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Infants' sensitivity to vowel harmony and its role in segmenting speech

Toben H. Mintz[a,b,*], Rachel L. Walker[b], Ashlee Welday[a,1], Celeste Kidd[b,2]

[a] Department of Psychology, University of Southern California, United States
[b] Department of Linguistics, University of Southern California, United States

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ABSTRACT

A critical part of infants' ability to acquire any language involves segmenting continuous speech input into discrete word forms. Certain properties of words could provide infants with reliable cues to word boundaries. Here we investigate the potential utility of vowel harmony (VH), a phonological property whereby vowels within a word systematically exhibit similarity ("harmony") for some aspect of the way they are pronounced. We present evidence that infants with no experience of VH in their native language nevertheless actively use these patterns to generate hypotheses about where words begin and end in the speech stream. In two sets of experiments, we exposed infants learning English, a language without VH, to a continuous speech stream in which the only systematic patterns available to be used as cues to word boundaries came from syllable sequences that showed VH or those that showed vowel disharmony (dissimilarity). After hearing less than one minute of the streams, infants showed evidence of sensitivity to VH cues. These results suggest that infants have an experience-independent sensitivity to VH, and are predisposed to segment speech according to harmony patterns. We also found that when the VH patterns were more subtle (Experiment 2), infants required more exposure to the speech stream before they segmented based on VH, consistent with previous work on infants' preferences relating to processing load. Our findings evidence a previously unknown mechanism by which infants could discover the words of their language, and they shed light on the perceptual mechanisms that might be responsible for the emergence of vowel harmony as an organizing principle for the sound structure of words in many languages.

1. Introduction

A fundamental problem that infants face from the earliest stages of language acquisition is identifying the sequences of sounds that are the words in their language. Pauses are poor predictors of lexical boundaries in continuous speech. Thus, infants must rely on other cues to identify beginnings and ends of words. Cues that have been identified include word stress (Curtin, Mintz, & Christiansen, 2005; Johnson & Jusczyk, 2001; Thiessen & Saffran, 2003), transitional probabilities between syllables (Aslin, Saffran, & Newport, 1998; Saffran, Aslin, & Newport, 1996; Thiessen & Saffran, 2003), and phonotactic cues involving representations of sound sequences that are more or less likely to occur at word boundaries (Mattys & Jusczyk, 2001; Mattys, Jusczyk, Luce, & Morgan, 1999). Both within a language and across languages, none of these cues alone is guaranteed to identify word boundaries. Hence, infants must make use of a number of probabilistic cues to segment words from fluent speech.

Here we present research concerning perceptual biases that could aid infants in segmenting continuous speech into words. Specifically, we present evidence that infants are sensitive to *vowel harmony*, a property of many languages whereby vowels within a word systematically exhibit similarity (or "harmony") for some aspect of the way they are pronounced. For example, in a language with vowel harmony for the property of lip rounding, within a word, all vowels are either produced with rounded lips (e.g., [u, o]) or with unrounded lips (e.g., [i, e]), but these two vowel types are never combined. Our research shows that 7-month-old infants learning English are sensitive to vowel harmony patterns, even though English does not exhibit vowel harmony. Our experiments demonstrate that infants segment words from continuous speech at locations where harmony patterns are disrupted. Since the infants in our study were never exposed to a natural language with vowel harmony, they never experienced the correlation of disruptions in harmony patterns with word boundaries, yet they segmented speech at junctures of disharmony. Our findings, thus, contribute to two important issues in language development. First, our finding of a previously unknown capability of human infants to rapidly

* Corresponding author at: Department of Psychology, University Park Campus, SGM 501, University of Southern California, Los Angeles, CA 90089-1061, United States.
E-mail address: tmintz@usc.edu (T.H. Mintz).
[1] Present address: Social Thinking Stevens Creek, San Jose, CA, United States.
[2] Present address: Department of Brain and Cognitive Sciences, University of Rochester, United States.

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detect vowel harmony patterns contributes to our understanding of the perceptual and representational capacities that could be a basis for human language learning. Second, our finding that infants use harmony patterns to extract words from continuous speech contributes to our understanding of the mechanisms by which infants can discover the fundamental building blocks of language: the words.

Before presenting our experiments and findings, we first provide a conceptual outline describing how a sensitivity to vowel harmony could be useful for word segmentation in infants, and how such a sensitivity might change with experience with a specific language or languages. We also provide a more in depth discussion of the typological and acoustic aspects of vowel harmony.

1.1. Vowel harmony and its potential role in infant word segmentation

Vowel harmony phenomena are widely attested in many of the world's major language families, including the Uralic languages (e.g., Finnish, Hungarian,), the Altaic languages (e.g., Mongolian, Turkish), the Niger-Congo languages (e.g., Kikongo, Swahili, Yoruba), and the Nilo-Saharan languages (e.g., Maasai, Turkana). Yet, languages vary in the specific kinds of harmony constraints they impose. For instance, Turkish exhibits vowel harmony for the front/back dimension, in which 'front' and 'back' refer to the generalized relative anteriority of the highest point of the tongue during production of different vowels. In Turkish, the vowels in a word are either all front vowels ([i, y, e, ø]) or all back vowels ([u, ɯ, o, a]) (although loanwords may be disharmonic). Turkish also displays vowel harmony for the property of lip rounding, preventing certain intra-word combinations of round and unround vowels. In contrast, Swahili shows restrictions that involve harmony for the dimension of peak tongue height in vowels. In Swahili, forms of verbal suffixes containing a mid vowel [e] are selected following a syllable with a mid vowel ([e] or [o]); elsewhere forms of these suffixes containing the high vowel [i] are selected.

