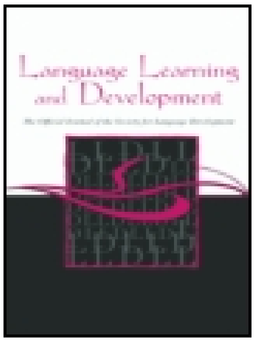

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Adults Fail to Learn a Type of Linguistic Pattern that is Readily Learned by Infants

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ABSTRACT

Beginning with the classic work of Shepard, Hovland, & Jenkins (1961), Type II visual patterns (e.g., exemplars are large white squares OR small black triangles) have held a special place in investigations of human learning. Recent research on Type II *linguistic* patterns has shown that they are relatively frequent across languages and more frequent than Type IV family resemblance patterns (e.g., exemplars have 2 out of 3 defining features). Research has also shown that human infants are adept at learning Type II patterns from very few exemplars, but adult learning appears to be more mixed. Because no study had directly compared adults and infants, Experiment 1 tested both groups on the same input and test stimuli. Adults at best showed weak learning of one of two Type II patterns, but infants showed robust learning of both patterns. Experiment 2 contrasted adults' ability to learn a Type II pattern with a Type IV pattern. Adults only showed learning of the latter, replicating previous research with different stimuli and testing procedures. Thus, adults are unable to learn a frequent linguistic pattern, one readily learned by infants. Implications for possible language learning differences between infants and adults are discussed.

Introduction

Phonotactic patterns among words, such as *words begin with a voiced consonant*, or *the vowels in words either share the phonological feature "front" or the feature "back"* (i.e., vowel harmony), have parallels in classic research on learning of different types of non-linguistic patterns or categories (Shepard, Hovland & Jenkins, 1961; henceforth SHJ). SHJ showed that adults who are given feedback are able to learn a single-feature visual category like "black shapes" (Type I categories, left column of Figure 1a) most easily, followed by categories involving disjunction (also called Exclusive OR, or *disjunction* pattern) like "black triangles OR white squares" (Type II categories, left column of Figure 1b), followed by categories involving *family resemblance* like two out of three of the following: large, black, triangle (Type IV categories; also see Love, 2002). However, when adults receive no feedback, the learning order is: Type I is easier than Type IV, which is easier than Type II.

Type II disjunction categories are particularly interesting, because their place in the supervised (i.e., with feedback) learning order cannot be predicted by the similarity of the category members to each other (i.e., "similarity ratio"; Shepard et al., 1961). That is because each part of the category on either side of "OR" shows high similarity among category members (black triangles, white squares); the two parts are not similar to each other (black triangles are not similar to white squares). The ability to learn such categories has heretofore not been observed in non-humans. For example, Smith, Minda, & Washburn (2004) trained adult humans and Rhesus monkeys on the SHJ categories

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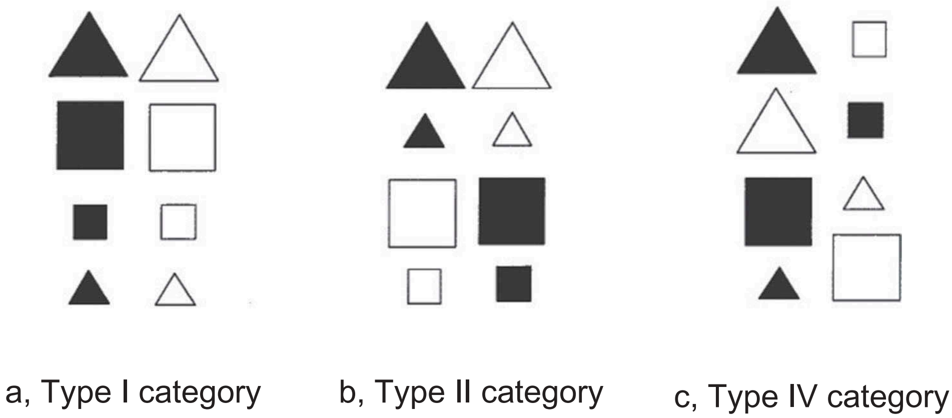

Figure 1. 3 types of visual categories studied by Shepard et al. (1961). The two columns of figures represent different categories.

shown in Figure 1, as well as other categories originally examined by SHJ. They found the expected supervised learning pattern for adult humans, with Type II categories easier to learn than Type IV. However, four out of four monkeys had more errors at test on Type II than Type IV categories.

Returning to the domain of language, recent work on the cross-linguistic frequency of the three SHJ categories shown in Figure 1, now manifest by phonotactic patterns shows that Type I is more frequent than Type II which is more frequent than Type IV (where ">" indicates more frequent; Moreton, Pater, & Pertsova, 2015; Moreton & Pertsova, 2014). Examples of linguistic manifestations of the three patterns are shown in Table 1. Note that the ordering of frequency of the three types across human languages mirrors learnability patterns in the classic non-linguistic studies for supervised learning. This parallel offers the intriguing possibility that some aspects of language learning are governed by general cognitive principles that also apply in non-linguistic domains (e.g., Moreton & Pater, 2012; Moreton et al., 2015).[1]

Given the potential parallels between non-linguistic and linguistic learning mechanisms for the SHJ order, what do we know about how human infants and adults learn Type II patterns in language? With respect to human infants, recent research from our lab indicates that 11-month-olds are able to readily generalize a Type II disjunction pattern like the one shown in 1b of Table 1 (Gerken & Knight, 2015; Gerken & Quam, 2016). Gerken and Knight (2015) familiarized 11-month-olds with one of two phonotactic patterns. All of the infants were presented with a small set of CVCV (C = consonant, V = vowel) words. Half of the infants learned a Voice Pattern (2a, in Table 2), such that the two consonants were both made with the vocal cords vibrating (voiced) or not vibrating (voiceless). The other infants learned a Place of Articulation (POA) Pattern (2b in Table 2),

Table 1. Linguistic examples of generalizations based on SHJ (1961). Patterns apply to voicing of consonants and frontness of vowels. C_1 = first consonant, C_2 = second consonant, V_1 = first vowel.

Example number	Shepard et al. Type	Linguistic Generalization
1a	Type I	C_1 is voiced
1b	Type II	C_2 is voiced if and only if (iff) C_1 is voiced OR C_2 is voiceless iff C_1 is voiceless
1c	Type IV	Words must have at least 2 out of 3 of: C_1 is voiced, V_1 is front, C_2 is voiced

Table 2. Two Type II linguistic patterns learned by 11-month-olds tested by Gerken and Knight (2015) and used in Experiment.

