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Phonetic Motivation as a Learning Bias

in Phonological Acquisition:

An Experimental Study

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Table of Contents

Section 1: Introduction.....	1
1.0 Introduction	1
1.1 Phonetic Motivation and Phonology	2
1.2 Phonetic Motivation and Acquisition.....	3
1.3 Phonetic Motivation and Acquisition by 4.5- and 10.5-Month-Olds	7
Section 2: Experimental Procedure.....	12
2.1 Subjects	12
2.2 Stimuli	12
2.3 Method.....	14
Section 3: Results.....	18
3.1 Results for Partial and Completed Experiments.....	19
3.1.1 Combined Results	19
3.1.2 Results for 4.5-Month-Olds	21
3.1.3 Results for 10.5-Month-Olds	24
3.2 Inclusion of Partial Data in the Analysis	28
3.3 Inclusion of Results from Bi-/Multilingual Infants	28
Section 4: Discussion.....	31
4.1 Interpretation of Primary Results.....	31
4.2 Possible Objections to Interpretation of Results: Data Level.....	33
4.3 Possible Objections to Interpretation of Results: Theoretical Level	34

4.4 Possible Objections to Interpretation of Results: Stimulus Level	36
4.5 A Contradictory Result in the Literature: Seidl & Buckley (2005)	38
4.6 Conclusion	38
Appendix A: Stimulus Blocks	40
Appendix B: Phonotactic Probabilities of Stimuli	41
Appendix C: Anomalous Trials	47
Works Cited	48

List of Figures and Tables

Figure 1: Headturn Preference Procedure Setup.....	16
Figure 2: Mean Looking Times ($\pm SE$) by Block and Condition for 4.5-Month-Olds	22
Figure 3: Mean Looking Times ($\pm SE$) by Initial Test Condition for 4.5-Month-Olds	23
Figure 4: Mean Looking Times ($\pm SE$) by Block and Condition for 10.5-Month-Olds	26
Figure 5: Mean Looking Times ($\pm SE$) by Initial Test Condition for 10.5-Month-Olds	27
Table 1: Analysis of Variance for Infant Looking Times.....	19
Table 2: Differences Between Blocks.....	20
Table 3: Z-Scores	20
Table 4: Analysis of Variance for 4.5-Month-Old Looking Times	21
Table 5: Motivated vs. Unmotivated Condition 4.5-Month-Old Looking Times	23
Table 6: Analysis of Variance for 10.5-Month-Old Looking Times	25
Table 7: T-Tests of Motivated vs. Unmotivated Condition 10.5-Month-Old Looking Times	27
Table 8: Reported Non-English Language Exposure in Hours per Week	29
Table 9: Condition Preference by Initial Test Condition.....	31
Table 10: Stimulus Phonotactic Probabilities	34

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Section 1: Introduction

1.0 Introduction

For over a decade, linguists have debated what *a priori* phonological knowledge infants bring to bear on the language learning task. Studying children's production only sheds light on their grammars after they have made enough progress in learning a language to have adopted quite a bit of the language's phonology, thereby altering their knowledge base significantly. To learn about their *a priori* state, it is therefore necessary to study infants at a much younger age by inferring their phonological preferences from their reactions to different phonological phenomena.

In the study presented here, 12 4.5-month-olds and 6 10.5-month-olds were exposed to stimuli exhibiting two phonological patterns, one with intervocalic voicing (a phonetically motivated pattern) and one with intervocalic devoicing (a phonetically unmotivated pattern), with no initial learning phase. The infants' looking times to the different stimuli were monitored to determine which pattern they preferred without prior familiarization. The 4.5-month-olds preferred the typologically common and phonetically motivated pattern of intervocalic voicing, while the 10.5-month-olds showed a preference for the unmotivated pattern. These results are interpreted as supporting evidence for Wilson's (2006) proposed framework of substantively-biased phonology. This hypothesis posits that there is a language-independent bias predisposing the learner toward phonetically motivated phonological patterns over those without such motivation, and further suggests that the effects of this bias emerge when the learner is given extremely minimal data from which to make generalizations.

1.1 Phonetic Motivation and Phonology

Though the field of phonology has long operated more or less separately from that of phonetics, recently many phonologists (and phoneticians) have come to believe that phonological theory can be carried out much more elegantly when principles of phonetic motivation are taken into account, specifically considerations of ease of articulation and ease of perception (e.g., Jun, 1995; Hayes, 1999, 2004; Steriade, 2001a,b; Hayes & Steriade, 2004). Phonological processes motivated by ease of perception would have as their goal a greater perceptual distinction between contrasting elements in a phonological form, to make identification of the form easier for the listener. Processes motivated by ease of articulation would result in outputs that require less overall effort on the part of the speaker to produce; i.e., they require a smaller degree of change in the position or movement of the articulators from segment to segment, or even within segments.

These two phonetic aims are often in competition with one another: when less effort is spent driving the articulators to distinct positions and locations, the result is a decline in perceptual and physical distinctness between adjacent segments, whereas more exaggerated—and hence distinctive—production of a segment requires greater energy expenditure to move the articulators precisely and quickly (Lindblom, 1983; Saltzman & Kelso, 1987; Saltzman & Munhall, 1989; Ohala, 1997; Kirchner, 2001). Current phonological theory is easily able to deal with this opposition, however, especially the theoretical framework of Optimality Theory, which has as its foundation the idea that different—and often conflicting—constraints are in competition with each other, but ranked or prioritized in such a way so as to pick the output for a particular form that best

fits the overall goals of the grammar. The two main types of constraints found in Optimality Theory can be thought of as roughly corresponding to the two main phonetic considerations: faithfulness constraints, which demand that output forms match their corresponding input forms in various ways, are similar to the phonetic principle of ease of perception, as these constraints drive output forms to retain all distinctions present in the input forms. Markedness constraints, on the other hand, match up to the principle of ease of articulation, as they forbid the appearance of infelicitous segments or sequences of segments in particular positions in a form; if ranked high enough, a markedness constraint can even prohibit a segment or sequence from surfacing anywhere in the language.

1.2 Phonetic Motivation and Acquisition

Determining precisely what effect the two principles of phonetic motivation have on the phonology of human languages is a difficult question. Due to the development of more and more sophisticated methods (e.g. Kemler Nelson et al., 1995), investigators can now explore what role these principles might play in the early stages of phonological acquisition. During the first year of life, pre-linguistic infants¹ lay the groundwork for the acquisition of the phonological patterns allowed and disallowed by their native language. These patterns include phoneme categorization (Aslin et al., 1981; Werker & Tees, 1984; Best et al., 1988; Werker & Lalonde, 1988; Kuhl et al., 1992), stress patterns (Jusczyk et al., 1993a), and phonotactic restrictions (Jusczyk et al., 1993b, 1994; Bosch & Sebastián-Gallés, 1997).