These generalized articulatory dimensions of vowels can be equated to acoustic properties of their sound waves. The sound wave for each vowel is characterized by resonant frequencies of its vocal tract configuration, known as formants. Shifts in the height dimension are reflected in the frequency of the first formant, in the backness dimension in the frequency of the second formant, and in the rounding dimension chiefly in the frequency of the second and third formants. Thus, adjacent syllables that exhibit some form of vowel harmony will have similar spectral properties due to their acoustic-phonetic realization. In principle, such similarities could constitute a perceptual basis for infants to treat adjacent syllables as a unit when segmenting speech.

Thus, vowel harmony patterns result in both phonological and acoustic similarities between syllables within a word,[3] which provides a powerful cue that a learner could exploit to segment speech into words: Learners could posit a boundary when they notice *disharmony* in the vowels of adjacent syllables, i.e. when the vowels differ in a particular aspect of their pronunciation. Indeed, research on adult speakers of languages with vowel harmony has shown that they actively use disharmony as a cue to word boundaries (Suomi, McQueen, & Cutler, 1997; Vroomen, Tuomainen, & de Gelder, 1998).

1.2. Vowel harmony and the role of language experience

Studies have shown that adult native speakers of languages that lack vowel harmony rules do not use disharmony as a cue to word boundaries (Vroomen et al., 1998), so adults' linguistic background clearly influences how they treat harmony patterns. Moreover, the fact that languages differ on the particular set of vowel harmony restrictions they implement, and indeed whether they implement vowel harmony restrictions at all, means that some aspects of harmony must be learned through experience, and there is evidence that this experience has an effect early on in development. For example, children acquiring a harmony languages show productive mastery of its harmony system by the time they start to combine words, generally before two years of age (Ketrez & Aksu Koç, 2003). Infants acquiring a harmony language show a sensitivity to the patterns as early as 6 months (Altan, Kaya, & Hohenberger, 2016; Hohenberger, Kaya, & Altan, 2017; van Kampen, Parmaksiz, van de Vijver, & Höhle, 2007).

Yet learning could occur in several computationally distinct ways. One possibility is that infants need to learn a sufficiently large number of word forms and then detect the consistent patterns that regularly occur. Another possibility is that infants are predisposed to attend to harmony patterns. On this alternative, the development of vowel harmony might be parallel to the development speech sound categories. From birth, infants can discriminate virtually all the speech sounds that serve as distinctive in any of the world's languages; experience narrows down and refines those representations to the ones relevant to the infant's linguistic environment (Eimas, Siqueland, Jusczyk, & Vigorito, 1971; Kuhl, 1979; Streeter, 1976; Werker & Lalonde, 1988; Werker & Tees, 1992). Infants may be inherently sensitive to harmony patterns and learn those patterns when they are present in their natural language input, but they may lose that sensitivity over development. If infants are predisposed to detect harmony patterns, they could also use vowel harmony as a source of information for segmenting words from continuous speech.

In our study, we ask whether English learning 7-month-olds who have had no experience with a vowel harmony language nevertheless use harmony patterns as a segmentation cue when the patterns are present. If they do, it demonstrates that infants learning a harmony language could detect word boundaries from vowel harmony patterns without building a prior lexicon (even a very small one) in which words conform to vowel harmony constraints. More broadly, such a finding would indicate that detecting and using harmony patterns in processing speech relies on mechanisms that do not require extensive exposure to a harmony language, but rather are available to all young infants.

To test this, we exposed infants to a continuous sequence of syllables that consisted of stretches with harmonizing vowels ("words") punctuated by points of disharmony (at "word" boundaries). We hypothesized that if infants treat vowel harmony as a linguistically significant property of the speech input, they should parse the harmonizing sequences as cohesive units upon hearing the continuous syllable stream, treating the junctures of disharmony as boundary points between units. That is, we hypothesize that infants would treat the harmonizing sequences as proto-word forms. We tested this by probing whether, after hearing the continuous speech stream, infants showed a systematic difference in their attention to syllable sequences that corresponded to the words compared to sequences of adjacent syllables that contained a word boundary, which we call part-words.

Since infants' linguistic experience has given them no evidence of an association between vowel harmony and word forms, if they parse the continuous speech stream into sequences that adhere to the harmony constraints, it would indicate that infants have an experience-independent sensitivity to vowel harmony patterns. It would further demonstrate that infants can use vowel harmony cues, when available, to detect word boundaries in fluent speech. We note, however, that this experiment—as many others that have investigated other segmentation cues (e.g., Aslin et al., 1998; Curtin et al., 2005; Mattys & Jusczyk, 2001; Saffran et al., 1996)—addresses the question of *segmentation* of sequences from fluent speech. When we refer to these segmented sequences as 'words,' we mean that they are word-sized units segmented from the continuous speech stream, not that infants have necessarily created a kind of lexical entry for them (Graf Estes, Evans, Alibali, & Saffran, 2007).

As the first step in this investigation, we describe a set of experiments that assess 7-month-old infants' response to the simplest form of

[3] Some cases are attested where harmony operates in domains that are larger than the word.

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