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THE ROLE OF PHONOLOGICAL DISTRIBUTIONAL INFORMATION ON THE ACQUISITION OF L2 ALLOPHONES

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It has been well attested that infants and adults are able to take advantage of statistical distributional information to acquire phonemes (Maye et al., 2002; Hayes-Harb, 2007) and that infants can learn novel phonological alternations on the basis of phonological distributional information (White et al., 2008). Less is known about the way in which adult second language (L2) learners acquire allophonic relationships. The present study investigates the role of a phonological distributional mechanism in a controlled experimental context. We asked whether naïve subjects were able to utilize phonological distributional information to determine whether two phones belong to separate phonemes or a single phoneme. We exposed native English speakers to one of two artificial languages in which two acoustically similar sounds ([b] and [β]) occurred in either overlapping or complementary distribution. After the exposure phase, participants completed an ABX discrimination task. Unexpectedly, participants did not perform differentially on the task depending on their exposure type, failing to provide evidence for the use of a phonological distributional mechanism in adult L2 allophonic acquisition.

INTRODUCTION

When acquiring the phonology of a language, learners must learn not only the contrastive sound categories, but also the positional variants (allophones) associated with those phonemes. Child language acquisition researchers have determined the timeline over which native language (L1) categories are acquired: vowels by 6 months (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 2006), most consonants by 8-10 months (Werker & Tees, 1984), and allophones by about 10-12 months of age (White, Peperkamp, Kirk, & Morgan, 2008). Several learning mechanisms have been identified to account for this rapid native phonological acquisition. Infant learners have been shown to be able to leverage a statistical distributional learning mechanism (Maye, Werker, & Gerken, 2002) as well as various lexical mechanisms, such as distinct visual referents (Yeung & Werker, 2009), and distinct word forms (Feldman, Myers, White, Griffiths, & Morgan, 2013) to support phonetic category learning. A phonological distributional mechanism has also been proposed for the learning of phonological status (Peperkamp, Pettinato, & Dupoux, 2003; Peperkamp, Le Calvez, Nadal, & Dupoux, 2006).

Research on adult L2 learners has also extensively investigated the acquisition of novel phonemic contrasts finding that numerous factors have an influence, including the relationship between L1and L2 phonetic and phonological systems, experience factors including age of acquisition and length of residence, and typological factors, among others (Flege, 1995; Best, 1995; Best & Tyler, 2007; Eckman, 1981). Evidence suggests that statistical distributional and lexical mechanisms may still be available for L2 phonological acquisition (Hayes-Harb, 2007). The present study investigates whether phonological distributional mechanisms, those thought to account for infant acquisition of allophone categories (Peperkamp et al., 2003; Peperkamp et al., 2006; White et al., 2008), may also be available for the acquisition of allophone categories by adult L2 learners.

BACKGROUND

Traditionally phonological theory has made a distinction between two levels of representation—phonemes and allophones—which differ in their phonological distributions. Phonemes occur in overlapping distribution; they occur in the same phonological environments as other phonemes and are, therefore, not predictable by their context. Allophones occur in complementary distribution; different allophones of the same phoneme do not occur in the same phonological environments. Instead, the phonological context conditions which allophone occurs. Categories at each of these levels of representation differ cross-linguistically (e.g. [d] and [ð] map to a single phoneme category in Spanish but to two different categories in English), so both L1 and L2 learners must use information available in their input to learn them. The properties of the input required to do this are not yet determined, although various learning mechanisms have been proposed for native phonological acquisition.

Maye et al. (2002) provided evidence for a statistical distributional learning mechanism—the ability to track the frequency of particular phones in acoustic-phonetic space in order to develop phonemic categories. Lexical mechanisms—the ability to leverage distinct word forms, visual referents, and word-meaning pairs to bootstrap the formation of distinct phonetic categories—can also be used by infant language learners (Yeung & Werker, 2009; Feldman et al., 2013). Others have provided evidence that phonological distributional mechanisms—the ability to track phones with regard to their phonological environment—contribute to word segmentation, parsing, and allophone learning (Saffran, Aslin, & Newport, 1996; Chambers, Onishi, & Fisher, 2003). Importantly, White et al. (2008) provided evidence that infants can use a phonological distributional learning mechanism to group allomorphic alternants into the same category.