¹ I.e., those who have not yet progressed to the one-word stage.

Many researchers have proposed that patterns which are easier for infants to learn are more likely to be prevalent in language typology (for example, Bever, 1970; Newport, 1982; Christiansen & Devlin, 1997; Ellefson & Christiansen, 2000; Saffran, 2002). If many of the most common phonological processes in the world's languages can be explained by factors of phonetic motivation (e.g., Hayes, 1999), the processes so motivated might be generally easier for infants to learn than their unmotivated counterparts (e.g., Tesar & Smolensky, 1993, 2000; McCarthy & Prince, 1995), thus directly affecting a language's synchronic phonology.² On the other hand, proponents of evolutionary phonology (see e.g. Blevins, 2004) would disagree with the theory that phonetic motivation has a measurable effect on phonological acquisition by an individual; rather, they would claim that it gradually influences the diachronic changes³ that shape a language's phonology.

Of course, it is not possible to test pre-linguistic infants' learning capabilities by eliciting judgments on possible words or repetitions of memorized forms. However, it is possible to access the infants' knowledge about what they have learned indirectly, by monitoring their attention to lists of linguistic forms. Hunter & Ames' (1988) analysis of infant reactions to various bodies of stimuli in various experimental conditions confirmed that infants' reactions to auditory stimuli can be inferred from their reactions to simultaneous visual stimuli. Depending on three main factors (infant age, difficulty of task, and familiarization time), longer looking times may reflect either a novelty or a

² The phonology of a language at a certain point in time, rather than over a period of its history.

³ Changes that take place within a language over an extended period of time, usually through several generations of speakers.

familiarity preference (Hunter & Ames, 1988). This method of interpreting longer looking times as reflecting a preference for (some aspect of) the preferred stimuli has since been implemented successfully by many researchers, including Echols et al. (1997), Jusczyk et al. (1993a,b, 1994, 1999, 2002), and Turk et al. (1995). Saffran et al. (1996), and Johnson & Jusczyk (2001), have further extended this method to interpret differences in looking times between a familiarized and non-familiarized condition as evidence of learning.

Another study which utilized differences in looking times to infer learning on the part of subjects is Saffran & Thiessen (2003). In their experiments, infants were exposed to 2 minutes of a “pattern induction” phase containing stimuli from one of the conditions, followed by a 1-minute “segmentation phase” of continuous speech composed of novel words from both conditions, and finally by the test phase, in which trials were divided evenly between the two conditions. In experiment 1, infants were exposed to either CVCV or CVCCVC stimuli in the first two phases. During the test phase, both groups of infants listened longer to stimuli following the familiarized pattern. All of the words in experiment 2 were CVCCVC, but one condition contained only voiceless onset consonants and voiced coda consonants, while the other condition contained only voiced onset consonants and voiceless coda consonants. In this case, both groups of infants listened longer to stimuli from the novel pattern. The patterns in experiment 3 were based solely on segment identity: one condition contained only /p/, /d/, or /k/ in syllable onsets, and /b/, /t/, and /g/ in codas, while the other condition allowed the same consonants in the opposite condition. In the test phase, infants showed no preference for

words following either the familiarized or novel pattern. Overall, these results were interpreted as evidence that infants are more easily able to learn regular phonological patterns than irregular ones.

Seidl & Buckley similarly interpreted a difference in looking times between a familiarized and non-familiarized condition, following a familiarization phase, as evidence of learning in their 2005 study. They found that 9-month-old infants are able to learn phonetically unmotivated patterns just as easily as motivated ones after 3 minutes of familiarization, evidence which would seem to support the theory that phonetic motivation does not influence synchronic phonology. Experiment 1 barred stops from occurring intervocally in the motivated pattern, and from occurring word-initially in the unmotivated pattern. The motivated pattern in experiment 2 only allowed labial consonants to appear before round vowels, and coronal consonants before front vowels; the unmotivated pattern restricted labial consonants to precede high vowels, and coronal consonants to precede mid vowels. In both experiments, infants from both familiarization conditions (motivated and unmotivated) displayed a novelty preference, listening longer to stimuli which did not follow the pattern with which they were familiarized. These results were interpreted as evidence that the infants are equally able to learn both types of patterns.

At first pass, Seidl & Buckley's (2005) results seem problematic for the position taken in this paper: following Wilson's (2003, 2006) framework of substantively-biased phonology, the proposal made here is that there is a language-independent bias that predisposes the learner to acquire phonetically motivated phonological patterns more

readily than those without such motivation. However, a crucial part of this proposal is that the bias might only surface when the input to the learner has not been informative enough to influence the learner in either direction—i.e., when the task is very difficult given a learner’s previous experience, the learner falls back on the bias as a backup strategy. Seidl & Buckley (2005) do not directly address the issue of the informativeness of their familiarization phase relative to the test phase task; however, it is possible that their subjects were given too much information to allow a bias for motivated patterns to emerge. Thus, Seidl & Buckley (2005) have merely shown that infants can learn phonetically unmotivated patterns under a specific set of conditions, a claim that is not at issue with the one being made here.⁴

1.3 Phonetic Motivation and Acquisition by 4.5- and 10.5-Month-Olds

This paper contributes experimental evidence from infants in favor of Wilson's (2003, 2006) framework of substantively-biased phonology, previously tested on adults,⁵ that there does exist a language-independent preference for phonetically motivated patterns, which surfaces when previous input has not been sufficient to override this preference. In order to test infants under such conditions, two age groups were recruited: 10.5-month-olds and 4.5-month-olds. The former are old enough to have become

⁴ Furthermore, generalizations other than those described by Seidl & Buckley (2005) are recoverable from their stimuli, so it is also possible that infants might be responding to patterns other than the ones Seidl & Buckley intended. For example, when the Hayes/Wilson learner (Wilson, 2007; Hayes & Wilson, in press) is trained on Seidl & Buckley’s (2005) experiment 1 stimuli, it learns “no non-initial stridents” and “no non-initial continuants” before uncovering “no initial non-stridents” (Bruce Hayes, personal communication, November 5, 2007).