Example number	Shepard et al. Type	Linguistic Generalization
2a	Type II (voicing)	C_2 is voiced iff C_1 is voiced OR C_2 is voiceless iff C_1 is voiceless
2b	Type II (place of articulation)	C_2 is labial iff C_1 is labial OR C_2 is coronal iff C_1 is coronal

such that the two consonants were both articulated with the lips (labial) or with the tongue behind the teeth (dental). Note that this type of pattern in which two (or more) consonants in a word must share a feature is called "consonant harmony" in linguistics. The data revealed that infants who heard one example each of just four words illustrating one of the two consonant harmony patterns were able to distinguish at test between new words that fit their familiarization pattern from very similar new words that fit the other infants' familiarization pattern.

Two very recent studies have examined infants' ability to note vowel harmony (a Type II disjunction pattern), in which two vowels share a feature. One study demonstrated that 7-month-olds could use a pattern of shared vowel features (V_1 and V_2 are both back OR V_1 and V_2 are both front) in lexical segmentation (Mintz, Walker, Welday, & Kidd, 2018). Although infants did not generalize to new vowel harmony words, these data indicate that a feature shared across two segments is a relation that infants readily notice. Another study showed that 13-month-olds, but not 10-month-olds, who were exposed to a language that employs vowel harmony (Hungarian) listened longer to non-words that did not exhibit vowel harmony. In contrast, a group of French 13-month-olds showed no preference for non-words with or without harmony (Gonzalez-Gomez, Schmandt, Fazekas, Nazzi, & Gervain, 2019). This study indicates that by 13-months, infants who are exposed to a language with a Type II disjunction pattern (vowel harmony) expect words to exhibit this pattern. In short, Type II disjunction patterns that involve shared features on consonants (Gerken & Knight, 2015; Gerken & Quam, 2016) or vowels (Gonzalez-Gomez et al., 2019; Mintz et al., 2018) appear to be readily noticed and learned by human infants.[2] To our knowledge, there is no published study that compares infants' ability to learn Type II disjunction vs. Type IV family resemblance patterns, although such research is currently underway in our lab. Therefore, we do not yet know with certainty the relative ease of Type II vs. Type IV patterns for infants. Given the relative frequency of Type II patterns in language compared to Type IV patterns, we might expect that infants would show more robust learning on Type II patterns, and pilot data suggest that this is indeed the case. If borne out in a full study, such a result would be important, given that infant learning is unsupervised, and in studies of unsupervised visual categorization, Type IV patterns are easier than Type II patterns (e.g., Love, 2002). We will return to the issue of supervised vs. unsupervised learning in the Discussion.

Turning now to studies of Type II linguistic pattern learning by adults, we will confine our discussion to patterns like those shown in Table 2 which, as noted above, are called harmony patterns in the linguistics literature. A number of studies have demonstrated that adults can learn such patterns when the two segments involved are vowels (vowel harmony, e.g., Finley & Badecker, 2009; Moreton, 2008; Pycha, Nowak, Shin, & Shosted, 2003; Skoruppa & Peperkamp, 2011). Adult studies that have investigated Type II disjunction patterns with consonants (consonant harmony, as in Table 2) yield more mixed results. Studies that have examined consonant harmony in morphological contexts (e.g., sound relations between a word stem and an affix) have generally shown successful learning by adults. For example, Finley (2011) presented adults with pairs of non-suffixed and suffixed non-word stems, in which the suffix had to share a consonant feature with the stem (e.g., [bise, bisesu] and [beʃa, beʃaʃu]). Note that adults needed to learn which suffix to add from a choice of two, and that the relevant consonants matched exactly, not just in a single feature. Similarly, Wilson (2003) employed two different suffixes: [na] when the last consonant of the stem was a nasal [n, m]; or [la] when the last consonant was not a nasal [k, g, t, b]. Note that, unlike the example in Table 2, neither of these consonant studies involved matching a single feature on two consonants.

In a study not involving consonants in stems and affixes, Kuo (2009) presented participants with non-words containing four C_1's and two immediately following C_2's ([w] and [y]). In the experimental condition, two of the four C_1's were bilabial ([p, $p^{h]}$ where the superscript h indicates aspiration) and preceded [y] and the other two C_1's were alveolar ([t, $t^{h]}$) and preceded [w]. Thus, the stimuli could be described by a Type II rule: C_2 is [y] if C_1 is bilabial OR C_2 is [w] if C_1 is alveolar. At test, participants chose which of two new non-words was more like the familiarization words, showing successful discrimination in the experimental condition. However, in the control condition, the two consonants preceding [w] or [y] did not share features (e.g., [p, t^h] preceded [w] and [p^h, t] preceded [y]). In this condition, adults did not show learning, even though they could simply have memorized the C1-C2 combinations. The contrast between the experimental and control conditions suggests feature-based learning in the former. Again, Kuo's stimuli are unlike those in Table 2, because they don't refer to a feature on C_2, which was always [w] or [y].

In contrast, two studies by Moreton and colleagues (Moreton, 2012; Moreton et al., 2015) that used stimuli like those in Table 2 failed to show learning by adults. Moreton (2008, Experiment 5) generated a set of $C_1V_1C_2V_2$ non-words from four consonants and four vowels. Participants were familiarized with a list of non-words in which the two C's shared voicing ([d, g] and [t, k]) and then tested on pairs of new items, one of which fit the pattern and one of which did not. Adults did not show significant discrimination of the test items. Similarly, adults tested by Moreton et al. (2015) using the same four-consonant stimuli and forced choice test procedure as Moreton (2012) failed to learn a Type II disjunction pattern when it involved stimuli like those in Table 2—a pattern on which infants showed robust learning.[3] Importantly, Moreton et al. (2015) compared the performance on Type II stimuli like those in Table 2 and Type IV family resemblance stimuli and found significantly better performance on the latter. Thus, in the one study that compared unsupervised Type II vs. Type IV linguistic pattern learning, adults showed parallel performance to what has been previously observed in unsupervised visual pattern learning.