Despite the differences that have been noted between L1 and L2 acquisition, evidence suggests that many of the learning mechanisms proposed for child language acquisition may also be available for and leveraged by adults. Hayes-Harb (2007) asked whether adult second language learners were able to use statistical and lexical information to learn a novel phonemic contrast. The results provided evidence that adult learners were able to use information about the acoustic-phonetic distribution of phones to learn novel contrasts. They were also able to use lexical information in the form of distinct visual referents to learn a novel contrast, suggesting that both statistical and lexical learning mechanisms continue to be available in second language phoneme category formation.

Peperkamp et al. (2003, Experiment 2) investigated the role of phonological distributional information (i.e. whether phones occurred in overlapping or complementary distribution), in addition to statistical distributional information (i.e. whether phones occurred in a monomodal or bimodal distribution along some phonetic dimension), on the acquisition of phonemic and allophonic categories. Three groups of adult native French speakers received exposure to an artificially manipulated continuum of the voiced and voiceless uvular fricative [ʁ-χ], a French allophonic alternation, that varied with respect to both the statistical distribution and the phonological distribution. Unexpectedly, the interaction between exposure type and the difference in error rates on an AX discrimination task at the pre- and post-test was not significant. However, only the group exposed to the continuum in bimodal overlapping distribution showed a significant difference between pre-and post-test. The authors interpreted these results as being in line with their hypothesis that category formation is informed by both statistical information and information about the contexts in which individual segments occur.

However, the lack of a significant interaction makes it difficult to draw a definitive conclusion. The surprising results were attributed to a difference between the groups at the pretest, but other factors may have also reduced the likelihood of observing an effect, such as the variability in exposure tokens (i.e. 40 different words per target sound). Additionally, the phones making up the target contrast were related as allophones of the same phoneme in the participants' native language, a factor known to reduce listener sensitivity to a phonetic contrast (Boomershine, Hall, Hume, & Johnson, 2008). Thus, it may be that the exposure phase in the experiment could not override the lifetime of exposure to the alternation that the participants already had, or that any learning that could occur happened during the pre-test.

In another non-lexical perception study (i.e. one that does not require lexical access) investigating the acquisition of allophones by adult learners, Shea and Curtin (2010) asked whether learners are able to acquire knowledge of the relationship between L2 allophones and their phonological environments as they gain experience with the language. They compared four groups of listeners (monolingual English speakers, monolingual Spanish speakers, low-intermediate Spanish learners, high-intermediate Spanish learners) on a stress-detection task to determine whether more advanced learners performed more like native Spanish speakers with regard to expectations about the conditioning context of a Spanish allophonic alternant. In Spanish, voiced stops [b, d, g] alternate with approximants [β, ð, ɣ]; stops occur initially or after a nasal in the onset of a stressed syllable, whereas approximants occur intervocalically and are post-tonic. Like the native Spanish speakers, higher-proficiency Spanish learners showed a preference for associating the stressed syllable with initial stop consonants. Lower-proficiency learners and monolingual English speakers did not show this preference. The authors concluded that increasing experience with a second language results in increasing sensitivity to the factors that condition allophonic alternants, and they attributed this learning to a phonological distributional learning mechanism. However, the learning of this association occurred prior to the experiment, failing to clarify which aspects of their input contributed to this acquisition.

Taken together, although it is compelling to claim that a phonological distributional mechanism remains available for L2 phonological acquisition, no study to date has provided clear evidence that this mechanism is still available for use in adult allophonic acquisition. We attempt to build on this early literature by relying on participants with relatively little experience, controlling their input, and isolating phonological distributional information as an independent variable.