⁵ Wilson (2003) showed that English-speaking adults more easily learn phonetically-motivated nasal assimilation and dissimilation rules than similar rules without such motivation; Wilson (2006) showed that adults extend a learned process of velar palatalization from mid front vowels to high front vowels but not vice versa, i.e., only in the phonetically motivated direction.

somewhat familiar with native-language phonotactics (Werker & Lalonde, 1988; Friederici & Wessels, 1993; Jusczyk et al., 1994; Mugitani et al., 2007), so that their phonological grammars would no longer be in their initial state. However, since neither of the patterns used in the stimuli (phonetically motivated intervocalic voicing and phonetically unmotivated intervocalic devoicing) are present in English, it is hard to predict their results: they might not prefer either pattern, since both are unfamiliar; they might prefer the motivated pattern, possibly because of the proposed bias; or they might prefer the unmotivated pattern, for reasons as yet unknown. The 4.5-month-olds, on the other hand, are the youngest that could reasonably be tested using the Head Turn Preference Procedure (Kemler Nelson et al., 1995)—the paradigm which is standard for this type of experiment⁶—as infants younger than 4.5 months generally do not yet have the motor control necessary to perform the movements (45° turn of the head while sitting up) recorded as data in this procedure (Jusczyk et al., 2002). Furthermore, while by 6 months infants show some ability to organize sounds into native phoneme categories (Kuhl, 1991; Kuhl et al., 1992), there is evidence that they might not yet be sensitive to more complex patterns in language, such as phonotactic organization (Jusczyk et al., 1993b) and prosodic phrase markers (Jusczyk et al., 1992). Thus it is reasonable to expect that infants younger than 6 months old also have yet to awaken to these aspects of their native language, and therefore would not yet be influenced by them. For these reasons, it was expected that 4.5-month-olds would show a preference for the

⁶ This procedure is particularly notable in the research program of Jusczyk and colleagues, but is also used in Saffran & Thiessen (2003) and Seidl & Buckley (2005), among others.

phonetically motivated voicing lists as evidenced by longer looking times to these stimuli, while 10.5-month-olds might not show such a preference, or might even prefer the phonetically unmotivated devoicing lists.

The goal of this experiment was to test for a possible *a priori* preference for one or the other type of pattern, rather than a relative ability to learn one or the other in a short period of time. Thus, the initial familiarization phase of artificial learning task experiments (see especially Saffran & Thiessen, 2003; Seidl & Buckley, 2005) is here replaced by a music phase designed to accustom the infant to the connection between the side of stimulus play and the blinking lights, following Jusczyk et al. (2002).

The processes chosen to be exemplified in the stimuli were that of intervocalic voicing and intervocalic devoicing. When applied regularly in a language, the former is generally held to be phonetically motivated by the principle of ease of articulation as it reduces the number of fast transitions from lax glottis (for voiceless segments) to tense glottis (for voiced segments) made in an utterance (see e.g., Kirchner, 2001), and in fact shows up in a large number of the world's languages (Kirchner, 2001). The latter has no known motivation and is attested in no language known to the author.

Finally, in order to test infants' relative preferences for phonetically motivated versus unmotivated patterns of alternation, rather than merely cross-linguistically marked versus unmarked single forms, the triad stimulus paradigm of Jusczyk et al. (2002) was adopted. In this method, the stimuli are not single words, but rather triads of syllables and words. The first two elements of a triad are individual syllables, A and B, and the third is their disyllabic concatenation with a minimal change to the second syllable, AB'.

In this experiment, the minimal change is the voicing or devoicing of the initial fricative⁷ of syllable B to create B', as in (1) below.

(1) A B AB'
 [pi] [si] [pizi]

The triad paradigm is relatively new to the field and therefore not yet accepted as viable as a matter of course; for instance, Seidl & Buckley (2005) express the concern that this paradigm's "validity has not been established by previous studies" (Seidl & Buckley, 2005, p. 293), in response to its use in Jusczyk et al. (2002). However, this paradigm merely relies on infants to exercise pattern recognition abilities that previous studies have already shown them to possess: Marcus et al. (1999) show that infants can detect repetition in ABB and ABA sequences, while Saffran & Thiessen (2003) demonstrate in their second and third experiments that 9-month-old infants can learn consonant voicing patterns that depend on syllable position: after being familiarized with words whose syllables allowed only voiceless onsets and voiced codas, and vice versa, infants looked significantly longer at test stimuli which followed the restrictions to which they had been familiarized. The triad paradigm as it is used here simply combines these two abilities and assumes that infants can also detect partially faithful repetition, in which the two syllables B and B' differ by the single feature of voice.

Seidl & Buckley (2005) further point out the possibility that infants may simply be showing preferences for the form of the AB' element, rather than inferring the

⁷ Square brackets indicate broad transcription in the International Phonetic Alphabet.

connection between the first two and third members of the triad; this concern will be addressed in two follow-up experiments, described below in section 4.3.

Thus, though new, the triad paradigm relies on documented abilities, and possesses great potential for helping experimenters probe into infants' knowledge of phonological processes, rather than simply their preferences for different sorts of surface forms.

Section 2: Experimental Procedure

2.1 Subjects

Subjects were recruited in two age groups: approximately 4.5 months and approximately 10.5 months. The results of 12 4.5-month-olds (mean age 4;18, range 3;27 – 5;24) and 6 10.5-month-olds (mean age 10;14, range 10;2 – 10;28) are analyzed here. 13 more 4.5-month-olds and 8 more 10.5-month-olds were tested, but their data was excluded from analysis due to: experimenter error (5), equipment malfunction (1), parent intervention (1), infant's failure to orient to center and/or side light(s) (3), and fussiness/crying (11). All subjects were recruited using information obtained from the credit reporting agency Experian, and parental consent was obtained prior to the experiment according to the guidelines of the Office for the Protection of Research Subjects at UCLA.

2.2 Stimuli

The stimuli used in this experiment were produced by a 29-year old female native speaker of Standard American English, in a careful, infant-directed style featuring an exaggerated pitch range. The recordings were made in the sound-attenuated recording booth in the UCLA Phonetics Laboratory, and subsequently digitized for playback during the experiment.