Two aspects of the Type II stimuli used by Moreton and colleagues (Moreton, 2012; Moreton et al., 2015) differed from the stimuli used with infants by Gerken and colleagues (Gerken & Knight, 2015; Gerken & Quam, 2016). First, the Moreton studies employed only four consonants, whereas the Gerken studies employed six consonants in familiarization and eight in test, and not all consonants in either familiarization or test occupied both C_1 and C_2 positions. Perhaps the added variability in the Gerken stimuli made generalization easier (e.g., Gómez, 2002). Second, in the Moreton studies, both familiarization and test stimuli allowed the C_1 and C_2 to match exactly (e.g., [didu]), and even for C_1V_1 and C_2V_2 to match exactly (e.g., [didi]), which was not the case for the Gerken stimuli. Perhaps the stimuli containing consonant and syllable repetition were so salient that adults failed to notice other, more subtle, feature-based patterns in the input. In addition, Moreton et al. (2015) collapsed both consonant harmony and anti-harmony (C_2 is voiced iff C_1 is voiceless OR C_2 is voiceless iff C_1 is voiced) conditions; the latter is less typical of human languages and therefore potentially more cognitively difficult. It would be useful to know if the Moreton et al. finding, that Type IV is easier than Type II, can be replicated when the Type II pattern involves only harmony.

Let us summarize the above results that motivate the current study: Infants appear to be adept at learning the kinds of Type II disjunction patterns shown in Table 2. Adults, on the other hand, can learn some types of Type II linguistic patterns, but the studies by Moreton and colleagues (Moreton, 2012; Moreton et al., 2015) suggest that adults cannot easily learn the Type II pattern in Table 2 that is so readily learned by infants. However, there were differences in the stimuli between the Moreton and Gerken studies that might have influenced the outcomes, and no direct comparison of infants vs. adults has been undertaken. Thus, our first goal (Experiment 1) is to familiarize infants and adults with identical Type II disjunction pattern input. Our second, related goal (Experiment 2) is to determine if the finding that Type IV is easier than Type II for adults will hold using only a Type II consonant harmony pattern (like the one learned so readily by infants).

To briefly foreshadow the experiments and findings presented here, Experiment 1 presented adults and infants with four words generated by the two Type II patterns in Table 2. Adults showed at best weak evidence of learning only one of the patterns, whereas infants showed significant learning from the same input of both patterns (thereby replicating previously published findings). Experiment 2 tested one group of adults on one of the Type II patterns from Experiment 1 (1b in Table 1) and another group on a Type IV family resemblance pattern (1c in Table 1). Adults again failed to learn the Type II pattern, but succeeded on the family resemblance pattern, thereby replicating the results of Moreton et al. (2015) with different stimuli and a different testing procedure. The current data, coupled with earlier data from Moreton (2012) and Moreton et al.

(2015), indicate that adults are remarkably poor at learning a version of a Type II linguistic pattern in which two consonants in a word share a feature. In contrast, adults are adept at learning a Type IV family resemblance pattern that involves more segments (3 instead of 2), despite the fact that the Type II pattern is both more frequent in natural language than Type IV patterns, and readily learned by infants from minimal input.

Experiment 1

The main goal of Experiment 1 was to determine if adults could learn the Type II disjunction pattern that was learned by infants in a previous study (Gerken & Knight, 2015). 11-month-olds were also tested to confirm and replicate the previous finding using a slightly different set of input stimuli. The input words reflected either the Voice Pattern (2a) or the POA Pattern (2b) shown in Table 2. Although Moreton (2012) and Moreton et al. (2015) found that adults were unable to learn a similar Type II pattern, the small number of consonants used and the existence of repeated C_1's and repeated C_1V_1's in the stimuli might have made learning more difficult.

Methods

Participants

The numbers of participants were selected to mirror previous adult and infant studies using the same kinds of Type II stimuli. 42 college students (19 male) ranging in age from 18–24 years participated in the experiment for course credit. In addition, 18 infants (11 male) ranging in age from 10.6–11.4 months, with a mean of 11.0 months participated in the experiment. All infants were at least 37 weeks to term, at least 5 lbs 8 oz. at birth, had no history of speech or language problems in their nuclear family, and were not given medication for an ear infection within one week of testing. Three additional infants were tested but not included: one who failed to complete the familiarization phase and two who had a mean listening time across all trial types that was over two standard deviations above the group mean (the latter exclusion criterion was used in Gerken & Knight, 2015).

Materials

Materials for Experiment 1 were four familiarization words generated by the Voice Pattern (*pota, tæpa, biza, dɛva*) for one group of participants and four words generated by the POA Pattern (*poba, tæza, bipa, dɛsa*) for the other group. These were the same words employed with 11-month-olds in the No Overlap Condition of Gerken and Knight (2015). In the current experiment, 6 identical tokens of each word were presented (instead of one token as in Gerken and Knight), for a total of 24 input word tokens. One pseudo-randomized order was created so adjacent words were never identical. Test words were the same 16 words used by Gerken and Knight (2015; 8 consistent with the Voice Pattern (and inconsistent with the POA Pattern): *dɛba, tæfa, bida, posa, tifa, bɛda, pæsa, doba*; and 8 consistent with the POA Pattern (and inconsistent with the Voice Pattern): *dɛta, tæda, bifa, pova, tida, bɛfa, pæva, dota*). Note that none of the test words have the same pair of consonants as any of the familiarization words, thus discrimination of test items as consistent vs. inconsistent with a participant's familiarization grammar requires generalizing the pattern beyond the particular pairs of consonants in the familiarization words. Familiarization and test words were recorded by the first author in infant-directed speech. The same 24-word familiarization string recording was used for infants and adults. The same test word recordings were also used for the two groups, but differences in testing methods resulted in different numbers and orders of test items.

Procedure

Adult participants were tested using SuperLab 4.0.6 software. They were informed that they would hear some words from an "alien" language. They were further told that spies were trying to infiltrate the alien group, and that after they heard a sample of the alien language, they would need to decide whether a new set of words they would hear were spoken by an alien or a spy. During familiarization, they saw a static scene of alien creatures sitting around a fire and heard 24 familiarization word tokens (of 4 word types). They then saw a screen with instructions on how to rate the upcoming test words as either alien or spy. The test words were presented one by one in random order, and for each, the participant clicked the mouse on one side of the screen labeled "alien" or on the other side labeled "spy".