THE PRESENT STUDY

We investigate whether adult second language learners can use phonological distributional information in the absence of lexical-semantic information or explicit instruction to determine whether two phones belong to the same or different underlying categories. To this end, we expose relatively inexperienced listeners to a novel contrast, such that the two target phones occur in either overlapping or complementary distribution. We predict that learners trained on the contrast in overlapping distribution will infer two categories (a phonemic distinction), whereas learners trained on the contrast in complementary distribution will infer that the two phones are related as allophones of a single underlying phoneme category. Perceptually, adult native speakers are less sensitive to the phonetic distinction between allophones of the same phoneme (Whalen, Best, & Irwin, 1997; Boomershine, et al., 2008) than to allophones of separate phoneme categories, so we expect participants in the complementary exposure group category to perform less accurately on an ABX task than those in the overlapping exposure group. The ABX task was selected because it can be completed by participants who are naïve with respect to the tested language, yet it is typically assumed to tap into a more phonological level of representation than does the AX task used by Peperkamp et al. (2007).

Participants

Participants were 40 native English speakers (M = 12 F = 27 Other gender = 1) between the age of 17-52 years old (mean = 24.15) recruited at the University of Utah from the Salt Lake City area. Participants had studied Spanish for no more than one year, and they had no history of hearing, developmental, or neurological disorders. They were randomly assigned to one of two exposure groups: Complementary group (n = 20, M = 8 F = 11 Other gender = 1, mean age = 23.5) or Overlapping group (n = 20, M = 4 F = 16, mean age = 24.6). Participants were either compensated $10 for their time or received course credit for their participation.

Stimuli

The stimuli were natural recordings produced by a Spanish-English bilingual with phonetic training. Each non-word stimulus (see Figure 1) was produced in the carrier phrase *Diga la/una __________, por favor (*Say the/a _________, please*).* An acoustic analysis of the intensity ratios, a measure of degree of consonant constriction, was made for each production of the target phones [b] and [β] following Carrasco, Hualde, and Simonet (2012) to ensure there was indeed an acoustic distinction to learn (mean [β] intensity ratio = 82.26, mean [b] intensity ratio = 60.08, consistent with greater constriction for [b] than [β]). Four tokens of each stimulus type were selected for the task. The target sounds occurred in a syllable with [a] and the target syllable was either preceded or followed by [ti] and [ku]. While this is much less variability than typical of the real world, this was a conscious choice to reduce variability in other syllable types, given that Peperkamp et al. (2003) suggested the variability of their exposure tokens may have introduced unwanted noise in their study. Stress was controlled such that all stimuli had penultimate stress. The overlapping exposure condition contained [b] and [β] in both initial and medial position, whereas in the complementary condition [b] was restricted to initial position and [β] to medial position. Because the complementary exposure tokens were a subset of those used for overlapping exposure, each of the target nonwords in the complementary exposure condition was played twice as frequently to ensure both groups receive exposure phases of equal length. Control stimuli were identical to the target nonwords except the target contrast was replaced with a native contrast, [m-l]. The distribution of [m] and [l] was not constrained for either exposure group; both groups were exposed to tokens containing [m] and [l] in both initial and medial position. A summary of the stimuli is provided in Figure 1.

Complementary

		initial	medial
Experimental contrast	[b]	bati	
		baku	
	[β]		tiβa
			kuβa
Control contrast	[m]	mati	tima
		maku	kuma
	[l]	lati	tila
		laku	kula

Overlapping

		initial	medial
Experimental contrast	[b]	bati	tiba
		baku	kuba
	[β]	βati	tiβa
		βaku	kuβa
Control contrast	[m]	mati	tima
		maku	kuma
	[l]	lati	tila
		laku	kula

Figure 1. Stimuli heard in each exposure group.

Procedure

The experiment consisted of two parts: an exposure phase and a test phase.

Exposure phase

During the exposure phase participants heard 768 auditory tokens (12 randomized blocks x 4 tokens x 16 words) separated by an ISI of 500 ms. Participants were instructed to listen and check a box on the sheet provided each time they heard a word. The exposure lasted approximately 16 minutes.