The full stimulus set consisted of 192 triads.⁸ Each triad was made up of two consonant-vowel (CV) syllables separated by 500ms, A and B, followed by 500ms of silence and then a two-syllable word composed of the two original syllables with one

⁸ A full list of the stimuli, organized into lists and blocks, can be found in Appendix A.

minimal change, AB'. The minimal change consisted of a change in voicing for the initial fricative of syllable B. For example, three such triads which exemplified intervocalic voicing were as in (2) through (4):

- | | | | | | |
|-----|------|---------|------|---------|--------|
| (2) | A | | B | | AB' |
| | [pi] | (500ms) | [fi] | (500ms) | [pivi] |
| (3) | A | | B | | AB' |
| | [ne] | (500ms) | [ʃe] | (500ms) | [neʒe] |
| (4) | A | | B | | AB' |
| | [gu] | (500ms) | [θu] | (500ms) | [guðu] |

Each triad had a counterpart with the same syllables but exemplifying the opposite process. Thus, the counterparts of (2) through (4) were (5) through (7), respectively:

- | | | | | | |
|-----|------|---------|------|---------|--------|
| (5) | A | | B | | AB' |
| | [pi] | (500ms) | [vi] | (500ms) | [pifi] |
| (6) | A | | B | | AB' |
| | [ne] | (500ms) | [ʒe] | (500ms) | [neʃe] |
| (7) | A | | B | | AB' |
| | [gu] | (500ms) | [ðu] | (500ms) | [guθu] |

As implied by these examples, the initial consonant of the A syllable was always a stop, while the initial consonant of the B syllable was always a fricative, so that only the fricative consonants showed a change between the input (initial two syllables) and output (final bisyllabic word).⁹ Additionally, the vowels of A and B were always identical to

⁹ To be more exact, there was also a difference in duration of the preceding vowel as a result of compensatory lengthening: the vowels preceding the voiced fricatives were shown to be significantly longer than those preceding the voiceless fricatives in their counterparts in a paired *t*-test, $t(95) = 18.017$, $p < .001$. The mean vowel length before a voiced fricative was 167 ms (SD = 33 ms), and that before a

avoid distracting the infant from the change in voicing within triads, as infants have been shown to be extremely sensitive to vowel quality (Kuhl et al., 1992; Polka & Werker, 1994).

The triads were separated into two groups according to condition (intervocalic voicing versus devoicing). They were then organized into lists of 8, with each list having a corresponding counterpart in the other condition. For instance, stimulus (2) above was contained in list Voicing 1, so its counterpart, stimulus (5) above, was contained in list Devoicing 1. The stimuli made a total of twelve pairs of corresponding lists. These pairs of corresponding lists were arranged into three phonetically-balanced blocks of 4 pairs of corresponding lists each. Every infant heard one member from each pair of corresponding lists, with only one of each pair of corresponding lists being heard by any one infant. Thus, if infant A heard list Voicing 1, she never heard list Devoicing 1. Selection between corresponding lists was constrained to balance number of lists per condition within each block. Each list constituted a single test trial in the experiment.

The mean length of the voicing lists was 30.27 seconds ($SD = .33$ seconds), and that of the devoicing lists was 30.14 seconds ($SD = .43$ seconds). The difference in mean length between the two conditions of lists was not significant in a two-tailed paired t -test ($t(11) = .91, p = .39, n.s.$).

voiceless fricative was 103 ms ($SD = 27$ ms). It is possible that this could be a confounding factor, as technically the infants could be reacting to difference in vowel length either along with or instead of the change in fricative voicing value.

2.3 Method

Before participating in the experiment, each infant's parent was seated with his or her infant in a room adjacent to that containing the experimental apparatus, and asked to provide a list of all languages to which the infant had been exposed, along with the extent and source of the exposure.

Infants were tested using the Head Turn Preference Procedure, described in Kemler Nelson et al. (1995). This method has been used successfully in much similar research, as in the work of Jusczyk et al. (1993a,b, 1994, 1999, 2002).

During the experiment, the infant was seated on the parent's lap in the middle of a three-sided booth as shown in Figure 1, surrounded by white curtains to minimize distractions. Three lights were positioned on the walls of the booth, a red one on each side and a blue one at the front. The stimuli were played from speakers located just behind the side red lights. A few inches above the blue light was placed a Sony SteadyShot 700x Digital Zoom video camera, through which the experimenter observed the infant. Both the parent and the experimenter listened to masking music through headphones, the former so that (s)he could not accidentally influence the infant's attention, and the latter so that she would not be biased in recording input for the motivated versus unmotivated trials. The parent was also required to keep his or her eyes closed, again to avoid influencing the infant's attention via the parent's responses to the stimuli.

In this study, the experiment itself was controlled by a PsyScope script written by Colin Wilson. The script controlled counterbalancing of side and randomization of list

order within blocks, in addition to randomization of triad order within lists. It also controlled the intervals of silence between triad members and between separate triads. Distribution of lists among blocks and selection of condition for each list had been

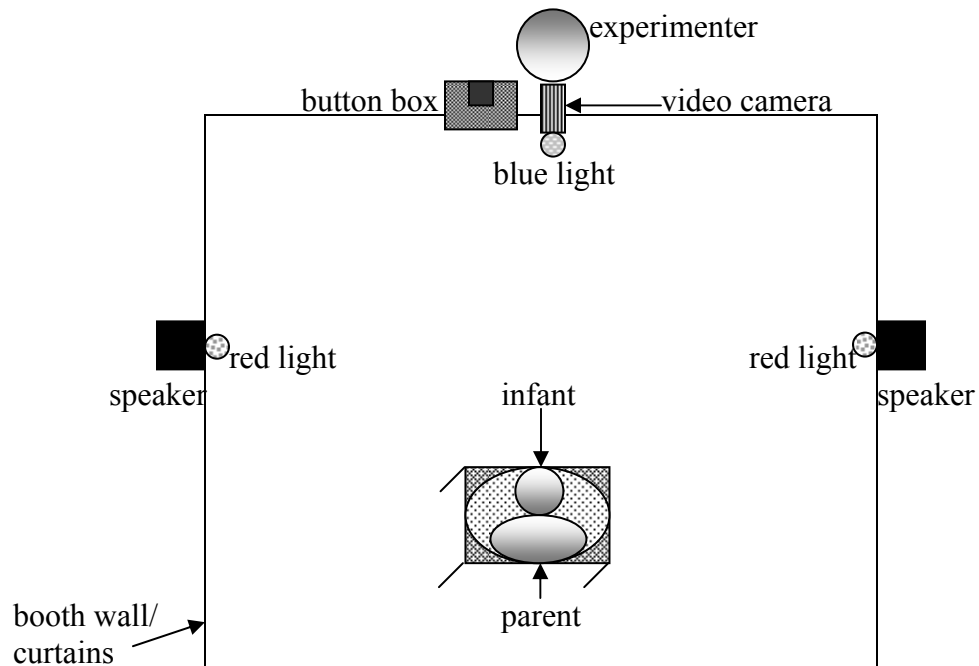


Figure 1: Headturn Preference Procedure Setup

previously pseudorandomized for each infant, to allow the experimenter to control for the condition of each subject's first list.