For infants, the headturn preference procedure (Kemler Nelson et al., 1995) was used. Infants were seated on a parent's lap in a small room. The parent listened to pop music through headphones in order to mask the stimuli heard by the infants and prevent inadvertent influence on the infant. During the familiarization phase when infants heard the 24 familiarization words, a light directly in front of the infant flashed until the observer, blind to the experimental condition and unable to hear the stimuli, judged the infant to be looking at it, at which point a light on the left or right would begin flashing. When the infant looked first at the side light and then away for two consecutive seconds, the center light would resume flashing, and the cycle would begin again. This continued for the duration of the familiarization phase, which played uninterrupted to its conclusion. Thus the familiarization phase not only exposed infants to the 24 familiarization words, but also introduced them to the contingency between where they looked (left, right, center) and which lights flashed. Because the 24 familiarization words only played for about 28 sec, they were preceded by about 1.5 min of Andean instrumental music to allow infants to become accustomed to the testing booth and procedure.

After the familiarization phase ended, the test phase began immediately. The flashing lights behaved the same way except that now the sound was contingent on the infant orienting to a side light. Each time a side light began flashing and the infant oriented toward it, one of the four test trials would play (each with a maximum duration of about 23.5 sec), continuing until either the infant looked away for two consecutive seconds or the test trial reached its conclusion. In keeping with the standard practice in our lab, test trials shorter than 2 seconds were excluded from the analysis, because it was unlikely that infants were able to fully encode the nature of the stimulus on such a short trial (e.g., Gerken & Knight, 2015). One trial was omitted for an infant familiarized with the POA pattern and two trials for two different infants familiarized with the voice pattern.

Results and discussion

The dependent measure for adults was the mean number of "alien" responses (i.e., "like familiarization"—vs. "spy" responses, i.e., "unlike familiarization") that participants gave for test items that were consistent vs. inconsistent with the language with which they were familiarized. A 2 × 2 Consistency (Consistent vs. Inconsistent with familiarization grammar) X Familiarization Grammar (Voicing vs. POA) ANOVA on these "alien" responses showed no main effect of Consistency ($F(1, 40) = 1.19$, $p = .43$). It did show a main effect of Grammar ($F(1, 40) = 6.03$, $p = .019$), such that adults gave more alien responses overall to voicing test items, and a Consistency X Grammar interaction ($F(1, 40) = 4.82$, $p = .034$). As shown in Figure 2a, the nature of the interaction was that participants who were familiarized with stimuli from the Voice Pattern produced marginally more "alien" responses for test items that were consistent vs. inconsistent (M consistent = 4.43, SE = 0.34; M inconsistent = 3.52, SE = 0.25) with that pattern ($t(20) = 2.03$, $p = .056$; 11 out of 21 participants made more "alien" responses to consistent than inconsistent test items, and 4 made an equal number of "alien" responses). By contrast, participants who were familiarized with the POA Pattern showed no difference in "alien" responses for test items that were consistent vs. inconsistent (M consistent = 3.10, SE = 0.32; M inconsistent = 3.52, SE = 0.22) with that pattern ($t(20) = 1.04$, $p = .31$; 7 out of 21 made more "alien" responses to consistent test items).

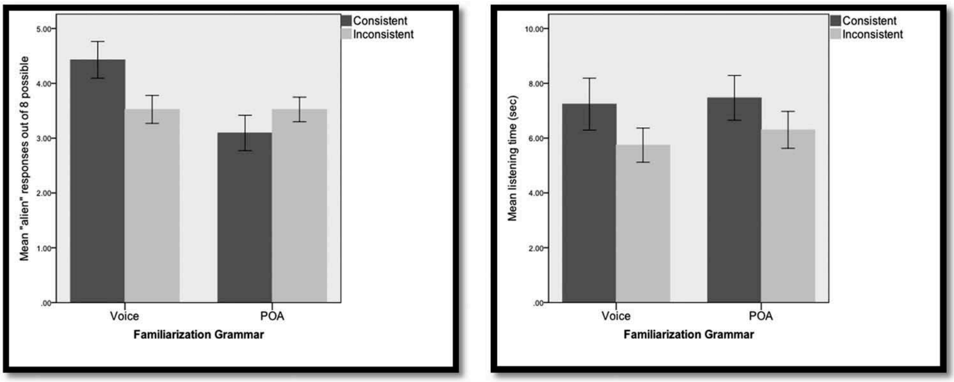

Figure 2. (a) Mean number of "alien" responses out of 8 possible by adult participants and standard errors for test items that are consistent vs. inconsistent with the Voice and Place of Articulation (POA) familiarization grammars; (b) mean listening times by 11-month-olds and standard errors for test items that are consistent vs. inconsistent with the Voice and POA familiarization grammars. Familiarization stimuli were identical for adults and infants.

The dependent measure for infants was the amount of time they listened to test items that were consistent vs. inconsistent with their familiarization grammar. A 2 × 2 Consistency (Consistent vs. Inconsistent with familiarization grammar) X Familiarization Grammar (Voicing vs. POA) ANOVA on these listening times revealed a main effect of Consistency ($F(1, 16) = 8.95$, $p = .01$), but no main effect of Grammar ($F(1, 16) < 1$) and no interaction ($F(1, 16) < 1$). As shown in Figure 2b, infants listened significantly longer to consistent ($M = 7.35$, $SE = 0.61$) than inconsistent ($M = 6.02$, $SE = 0.45$) test items, indicating a familiarity preference.[4] For each familiarization pattern, 7 out of 9 infants listened longer to the consistent test items.

Because different dependent measures were used for adults and infants, a nonparametric test was used to compare the numbers of participants in each group who either made more "alien" responses to consistent vs. inconsistent test trials (adults) or who listened longer to consistent vs. inconsistent test trials (infants). A chi-square with Yates indicated a significantly different pattern of responding between the two groups (X^2 (1, N = 60) = 4.85, $p = .028$).

The infant data from Experiment 1, as well as the findings of Gerken and Knight (2015) and Gerken and Quam (2016), make it clear that 11-month-olds are able to learn a Type II linguistic pattern. Infants in all studies showed a significant main effect of consistency and no other effects (but see Footnote 4 above). Adults, on the other hand, did not show a significant main effect of consistency, making their ability to learn the same Type II pattern much less clear. How should we interpret apparent differences in the pattern of responding between infants and adults? We consider two possibilities.

One possibility assumes that adults' pattern of performance indicates that they actually learned the Type II voicing pattern but not the POA pattern. Importantly, on this view, both infants and adults are able to learn at least some Type II linguistic patterns. Thus, unlike the adults studied by Moreton and colleagues (Moreton, 2012; Moreton et al., 2015), who failed to learn Type II patterns like those shown in Table 2, adults in Experiment 1 showed weak learning of a Type II pattern that involved shared voicing on two consonants. If adults did learn a Type II pattern in Experiment 1, why did they learn only the voicing pattern? Perhaps because the POA pattern is counter to English phonology: words in which consonants share place of articulation are relatively more rare than words in which consonants have different places of articulation (e.g., Frisch, 2004). Because adults are more familiar with the structure of English words than are 11-month-olds, adults would have been less able to learn the POA pattern than were infants.