Test phase

The test phase consisted of an ABX discrimination task in which the participant indicated whether the third sound was the same as the first or the second. Each token (4 tokens x 16 words = 64 trials) appeared as X; in each trial, the three words were all physically different tokens. Trials were counterbalanced for A and B matches and were presented in a random order for each participant. The test was divided into two blocks of 32 trials. Test items were separated by an ISI of 500 ms and trials timed out at 2500 ms.[1]

RESULTS

Two analyses were conducted. For the first, the dependent measure was mean proportion correct, and for the second, the dependent measure was d-prime score.

[1] Although the complementary distribution group was exposed to only [b] initially and [β] medially during the exposure phase, due to the nature of an ABX task, during the test phase they received input to each target token in the "wrong" position. For example, in trial [bati] – [βati] – [βati], participants were exposed to two instances of initial [β]. We ensured that the ratio of "wrong" test items to "right" training items remained low (9%). This concern informed the duration of the exposure phase as well as the number of trials in the test phase.

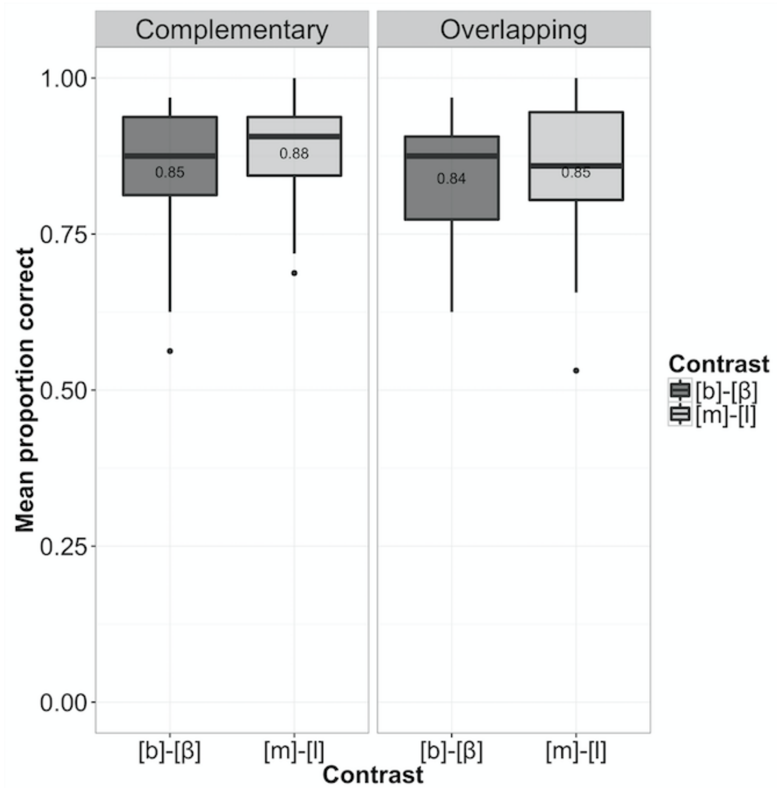

Figure 2. Boxplot of Mean Proportion Correct by Exposure Group and Contrast. Superimposed text represents group means.

As seen in Figure 2, the mean proportion correct for the complementary exposure group was 0.85 for the target contrast and 0.88 for the control contrast. For the overlapping exposure group, mean proportion correct for the target contrast was 0.84 and for the control contrast was 0.85. A two-factor mixed-design ANOVA was conducted with exposure group as the between-subjects factor (two levels: complementary and overlapping) and contrast as the within-subjects factor (two levels: [b- β] and [m-l]). There was no significant main effect of exposure group $F(1, 38) = 0.498$, $p = 0.484$ or of contrast $F(1, 38) = 2.791$, $p = 0.103$. Crucially, there was no significant interaction between group and contrast $F(1, 38) = 0.112$, $p = 0.740$, indicating that the two groups did not differ from one another in their performance on the [b-β] contrast.