Once the infant and parent were ready to begin, the lights were dimmed, the video camera was set to record, and the music phase—designed to familiarize the infant with the arrangement of flashing lights and simultaneous sound (first music, then speech)—was initiated. First, the blue center light flashed until the infant oriented to it. The script then picked a side and started the light on that side flashing. Once the infant oriented to that side, the first music stimulus (a 30 second passage from Ottorino Respighi's "Pines

of Rome") began to play on the same side while the light continued to flash. The music clip was allowed to play for 30 seconds regardless of the infant's continued attention as evidenced by visual fixation on the flashing light. The side light was then extinguished and the center light began to flash again. Once the infant had oriented to the center light, the light opposite that for the first practice trial began to flash—the only time during the experiment when the side of play was not randomly chosen. When the infant oriented, the second music stimulus (a different passage from the same work) was played for 30 seconds, after which the light was extinguished, completing the music phase of the experiment.

The test phase followed immediately according to the same procedure, replacing the music passages with stimulus lists, with one key difference in protocol; namely that the test trials were fully infant-controlled. If the infant continued to attend to the light until the trial ended, the side light extinguished and the center light began to flash again. If before the end of the trial the infant looked away by more than 30 degrees for more than two seconds, the trial was terminated, the side light was extinguished, and the center light began to flash again.

The test phase procedure was repeated 11 times, for a total of 12 test trials. However, if at any time the infant began to fuss excessively or the parent intervened in any way, the experiment was terminated.

PsyScope kept track of looking times for each trial for each infant. These times were used as the dependent variable for the analysis, given below, and inferred to have a direct correlation to preference for the associated condition of stimuli.

Section 3: Results

3.1 Results of Statistical Analyses

3.1.1 Combined Results

The primary hypothesis under consideration was that 4.5-month-old infants would listen longer to stimulus lists following the phonetically motivated pattern (intervocalic voicing) versus the phonetically unmotivated pattern (intervocalic devoicing). A repeated-measures multi-factor ANOVA, with looking times as the dependent variable, age and initial test condition as a between-subjects factor, and block and condition as within-subjects factors, showed a significant effect of block, as well as a significant interaction of both condition and age and condition and initial test condition:

Table 1

Analysis of Variance for Infant Looking Times

Source	<i>df</i>	<i>F</i>	η^a	<i>p</i>
Between subjects				
Age (A)	1	1.48	.07	.32
Initial Condition (I)	1	.01	.00	.90
A x I	1	1.54	.18	.12
Subjects (S) within-group error	14	(95.09 x 10 ⁶)		
Within Subjects				
Condition (C)	1	.00	.00	.95
C x A	1	14.07**	.50	.00
C x I	1	12.69**	.48	.00
C x A x I	1	.10	.01	.76
C x S within-group error	14	(8.24 x 10 ⁶)		
Block (B)	2	20.72**	.60	.00
B x A	2	.64	.04	.53
B x I	2	1.67	.11	.21
B x A x I	2	.75	.05	.48
B x S within-group error	28	(57.14 x 10 ⁶)		
C x B	2	1.12	.07	.34
C x B x A	2	.11	.01	.90
C x B x I	2	1.70	.11	.20
C x B x A x I	2	.15	.01	.87
C x B x S within-group error	28	(27.71 x 10 ⁶)		

Note. Parentheses indicate mean square errors. ^aPartial Eta Squared. **p* < .10. ***p* < .05.

As a significant effect of block was found, three post-hoc two-tailed *t*-tests were run to determine which blocks had looking times that were significantly different from each other. Block 1 had significantly longer looking times than either of blocks 2 and 3, but the latter two were not significantly different from each other:

Table 2

Differences Between Blocks

Descriptives			T-Test Results		
Block	<i>M</i> (s)	<i>SD</i> (s)	Pair ^a	<i>t</i>	<i>p</i>
1	21.23	5.58	1 & 2	5.09**	.00
2	12.11	5.63	1 & 3	5.72**	.00
3	9.59	6.82	2 & 3	1.55	.14

Note. ^an = 18 for each pair. ***p* < .05.

Furthermore, Z-scores of skewness and kurtosis were computed for looking times to both the motivated and unmotivated condition; since none had an absolute value greater 1.96, as can be seen in Table 3, no non-parametric tests were conducted.

Table 3

<i>Z-Scores</i>		
Condition	Skewness	Kurtosis
Motivated	.73	-1.68
Unmotivated	1.79	-1.19

3.1.2 Results for 4.5-Month-Olds

Due to the near-significant effect of age, further repeated-measures multi-factor ANOVAs were conducted for the results of each age group alone, with looking times as the dependent variable, initial test condition as a between-subjects factor, and block and condition as within-subjects factors. The results for the 4.5-month-olds ($N = 12$) indicated a significant effect of block, a significant effect of condition, and a significant interaction of both block and initial test condition, and condition and initial test condition:

Table 4

Analysis of Variance for 4.5-Month-Old Looking Times

Source	<i>df</i>	<i>F</i>	η	<i>p</i>
Between Subjects				
Initial Test Condition (I)	1	1.40	.12	.27
Subjects (S) within-group error	10	(117.23 x 10 ⁶)		
Within Subjects				
Condition (C)	1	8.06**	.45	.02
C x I	1	6.24**	.38	.03
C x S within-group error	10	(10.23 x 10 ⁶)		
Block (B)	2	24.05**	.71	.00
B x I	2	3.89**	.28	.04
B x S within-group error	20	(48.93 x 10 ⁶)		
C x B	2	.71	.07	.50
C x B x I	2	1.31	.12	.29
C x B x S within-group error	20	(25.75 x 10 ⁶)		

Note. Values enclosed in parentheses represent mean square errors.