The second account of infant-adult differences, and the one we favor, is that adults' performance in Experiment 1 does *not* show Type II pattern learning. This result is consistent with the fact that in neither the Voicing or POA conditions did a clear majority of adults give more "alien" responses to consistent vs. inconsistent test items (11 and 7 out of 21 participants, respectively; nor did adults' responses meet the threshold for significance in either condition). Rather, we suggest that adults' performance at test shows only their preference for non-words that do not conform to the POA pattern, since such forms are less English-like than non-words in which consonants have different POAs. Because of the way that the test items were constructed, the test items that were inconsistent with the POA Pattern were consistent with the Voice Pattern. This explanation is supported by the fact that adults gave overall higher ratings at test to items that conformed to the voicing pattern, regardless of whether that was the pattern they should have learned during familiarization (i.e., the main effect of grammar seen in the ANOVA on adult responses).

Given the difficulty interpreting adults' performance in Experiment 1, we took a different approach in Experiment 2, in which we compared adults' ability to learn a Type II voicing pattern like the one used in Experiment 1 and a Type IV family resemblance pattern in which consonant voicing was one of two features shared among "family members." If adults in Experiment 2 behave like those observed by Moreton and colleagues (Moreton, 2012; Moreton et al., 2015) and learn only the Type IV family resemblance pattern, we would have stronger evidence that infants and adults are truly different in their abilities to learn some Type II linguistic generalizations.

Experiment 2

As noted above, the goal of Experiment 2 was to compare adults' ability to generalize two types of linguistic patterns: the Type II voicing pattern shown in 1b of Table 1, and the Type IV family resemblance pattern shown in 1c of Table 1. Two possible outcomes would be of interest in Experiment 2. One is that adults will learn both the Type II and the Type IV pattern. This finding would suggest that the data reported by Moreton et al. (2015) underestimated adults abilities to learn a Type II pattern that involves feature matching on two parallel segments. This finding would also suggest that adults can indeed learn the Type II voicing pattern used in Experiment 1 and that adults and infants are both capable of learning Type II patterns.

Alternatively, Experiment 2 might replicate the data of Moreton and colleagues (Moreton, 2012; Moreton et al., 2015), in which adults are able to learn a Type IV family resemblance pattern but not a Type II disjunction pattern involving shared features on two consonants. This outcome would be consistent with our favored interpretation of Experiment 1, in which adult responses to test items show only a bias against non-words in which the two consonants share place of articulation. Note that the Type II voicing pattern used in Experiment 2 is the same one that infants have been shown to learn so readily (e.g., Experiment 1 and Gerken & Knight, 2015). Therefore, a replication of the results of Moreton and colleagues showing that adults fail to learn a Type II pattern, but using different stimuli and testing procedures, would lend support for our hypothesis that infants are better than adults at learning the sorts of Type II patterns shown in Table 2.

Methods

Participants

Forty-eight adult college students (20 male) ranging in age from 18–34 participated in the experiment for course credit. Twenty-four participants were exposed to a Type II Pattern and 24 to a Type IV Family Resemblance Pattern.

Materials

Materials for Experiment 2 were again $C_1V_1C_2V_2$ non-words that were created using the schematic shown in Table 3. The voicing of the first and second consonants and the frontness/backness of the first vowel were manipulated to generate eight word templates—four of which were consistent with the Type II Voice Pattern and four of which were consistent with the Type IV Family Resemblance Pattern. Two of the word templates were consistent with both patterns, two were consistent with only the Type II pattern, two were consistent with only the Type IV pattern, and two were not compatible with either pattern.

C_1's and C_2's were b, d, v, z (voiced) and p, t, f, s (voiceless). V_1's were ε, i (front) and o, u (back). Crossing the 8 C_1's, 8 C_2's, and 4 V_1's yielded 256 CVCV non-words. From the set of 256, 32 words (4 from each of the 8 word templates shown in Table 3) were selected for test words. All of the test words had labial consonants (b, p, f, v) in both C_1 and C_2 positions, because the stimuli were designed to also be used in a production experiment in which lip movements are monitored using articulatory movement capture technology (not reported here). Half (16) of the test words were consistent with the Type II pattern and a partially overlapping set of 16 were consistent with the Type IV pattern (see Table 3). During pilot testing, we eliminated two test words because they were similar or identical to English words, leaving 30 test words total. After elimination of those familiarization words that were similar or identical to English or common Spanish words (e.g., *viva*), two familiarization lists of 76 words each were created, one containing a randomly ordered set of words that are consistent with the Type II pattern and the other containing a randomly ordered set of words that are consistent with the Type IV pattern. 250 msec pauses were placed between words in each list.

Procedure

To ensure that participants didn't have an a priori preference for some types of test words over others, 15 adults who did not participate in the main experiment were presented with the 32 test words in different random orders. They rated each word on a 1–5 scale as to how good a possible word of English it was. An ANOVA on the eight word types was not significant ($F(1,14) = 0.79$, $p = .78$). Means for the eight types ranged from 2.48–2.96 with a mean of 2.65 (Figure 3). In addition, we performed two t-tests on the data shown in Figure 3. We first compared the test items that are consistent vs. inconsistent with the Type II pattern (bars 1, 3, 5, 7 vs. 2, 4, 6, 8; $t(14) = .19$, $p = .85$). We then compared the test items that are consistent vs. inconsistent with a Type IV pattern (bars 1–4 vs. 5–8; $t(14) = .40$, $p = .70$). All three analyses suggest no a priori preference for any of the stimuli; therefore any effects we might find in the main experiment of Experiment 2 for adults familiarized with Type II vs. Type IV stimuli are not due to a priori preferences.

Table 3. Schematic of 8 word templates used in Experient 2. For C_1 and C_2, + indicates *voiced*, – indicates *voiceless*. The Type II pattern is that C_1 and C_2 must have the same voicing (1a-b above), and the Type IV pattern is that 2 of these 3 features must be present: C_1 voiced, C_2 voiced, V_1 front (2 above). The first row is the Family Resemblance prototype (with all three features).

