (28.647)	$t(22) = 0.188;\ p > .05$
First syllable of Target words; average intensity (dB)	73.43 (2.765)	74.32 (4.146)	$t(22) = 0.542;\ p > .05$
Second syllable of Target words; average intensity (dB)	71.861 (2.28)	71.914 (2.585)	$t(22) = 0.958;\ p > .05$