In addition to considering the mean proportion correct, d' scores were also computed and submitted to statistical analysis. D-prime is a measure of sensitivity that factors out individual response bias.

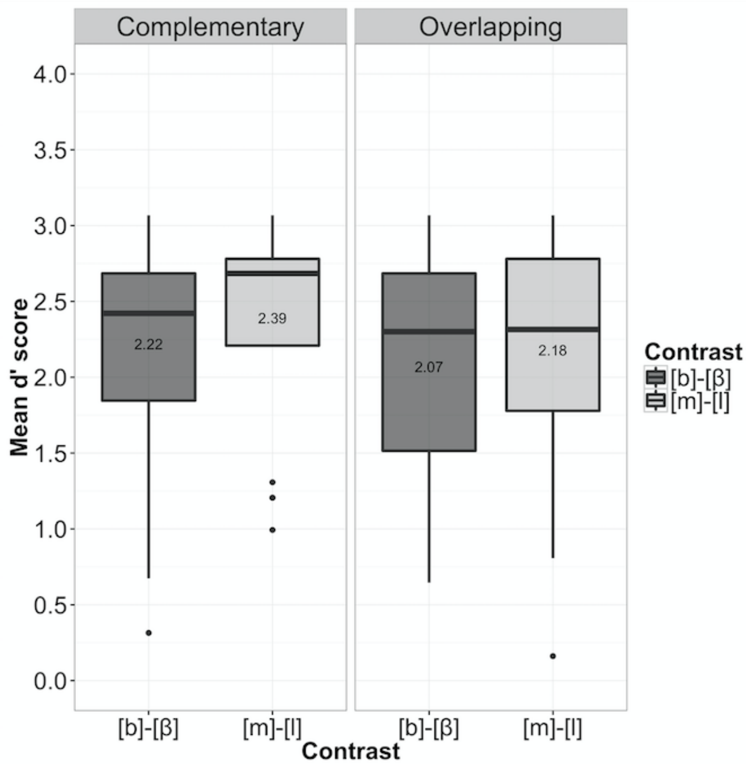

Figure 3. Boxplot of D-Prime Scores by Exposure Group and Contrast. Superimposed text represent group means.

As seen in Figure 3, the mean d' score for the complementary group was 2.22 for the target contrast and 2.39 for the control contrast. For the overlapping group, mean d' score for the target contrast was 2.07 and for the control contrast was 2.18. A second two-factor mixed-design ANOVA was performed. Again, there was no significant main effect of exposure group $F(1, 38) = 0.698$, $p = 0.409$ or of contrast $F(1, 38) = 2.754$, $p = 0.105$, and there was no interaction of group and contrast $F(1, 38) = 0.140$, $p = 0.710$.

DISCUSSION

This study investigated the role of phonological distributional information in adult L2 phonological acquisition. We asked whether participants exposed to a novel phonetic contrast [b-β] in either complementary or overlapping phonological distribution performed differentially on an ABX task following the exposure. Unexpectedly, we observed no difference in the two groups' performance on the [b-β] contrast, suggesting that participants were not able to use phonological distributional information alone to determine whether the two phones were allophones of the same phoneme or whether they were different phonemes. These results are consistent with those of Peperkamp et al. (2003), suggesting that perhaps, at least under these constrained laboratory conditions, a phonological distributional mechanism alone may be insufficient for adult learners to infer the phonological status of a novel pair of phones.