Stimulus Description C_1 V_1 C_2	Short Description used in Figs. 4–5, (C indicates a voiced consonant and V indicates a front vowel)	Consistent with Type II Voice Pattern?	Consistent with Type IV Family Resemblance Pattern?
+ front +	CVC	yes	Yes
+ front -	CV	no	Yes
+ back +	CC	yes	Yes
- front +	VC	no	Yes
- front -	V	yes	No
- back +	C1	no	No
- back -	NONE	yes	No
+ back -	C2	no	No

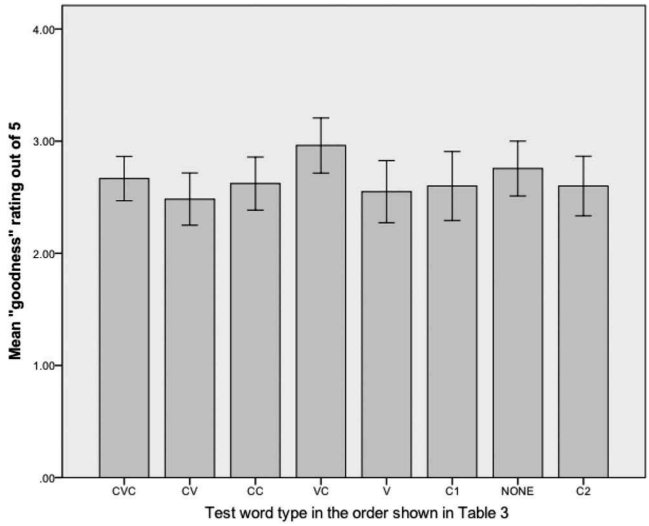

Figure 3. Mean "goodness" ratings and standard errors for the 8 test item types used in Experiment 2. Bars 1, 3, 5, and 7 are consistent with the Type II disjunction pattern and Bars 1–4 are consistent with the Type IV family resemblance pattern.

For the main experiment, the procedure for Experiment 2 was identical to the one used for adults in Experiment 1.

Results and discussion

A 2 × 2 Pattern Type (II vs. IV) X Consistency (consistent vs. inconsistent with the familiarization pattern) ANOVA was performed on the mean number of "alien" responses made by participants for consistent and inconsistent test items (see Figure 4). There was a significant main effect of Consistency ($F(1,46) = 17.78$, $p = .0001$). There was no main effect of Pattern Type ($F(1,46) < 1$). Importantly, as predicted, there was a significant Consistency X Pattern Type interaction ($F(1,46) = 9.05$, $p = .004$).

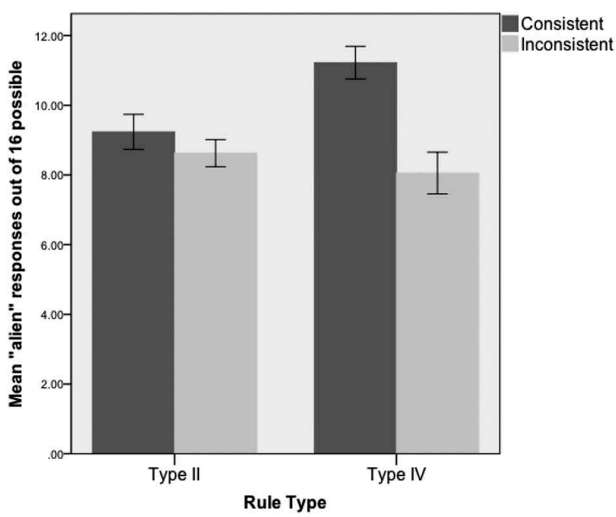

Figure 4. Mean number of "alien" responses and standard errors for test items that are consistent vs. inconsistent with the Type II disjunction and Type IV family resemblance patterns.

Follow-up t-tests revealed that, as predicted, adults who received input from the Type II disjunction pattern failed to give significantly more "alien" responses to consistent test items (M = 9.24 SE = 0.50) than inconsistent test items (M = 8.63, SE = 0.39; t(23) = 1.12, p = .275). In marked contrast to adults who received Type II input, adults who received input from the Type IV family resemblance pattern made significantly more "alien" responses to consistent test items (M = 10.57, SE = .64) than inconsistent test items (M = 6.92, SE = 0.72; t(23) = 4.30, p = .0002).

Recall that participants received all eight of the test item types shown in Table 3. Figure 5 shows each group's performance on the four test items that were consistent vs. inconsistent with their familiarization pattern (Type II or Type IV). For the Type II familiarization group, the mean "alien" response rates for consistent and inconsistent test item types were largely intermixed, with the three highest means going to two consistent and one inconsistent test item types. In contrast, all four test item types that are consistent with the Type IV familiarization group's input were greater than or equal to all of the inconsistent test items. The pattern of responding across the eight test item types supports the contention that adults have difficulty making Type II generalizations.

In keeping with the data of Moreton and colleagues (Moreton, 2012; Moreton et al., 2015), and in keeping with our preferred interpretation of Experiment 1, adults in Experiment 2 who were familiarized with the Type II disjunction pattern failed to distinguish new test items that were consistent vs. inconsistent with the pattern. Adults' failure to learn the Type II pattern in Experiment 2 lends support to the explanation offered for adult performance in Experiment 1: Adults failed to learn either the voicing or POA pattern, but their responses at test reflected an English-based bias against the test items that were consistent with the POA pattern (note that test items inconsistent with the voicing pattern in Experiment 2 were not consistent with the POA pattern).

In contrast with adults in Experiment 2 who were familiarized with the Type II disjunction pattern, those who were familiarized with the Type IV family resemblance pattern were able to robustly discriminate between new consistent vs. inconsistent test items. This finding is in keeping with the literature on Type IV visual categorization without feedback and with the data of Moreton et al. (2015). The fact that adults who were familiarized with Type IV stimuli could learn a pattern