S = subject. * $p < .10$. ** $p < .05$

These results are reflected visually in Figure 2 below:

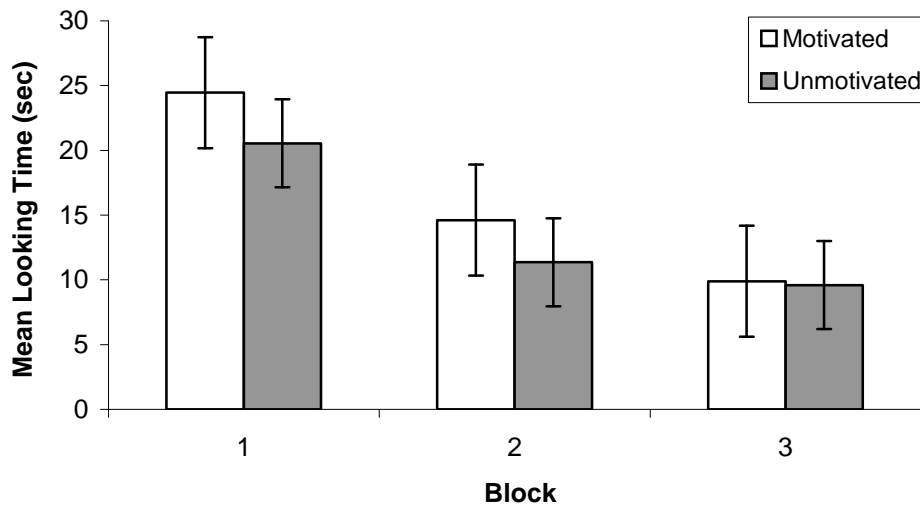


Figure 2. Mean Looking Times ($\pm SE$) by Block and Condition for 4.5-Month-Olds.

Overall, nine infants in this age group listened longer overall to the voicing lists, as opposed to three who listened longer to the devoicing lists. Because of the significant interaction of condition and initial test condition indicated in Table 4 above, post-hoc *t*-tests were conducted to determine whether the effect of condition was significant when the results were separated by subjects' initial test condition. The results are given in Table 5 below:

Table 5

Motivated vs. Unmotivated Condition 4.5-Month-Old Looking Times

Initial Test Condition	Descriptives			T-Test Results		
	Condition	<i>M</i> (s)	<i>SD</i> (s)	<i>df</i>	<i>t</i>	<i>p</i>
Motivated	Motivated	18.39	5.75	6	3.84**	.01
	Unmotivated	14.31	5.56			
Unmotivated	Motivated	13.42	3.04	5	.26	.81
	Unmotivated	13.16	1.00			

Note. ** $p < .05$.

As can be seen in Figure 3, the results show that 4.5-month-olds who heard the motivated condition first had significantly longer looking times to the motivated condition throughout the experiment, while those who heard the unmotivated condition first had no significant preference.

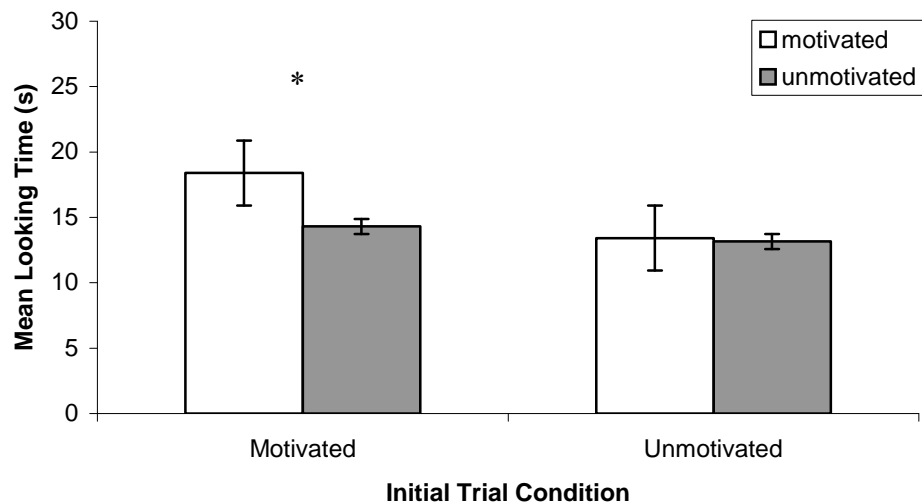


Figure 3. Mean Looking Times ($\pm SE$) by Initial Test Condition for 4.5-Month-Olds.

These results indicate that 4.5-month-olds are able to distinguish the two conditions, at least when exposed first to the motivated condition. Furthermore, they also suggest that they may be treating the first test trial as a familiarization phase, and showing a familiarity preference only for the motivated condition; if this is the case, then it appears that 4.5-month-old infants may be better able to learn the motivated pattern than the unmotivated one.

3.1.3 Results for 10.5-Month-Olds

A repeated-measures multi-factor ANOVA was similarly run for the 10.5-month-olds ($N = 6$), with looking times as the dependent variable and block and condition as within-subjects factors. The results indicated a near-significant effect of block, a significant effect of condition, and a significant interaction of condition and initial test condition:

Table 6

<i>Analysis of Variance for 10.5-Month-Old Looking Times</i>				
Source	<i>df</i>	<i>F</i>	η	<i>p</i>
Between Subjects				
Initial Test Condition (I)	1	1.52	.28	.28
Subject (S) within-group error	4	(38.52 x 10 ⁶)		
Within Subjects				
Condition (C)	1	13.93**	.78	.02
C x I	1	14.41**	.78	.02
C x S within-group error	4	(3.26 x 10 ⁶)		
Block (B)	2	4.11*	.51	.06
B x I	2	.09	.02	.92
B x S within-group error	8	(77.69 x 10 ⁶)		
C x B	2	.50	.11	.62
C x B x I	2	.66	.14	.55
C x B x S within-group error	8	(32.59 x 10 ⁶)		

Note. * $p < .10$. ** $p < .05$.

These results are reflected visually in Figure 4 below:

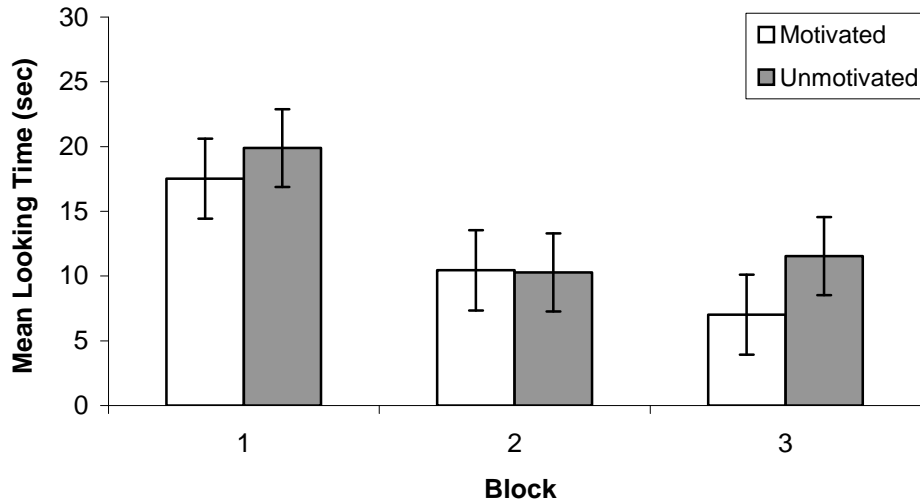


Figure 4. Mean Looking Time ($\pm SE$) by Block and Condition for 10.5-Month-Olds

Figure 4 suggests a possible trend on the part of the 10.5-month-olds to listen longer to the unmotivated condition, supported by the fact that four infants in this age group listened longer to the unmotivated condition, while only two listened longer to the motivated condition.