We attempted to build on earlier work by controlling for previous input regarding the novel phones, using a measure of perception that relies on higher levels of phonological representation, and isolating the variable of phonological distributional information as a potential contributor to the acquisition of a novel allophonic alternation. Previous research (i.e. Peperkamp et al., 2003; Shea & Curtin, 2010) used stimuli created by splicing allophones produced in their conditioned contexts into phonotactically illegal contexts, while the stimuli in this study were naturally produced in illegal contexts. This solution may have eliminated extraneous cues introduced by cross-splicing. However, it also had limitations, such as the difficulty of producing phones in unnatural positions and the necessity of ensuring that productions in illegal contexts were produced with similar intensity ratios as those in legal contexts. The stimuli were chosen based on a phonetic analysis of the intensity ratio between the target consonant and the following vowel [a] as well as the presence/absence of a burst. Carrasco et al. (2012) showed that there is a bimodal distribution of the intensity ratios of [b] and [β] in both Madrid and Costa Rican Spanish, so we sought to verify that a similar distribution was present in our stimuli. However, some research suggests that allophones are not only perceived as more similar than contrastive phones, but that they are also produced more similarly in languages for which they are allophonic than they are in languages for which they are phonemic (see e.g., Seidl & Cristia, 2012). It is possible that we artificially enhanced the statistical distribution of these phones due to this analysis.

The task used in this experiment was carefully considered, as the foundational literature in L2 allophone acquisition is relatively sparse. Shea and Curtin (2010) successfully showed gains in allophonic knowledge of learners using a metalinguistic task that demonstrated understanding of allophones with respect to their conditioning contexts. Because we asked a different question—whether learners could make use of phonological distributional information to group phones as allophones of a single phoneme category—we chose a different task. Using a task that relied on the perceptual correlates of phonemes and allophones as a measure was a less metalinguistic way of detecting early knowledge about phonological status. This task also had limitations, such as the necessity of including tokens that one of the groups did not hear during the exposure phase in the test and the possibility that phonological status could be "unlearned" through this conflicting evidence. It is also possible that participants used an acoustic strategy, such as treating B and X as an AX task and ignoring A altogether, a possibility that could be effectively eliminated by using more than one talker to produce stimuli in future research.

At the same time, the null effects may have been caused by an unexpected pattern of perceptual assimilation. The alternation was chosen to be maximally similar to Shea and Curtin (2010), who looked at the entire natural class that undergoes this alternation in Spanish, /b,d,g/. We considered the alternation [g]-[ɣ] because it would likely result in a same-category assimilation in English (Best, 1995), but we were concerned about the perceptual salience of this distinction. Additionally, an acoustic analysis of intensity ratios found that these phones are monomodally, as opposed to bimodally, distributed in Spanish (Carrasco et al., 2012). We avoided the third pair [d]-[ð] because they are contrastive in English. English does not have a category /β/, so the study was designed as if participants would hear one familiar sound /b/ and another that was also assimilated to /b/ but may have been a poorer exemplar of the category. However, pilot studies indicated that [β] was frequently assimilated to the category /v/ by English speakers. It could be that this two-category assimilation (Best, 1995) blocked distributional learning during the short exposure period. While we strategically chose a pair that contained one familiar and one unfamiliar phone for English speakers, it is worth noting that the L1 English L2 learner of Spanish would be required to master all of these assimilation patterns.

Moreover, although earlier studies have shown that infants can learn from distributional information with as few as two minutes of exposure (Saffran et al., 1996) and adults with as few as nine (Hayes-Harb, 2007; Peperkamp et al., 2003), it is also possible that a longer exposure period may be required to learn this particular alternation or allophonic alternations in general.

Finally, we would have ideally used participants who were completely naïve to Spanish, but it proved challenging to find participants without Spanish experience in the Salt Lake City area. It is possible that informal and/or limited formal exposure to Spanish (which was not controlled for in this study) provided prior input from which participants could have learned about the alternation.

This study attempted to tightly control many variables that researchers noted may have contributed statistical noise in their studies and masked small but reliable effects from being detected. Despite these modifications, we failed to find support for the hypothesis that adult second language learners are able to use phonological distributional information alone to learn that two phones are related as allophones of the same phoneme. Nevertheless, there is much to build upon. For future research, other ways of selecting stimulus tokens should be considered and other contrasts should be investigated. Alternations from other languages may be better when a large number of participants in an area speaks Spanish as an L2. Despite the null results, the role of phonological distributional information is an important area of research in which study should continue in order to deepen our understanding of adult second language phonological acquisition.

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