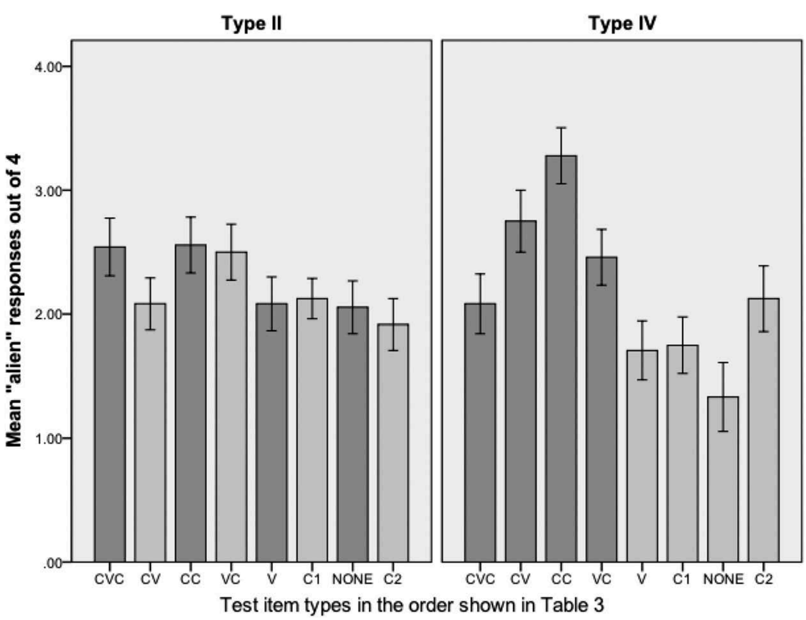

Figure 5. Mean number of "alien" responses and standard errors for test items that are consistent (dark bars) and inconsistent (light bars) with Type II Disjunction and Type IV Family Resemblance grammars. C indicates a voiced consonant. V indicates that the first vowel is fronted.

that involved consonant voicing (plus a vowel feature) suggests that their failure with the Type II pattern was probably not due to their failure to encode the voicing feature, nor to general task demands. Taken together, the data from Experiment 2 corroborate previous findings on visual categorization and the work of Moreton et al. (2015), indicating that, in the absence of explicit feedback, adults are more easily able to learn a Type IV pattern than a Type II pattern.

General discussion

The starting points for this research were the classic findings of Shepard et al. (1961) on the relative difficulty of several types of visual categorization and three recently published observations. First, among human languages, Type II linguistic patterns are more frequent than Type IV family resemblance patterns. Second, 11-month-olds have succeeded at learning two Type II linguistic patterns (Gerken & Knight, 2015; Gerken & Quam, 2016). Third, adults have failed to learn Type II linguistic patterns like those learned so readily by infants (Moreton, 2012; Moreton et al., 2015). Across prior studies, the Type II linguistic patterns presented to infants have been arguably simpler than the versions given to adults (Moreton et al., 2015). Because adults and infants had never been tested on the same Type II linguistic patterns, the first goal of the research reported here was to determine whether adults' learning of Type II patterns was still worse than infants' when both groups were presented with the same input. Experiment 1 familiarized adults and infants with the same input and tested them on the same items. Adults showed at best equivocal learning of the Type II voicing pattern and no evidence of learning the place of articulation (POA) pattern. We suggested that adults' somewhat better performance on the voicing pattern might actually reflect a bias against the POA pattern, which is counter to the statistics of English words. In contrast with adults, infants appeared to learn both patterns, replicating previous findings (Gerken & Knight, 2015).

If adults had been able to learn the Type II voicing pattern in Experiment 1, the result would contradict the findings of Moreton and colleagues. Therefore, Experiment 2 compared adults' ability to learn the same Type II voicing pattern with a Type IV family resemblance pattern that also involved a consonant voicing feature, as well as a vowel feature. Participants in Experiment 2 showed no evidence of learning the Type II pattern, suggesting that their pattern of responses in Experiment 1 reflected a bias against the POA pattern as opposed to true learning. In contrast, they showed robust learning of the Type IV family resemblance pattern in Experiment 2.

Thus, both the adult and infant data in Experiments 1 and 2 replicate the two previous findings that motivated the current research, and confirm that differences between adults and infants still hold even when the same input stimuli are presented to both groups. The main message we take from the previous findings coupled with the experiments presented here is that adults learn Type IV family resemblance patterns but not Type II disjunction patterns involving consonant harmony (two consonants that share a feature, Table 2), despite the latter being readily learned by infants.

In the remainder of the discussion, we address three related issues: First, why do infants outperform adults on Type II consonant harmony patterns like those in Table 2 that are common among human languages? Second, what is the role of feedback in learning Type II non-linguistic and linguistic patterns? Third, why do adults apparently succeed at vowel harmony patterns in which two vowels share a feature, but not at consonant harmony patterns in which two consonants share a feature, when both patterns appear to be readily learned by infants?

Beginning with the first question, the difference between infants and adults in their ability to learn a Type II pattern like the one in Table 2 is the first finding, to our knowledge, of infants outperforming adults in a language-learning experiment in the lab. What might be the nature of this effect? One possibility concerns how infants are tested, with the C_1 and C_2 voiced items occurring in the same test lists as the C_1 and C_2 voiceless test items. That is, individual infants might have noticed only one of the two sub-patterns, which would still allow them to discriminate the test items that were consistent with their familiarization input from the other infants' familiarization input. Recent research from our lab rules out this possibility by testing infants on the same eight types of test items shown in Table 3 (Gerken, Ahmed, & Goffman, in preparation). Infants familiarized with Type II input listened longer to all four consistent test item types (two types with C_1 and C_2 voiced and two with C_1 and C_2 voiceless). Thus, the difference between infants and adults appears not to be an artifact of differences in testing methods.

Another possibility is that infants are better able to notice consonant features such as voicing or place of articulation than adults are. However, because the Type IV Family Resemblance pattern used in Experiment 2 also employed linguistic features (e.g., voicing and vowel frontness/backness), and because adults learned these patterns, it appears that adults are sensitive to the features in question.

Two other potential explanations for infant-adult differences in Type II pattern learning both concern the domain over which the two groups of learners are most likely to generalize. Infants appear to notice similarities in stimulus features over short distances—within a word or between adjacent words. Noticing that C1 and C2 have the same voicing value is all that is needed to make the relevant generalization for the Type II Voice pattern. There is good evidence that infants of the age tested here are incremental processors and note spurious generalizations that occur between adjacent words (e.g., two words starting with/p/; Gerken & Quam, 2016). In contrast, it is possible that adults' greater memory resources might allow them to store larger runs of input and only notice similarities among larger sets of input items. That is, due to memory differences, infants are more incremental learners and adults are more batch learners (see Gerken & Quam, 2016). Similarity-based generalization over sets of words favors Type IV generalizations, because there is a larger degree of overlap among the set of Type IV words, which all share some features, than among the set of Type II words, which reflect disjoint sets (words with voiced consonants vs. words with voiceless consonants occur within the same learning set).