Because of the significant interaction of condition and block, post-hoc *t*-tests were conducted to determine whether the 10.5-month-olds' looking times to each condition were significantly different when separated by initial test condition. The results are given in Table 7 below:

Table 7

T-Tests of Motivated vs. Unmotivated Condition 10.5-Month-Old Looking Times

Initial Test Condition	Descriptives			T-Test Results		
	Condition	<i>M</i> (s)	<i>SD</i> (s)	<i>df</i>	<i>t</i>	<i>p</i>
Motivated	Motivated	11.52	3.53	3	.04	.97
	Unmotivated	11.48	1.76			
Unmotivated	Motivated	11.79	1.88	3	7.20**	.02
	Unmotivated	16.32	2.96			

Note. ***p* < .05.

As can be seen in Figure 5 below, these results indicates a trend opposite to that of the 4.5-month-olds. The 10.5-month-olds also seemed to show a possible familiarity preference if the initial test trial is treated as a familiarization phase, yet this preference appeared only when the initial test had been in the unmotivated condition.

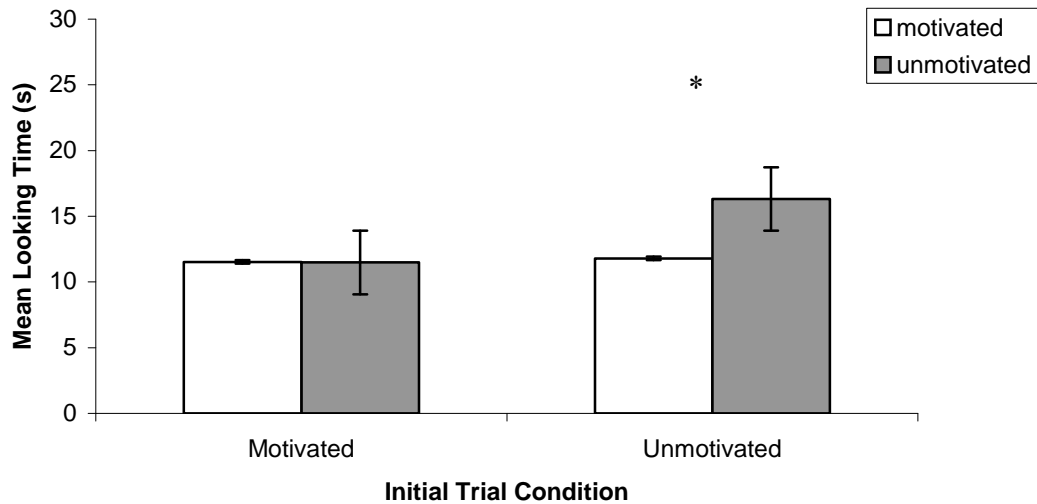


Figure 5. Mean Looking Times (±SE) by Initial Test Condition for 10.5-Month-Olds

As with the 4.5-month-olds, these results indicate that 10.5-month-olds are able to distinguish the two conditions, at least when exposed first to the unmotivated condition. The results also suggest that, like the 4.5-month-olds, the 10.5-month-olds may be treating the first test trial as a familiarization phase, and showing a familiarity preference only for the unmotivated condition.

3.2 Inclusion of Partial Data in the Analysis

It is important to note that partial data from infants with one or more anomalous trials was included in the analysis.¹⁰ This was done to compensate for a lack of participants at the time of writing, as only a total of 11 subjects overall (eight in the 4.5-month group and three in the 10.5-month group) completed the full experiment with no anomalous trials. However, careful consideration was taken in each case to ensure that the remaining data had been accurately recorded. Furthermore, to maintain integrity of comparison, in each case both the anomalous trial and a randomly-chosen trial from the opposite condition in the same block were dropped, so that an individual looking time was never paired with an average looking time in statistical comparison. If both trials in either condition within a block were anomalous, the infant's data was dropped entirely.

3.3 Inclusion of Results from Bi-/Multilingual Infants

It should further be noted that data from infants whose language background included secondary exposure to one or more languages other than English are also included in the analysis, as there were again too few participants at the time of writing to

¹⁰ A complete list of individual trials excluded and the reason for exclusion can be found in Appendix C.

analyze only those with no regular exposure to any other language¹¹ (11 participants fit this criteria across both age groups; of them, only 4 completed the full experiment with no anomalous trials). Each subject's non-English language experience as reported by his or her accompanying caregiver is given in Table 8 below.

Table 8

Reported Non-English Language Exposure in Hours per Week

4.5 Months		10.5 Months	
Subject	Language Exposure	Subject	Language Exposure
4	<u>Japanese</u> : 17	7	_ ^b
10	^a	9	<u>Spanish</u> : 6-10
16	<u>Spanish</u> : 0.5	14	<u>Swahili</u> : 1
17	<u>Spanish</u> : 30	25	
20		35	
26		38	
27			
28	<u>Greek</u> : 5		
29	<u>Spanish</u> : 40		
33	<u>French</u> : 1 <u>Spanish</u> : 3		
34	<u>Spanish</u> : 5		
37			

Note. ^aBlank cells indicate no relevant exposure.
^bLanguage exposure was not reported for this subject.

¹¹ I.e., infants with less than ½ hour a week of direct exposure to the language from live speakers (not including television, radio, etc. when no live reinforcement was given).

The effect of monolingualism on looking times was originally included in the primary analysis; however, it failed to reach significance either as a single effect or as part of an interaction. It is possible that this is due to the small number of subjects. As mentioned above, more subjects—specifically monolinguals—will be tested in the coming months to rule out language exposure as a confounding factor.

Section 4: Discussion

4.1 Interpretation of Primary Results

After testing 12 4.5-month-olds and 6 10-month-olds for preferences regarding intervocalic voicing of fricatives (a phonetically motivated phonological pattern) versus intervocalic devoicing of fricatives (a phonetically unmotivated pattern), it was found in two multi-factor ANOVAs that the 4.5-month-olds as a group displayed a significant preference for the motivated voicing pattern ($F(1) = 8.06, p = .02$), while the 10.5-month-olds showed a significant preference for the other pattern ($F(1) = 13.93, p = .02$).

