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Artificial language learning and feature-based generalization

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ABSTRACT

Abstract representations such as subsegmental phonological features play such a vital role in explanations of phonological processes that many assume that these representations play an equally prominent role in the learning process. This assumption is tested in three artificial grammar experiments involving a mini language with morpho-phonological alternations based on back vowel harmony. In Experiments 1 and 2, adult participants were trained using positive data from four vowels in a six-vowel inventory: the two remaining vowels appeared at test only. If participants use subsegmental phonological features and natural classes for learning, they should generalize to the novel test segments. Results support a subsegmental feature-based learning strategy that makes use of phonetic information and knowledge of phonological principles. A third experiment (Experiment 3) tests for generalizations to novel suffixes, providing further evidence for the generality of learning.

Introduction

The generative approach to the study of phonological representations has traditionally taken phonemic distributions and phonological alternations to be the primary sources for understanding the nature of phonological representations and how they might be acquired. Abstract theoretical constructs, such as subsegmental phonological features (Chomsky & Halle, 1968), segmental and autosegmental features (Clements, 1985; Clements & Hume, 1995; Goldsmith, 1975; McCarthy, 1988; Sagey, 1986), and the hierarchical structure of syllables (Hayes, 1995), serve to explain the patterns of phonological data found in the world's languages. Further, abstract phonological features are necessary to capture even the most phonetically unnatural processes (Anderson, 1981). While the bulk of phonological theory has assumed that mental representations of phonemic segments consist of sets of subsegmental phonological features, there has been some debate regarding the nature of these abstract representations. For example, the traditional generative approach to phonology cannot handle 'performance' factors such as frequency and fine-grained phonetic details (Pierrehumbert, 2001, 2002, 2003). This concern has led some phonologists to adopt exemplar models of language in which subsegmental phonological features are no longer primitives for explaining phonological patterns (Johnson, 1997; Pierrehumbert, 2001). Rather, each individual utterance encountered by the language user (through perception and production) is stored as a memory trace and contains all perceptible fine-grained phonetic and contextual details of that utterance. Phonological categories are formed when similar sounding exemplars are mapped onto overlapping areas of acoustic and perceptual space. Novel instances of a category are recognized based on the similarity to existing exemplars (Goldinger, 1996, 1998; Hintzman, 1986; Nosofsky, 1986, 1988). Because each individual experience with a word or sound is stored as its own exemplar, frequency and context are automatically encoded (Johnson, 1997, 2005; Kirchner, 2004; Nosofsky, 1986, 1988; Pierrehumbert, 2001, 2003; Port & Leary, 2005). While exemplar models are not incompatible with abstract representations and subsegmental phonological features (Kruschke, 1992; Pierrehumbert, 2002), typical exemplar-based analyses of phonological processes only require segment-level categories (Ettlinger, 2007; Johnson, 1997; Wedel, 2006),

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supra-segmental categories (Coleman & Pierrehumbert, 1997; Frisch, Large, & Pisoni, 2000) or representations of the phonetic similarity of segments (Luce, Goldinger, Auer, & Vitevitch, 2000). Thus, it is important to understand the ways in which abstract representations play a role in phonological processes.

Exemplar theory in its current state of formulation is uncommitted to the specific types and degree of abstraction that bias a learner (e.g., syllable span, consonant cluster, segment or subsegmental feature) (Tenpenny, 1995). In contrast, generative theories of phonology require abstract segmental and subsegmental representations and postulate that these representations are available to the language learner. One promising approach to testing the availability of abstract levels of representation during language learning is through the artificial grammar learning paradigm, in which it is possible to test whether learners generalize to novel segments outside the training space.