This memory-based explanation of adults' better performance on Type IV than Type II words is consistent with modeling efforts by Moreton et al. (2015), in which similarity-based models account better for the data than pattern induction models. On this account, infants' weaker memory ability might be what allows them to discover Type II patterns. Such a view, that weaker memory abilities actually lead to better learning of certain types, is consistent with Newport and colleague's "Less is More" explanation of the fact that learning at younger ages results in better ultimate language outcomes than learning at older ages (Goldowsky & Newport, 1993; Kam & Newport, 2005, 2009). Although this explanation has been used to explain how young learners regularize messy input, it might also explain why infants are better at learning Type II linguistic patterns, which are more frequent in typological studies across languages than Type IV patterns. Thus, a similar memory-based mechanism might explain several facets of younger learners superior outcomes.[5]

A second possible explanation is similar to the memory hypothesis, but it focuses on the *units* over which infants and adults are seeking regularities. When adults hear forms like those used in the experiments presented here, they may treat the forms as potential words and organize them based on featural similarities, like they would with words in their lexicon. As noted above, Type II words compose a disjoint set, with words containing two voiced consonants forming one similarity-based cluster and words containing two voiceless consonants forming another cluster. Type IV words fit together into a single cluster. On the units hypothesis, it is adults' treatment of Type II input as words, which are stored based on featural similarity, that prevents them from learning. This explanation makes the testable prediction that Type II linguistic pattern learning should be negatively correlated with the ability to rapidly recognize words or encode new words. Conversely, it predicts that learning Type IV linguistic patterns should be positively correlated with word recognition and/or word-learning ability. We are planning to test these predictions in future work. While the units explanation of adult performance is very similar to the memory-based account given above, the units hypothesis may offer a better explanation than the memory hypothesis for a puzzling finding by Morteton et al. (2015) that concerns feedback. Therefore, let us turn to the issue of the role of feedback in learning Type II linguistic and non-linguistic patterns.

Recall that in non-linguistic pattern learning, Type II is easier than Type IV with feedback, but the opposite is true without feedback (e.g., Love, 2002). One reason for the role of feedback may be that, as noted already, Type II patterns are disjoint. If adults are biased toward similarity-based visual patterns, Type II patterns are difficult to discern. Perhaps the role of feedback is to force adults to abandon their search for similarity-based patterns in favor of another category structure. On this view, can feedback aid adults in learning a Type II linguistic pattern? Moreton et al. (2015) asked this question and found that the answer was *no*, thereby revealing a potentially interesting difference between Type II linguistic and non-linguistic pattern learning. What is the nature of this difference? On the units hypothesis, adults appear not to have a feature-base storage structure for visual input (e.g., Brady, Konkle, Alvarez, & Oliva, 2013; Konkle, Brady, Alvarez, & Oliva, 2010), that is comparable to the lexicon. Therefore, feedback allows adults to change their initial organization of Type II visual input, but not linguistic input, because the lexicon is not easily by-passed for purposes of re-organization. This explanation of the role of feedback in learning Type II patterns leaves open the question of why infants are apparently able to easily learn Type II linguistic patterns without feedback. However, this question cannot be addressed until we have a clearer picture of infants' abilities to learn Type II vs. Type IV patterns.

Why do adults apparently succeed at vowel harmony patterns but not at consonant harmony patterns in which two consonants share a feature, when both patterns appear to be readily learned by infants? A number of researchers have suggested that vowel harmony reflects an underlying co-articulation process, such that the gestures for two nearby vowels overlap, whereas consonant harmony reflects the anticipation of upcoming featurally-specified consonants (see Finley, 2017 for review). Adults appear to be able to perceive as well as produce co-articulation, or at least use the presence of co-articulation in spoken input to treat co-articulated segments as belonging to the same word and non-co-articulated segments as belonging to different words (e.g., Mattys, White, & Melhorn, 2005). This may be especially true in languages with grammatically-required vowel harmony, where adults have been shown to actively use disharmony as a cue to word boundaries (Suomi, McQueen, & Cutler, 1997; Vroomen, Tuomainen, & de Gelder, 1998). If vowel harmony is represented as co-articulation, perhaps it doesn't necessarily entail that it is represented as a Type II disjunction pattern at all. That is, both vowel harmony and consonant harmony are formally Type II patterns, but perhaps only consonant harmony is psychologically a Type II pattern. On this view, the observation that Type II patterns are second in frequency among human languages (Moreton & Pertsova, 2014) does not necessarily entail that Type II patterns as a whole are easier to learn. Clearly, the difference in learning ease of vowel vs. consonant harmony for adults but not infants requires an explanation, but that explanation is beyond the scope of the current work.

Regardless of what is revealed by future work, the current research points out the usefulness of the original SHJ categories for research on language learning. These categories allow not only for adult–infant learning comparisons like the sort explored here, but also human–animal comparisons that are likely to give us clearer insights into how language can and cannot be learned via general cognitive mechanisms (e.g., Smith et al., 2012).

Notes

However, any parallel between non-linguistic and linguistic domains is tempered by the observation that language learning is probably unsupervised. See below and Discussion.

Moreton and Pater (2012) suggest that two studies employed "defective" Type II patterns (Cristia & Seidl, 2008; Saffran & Thiessen, 2003) as their no-pattern control conditions, which infants had difficulty learning. However, neither of these control conditions had the same OR structure as the one shown in Table 2.

Moreton et al. (2015) did find successful learning for a Type II pattern unlike that in Table 2, in which both features were on the same segments (e.g., C_1 is voiced iff C_1 is coronal OR C_1 is voiceless iff C_1 is dorsal), but learners in this condition could simply remember that words begin with k or d and thus rely on Type 1 learning.

Gerken and Knight (2015) found a novelty preference when each of the four words was presented once, and we found a familiarity preference when the words were presented six times. We believe that the difference is that presenting the words multiple times resulted in three occasions where the same word appeared with just one other word intervening (e.g., *tæpa pota tæpa*). We know that infants are sensitive to such alternations (e.g., Gómez & Gerken, 1999; Marcus, Vijayan, Rao, & Vishton, 1999), and their presence in the input could have caused infants to implicitly consider this local regularity in the input in addition to the intended one (Gerken & Quam, 2016). Detecting more than a single regularity in the input during familiarization may increase the complexity of the learning task, resulting in a familarity preference at test.

Note that neither this explanation for adult vs. infant difference (nor the next one) account for differences in adults' ability to learn Type II consonant vs. vowel harmony patterns.

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