The robust finding that both adults and young children can extract regularities presented in artificial 'mini-languages' in a relatively short time with little or no explicit instruction has opened new doors for asking questions about the language faculty and the nature of language itself (Aslin, Saffran, & Newport, 1997; Berent, Steriade, Lennertz, & Vaknin, 2007; Chambers, Onishi, & Fisher, 2003; Gomez & Gerken, 1999, 2000, 2002; Gomez & Lakusta, 2004; Guest, Dell, & Cole, 2000; Kersten & Earles, 2001; Moreton, 2008; Pater & Tessier, 2005; Pena, Bonatti, Nespor, & Mehler, 2002; Peperkamp, Skoruppa, & Dupoux, 2006; Pycha, Nowak, Shin, & Shosted, 2003; Saffran, 2003; Saffran, Aslin, & Newport, 1996; Saffran, Newport, Aslin, Tunick, & Barrueco, 1997; Tessier, 2006; Wilson, 2003, 2006). The experiments presented here probe the representational commitments of different theories of language learning by using the poverty of the stimulus method for artificial language learning (Wilson, 2006). This method involves a test phase that includes items heard at training, novel items (that include all the same segments heard in training), and items containing novel segments (not heard during training). If learners make use of feature-based representations during learning, then they should generalize to novel segments; if they learn at the segment level, they should not generalize to novel segment types. If learning is purely item-specific, then no generalization beyond the training items is expected. Our experiments make use of a pseudo-morphophonological alternation related to vowel harmony to test these different proposals.

Vowel harmony

The experiments presented in this paper use vowel harmony as a case study. Vowel harmony is a process that compels vowels to agree along particular articulatory phonetic dimensions (e.g., back, round, etc.), and therefore creates strong tendencies for co-occurrence of particular vowels across lexical items (e.g., in back vowel harmony, there are many lexical items containing both [i] and [e] but few if any lexical items containing both [i] and [o]). Vowel harmony is a good phonological process for testing the level of generalization to novel segments because this process can involve all major phonological features: round, back, high and, tense (van der Hulst & van de Weijer, 1995). If learners are able to use natural classes in a vowel harmony situation, then it is likely that they will use natural classes in other rules that they learn, supporting theories of phonological learning and processing that appeal to subsegmental structure (see Goldrick (2002) for an overview of theories of phonological processing).

To make these issues more concrete, consider a hypothetical language with front/back vowel harmony in which front vowels [i, e, æ] trigger the front vowel suffix [-mi] (e.g., [bæge-mi]; [nibe-mi]), and back vowels [u, o, a] trigger the back vowel suffix [-mu] (e.g., [dapa-mu]; [bano-mu]). If the learner is exposed only to non-low vowels [i, e, u, o], different theories of learning make contrasting predictions as to whether the learner will treat low vowels, which they have never heard before, as harmony triggers (i.e., prefer [-mi] for [bægæ], but [-mu] for [bano]). We begin by comparing three learning hypotheses that differ in their approach to rule formulation when the learning data is systematically incomplete in this way. For expository reasons, we will refer to these as the Segment-Based Learning Hypothesis, the Feature-Based Learning Hypothesis, and the Interpolation-Based Learning Hypothesis.

(1) *Segment-Based Learning Hypothesis*: Learners formulate generalizations based entirely on the behavior of specific, familiar segments. This allows them to formulate segment-based generalizations, but they should not extend their generalization to novel segments.

$$\text{Harmony Rule}: V \rightarrow [i]/\{i, e\}C\_\_\_$$
$$V \rightarrow [u]/\{u, o\}C\_\_\_$$

A vowel becomes [i] following the vowels {i, e}, and [u] following the vowels {u, o}.

(2) *Subsegmental Feature-Based Learning Hypothesis*: Learners posit the most general pattern that fits the data based on the representational resources that are provided by subsegmental features. As long as novel segments fit into this highly general rule, the learner will generalize to novel segments.

$$\text{Harmony Rule}: V \rightarrow [\text{BACK}]/[\text{BACK}]C\_\_\_$$

A vowel becomes back following a back vowel.

(3) *Interpolation-Based Learning Hypothesis:* Learners infer that novel exemplars undergo harmony if they fall within the range of acoustic space of prior exemplars shown to undergo harmony (e.g., interpolate mid vowel participators from high and low vowel exposure).

These three hypotheses make different predictions about whether a learner will generalize vowel harmony to segments that they have never heard before. The Segment-Based Learning Hypothesis predicts no generalization