Furthermore, when the effect of initial test condition was factored out, it was shown that the infants' preferences only became apparent when the initial condition was in the preferred condition; when the initial trial was in the dispreferred condition, no significant preference was found, as can be seen in Table 9.

Table 9

Condition Preference by Initial Test Condition

Initial Condition	<i>df</i>	<i>t</i>	<i>p</i>
4.5 Months			
Motivated	6	3.84**	.01
Unmotivated	5	.26	.81
10.5 Months			
Motivated	3	.04	.97
Unmotivated	3	7.20**	.02

Note. ** $p < .05$.

The 4.5-month-olds' results are here interpreted as a language-independent preference for the motivated pattern, since at this age the infants are too young to have made significant enough progress in native language learning to influence them in this task: though infants of 6 months show evidence of some phoneme categorization (Kuhl et al., 1992), they still show no evidence of phonotactic learning at the segmental level (Jusczyk et al., 1994).

The preference for the unmotivated pattern on the part of the 10.5-month-olds is more difficult to interpret. This is not necessarily evidence that they no longer have language-independent preferences, especially since the 10.5-month-olds still distinguish the two patterns. Given room to speculate, it could be that the 10.5-month-olds have a lower threshold for boredom, causing them to become bored with the motivated pattern early on and turn their attention to the unmotivated pattern.

If the claim regarding the 4.5-month-olds is correct, and their longer looking times for the motivated pattern are due to an *a priori* preference, then this preference would have to be a component of the language faculty, a commonly held bias in favor of patterns which are motivated by at least the phonetic principle of ease of articulation.¹² This recognition of, and preference for, phonetically motivated patterns would be in keeping with current theories of natural language learning that posit a language-independent affinity for “natural patterns,” as phonetically motivated patterns would be considered natural by most researchers' definitions. Theories along these lines have not

¹² N.B.: In this experiment, the only phonetic principle which would apply to the motivated pattern was ease of articulation; though the author suspects that patterns motivated by ease of perception would also be preferred by infants, a strong claim to that effect cannot be made on the basis of this data alone.

only been explored by experimentalists with promising results (most notably, see Wilson 2003, 2006; also e.g. Saffran & Thiessen, 2003), but also mesh well with some models of language learning proposed by theoreticians which do not include such a component (e.g., Tesar & Smolensky, 1993, 2000).

4.2 Possible Objections to Interpretation of Results: Data Level

Those who disagree with the line of reasoning put forth here could point to the fact infants exposed to other languages in addition to English were included in the analysis. This was done mainly due to a lack of subjects at the time of this report; more infants will be tested in the coming months to increase the sample size for monolingual infants and verify that the effect is significant with a larger number of subjects.

A supporting reason why bi-/multilingual infants' results were included in the analysis is that by far the most common second language to which the infants were exposed was Spanish. Spanish does exhibit intervocalic lenition of voiced stops to voiced fricatives, as well as voicing of an alveolar sibilant before a voiced consonant (Harris, 1969; Kirchner, 2001), but has no regular process of pure intervocalic voicing as was used in the motivated stimuli in this experiment. Even if the infants had acquired some knowledge of lenition in Spanish, it seems unreasonable to expect them to generalize from lenition or anticipatory voicing assimilation to intervocalic voicing. Therefore, those infants exposed to both Spanish and English have received no more input regarding intervocalic (de)voicing than the monolingual English infants.

Readers could also object to the fact that infants with anomalous trials were not entirely excluded from the analysis. However, it is still feasible to treat the group of

subjects tested so far as a pilot group, and more subjects will be tested in the current months until a suitable number have completed the full experiment.

4.3 Possible Objections to Interpretation of Results: Theoretical Level

Critics could also challenge the claim that the 4.5-month-olds are too young to have learned enough phonotactics to bias them in this task. They might instead posit that their preference for the motivated pattern is due to the fact that the stimuli used to present this pattern have an overall higher phonotactic probability in English, as confirmed by both a string count performed in CELEX (Baayen et al., 1993)¹³ and the Phonotactic Probability Calculator (PPC) (Vitevitch & Luce, 2004), as seen in Table 10:¹⁴

Table 10

<i>Stimulus Phonotactic Probabilities</i>				
Calculation Method	Descriptives		T-Test Results	
	Mean List Sum	SD	<i>t</i>	<i>p</i>
CELEX			7.75**	.00
Motivated ^a	.3260	.0017		
Unmotivated	.2711	.0014		
PPC			5.00 x 10 ⁶ **	.00
Motivated	.3564	.0030		
Unmotivated	.2700	.0030		

Note. ^an = 12 for all conditions. **p < .05.

¹³ Phonotactic probabilities for CELEX were calculated as follows: a string search for each individual triad member was performed. The resulting number of hits was then divided by 160,595, the total number of entries in the CELEX English database, to determine each triad member's probability. Probabilities for a full triad were reached by adding together the probabilities of its 3 members. Probabilities for a full triad list were reached by adding together the probabilities of its 8 triads. Probabilities for a full condition were reached by adding together the probabilities of its 12 lists.

¹⁴ Probabilities for individual triads and lists can be found in Appendix B.

However, these probabilities can only evaluate the triad members as independently occurring words. Even if further research uncovers evidence for phonotactic learning prior to 4.5 months, the author is aware of no generalization included in English phonotactics that should affect infants' responses to the stimuli used in this experiment when the relation between triad members is taken into account. To begin with, it is the final, AB' member of each triad which is crucial to the interpretation of the triad as a whole as exemplifying a voicing or devoicing process. In this final member, the only difference between the motivated and unmotivated lists is the voicing or voicelessness of the intervocalic fricative, and both voiced and voiceless fricatives show up intervocalically in English words, as in (8) through (10) below.

- | | | | | |
|------|------------------------|----------|-----------------------|-----------|
| (8) | [^h oʊvɪ] | “over” | [^h soʊfə] | “sofa” |
| (9) | [^h ʌðɪ] | “other” | [^h ɔθɪ] | “author” |
| (10) | [^h klazɪt] | “closet” | [^h fɔsɪt] | “faucet” |
| (11) | [^h vɪʒən] | “vision” | [^h vɪʃəs] | “vicious” |

The final member of each triad in the experiment was also evaluated using both CELEX (Baayen et al., 1993) and the PPC (Vitevitch & Luce, 2004), and no final member had a resulting probability of greater than .00005 using either method. As described in Section 4.4 below, two follow-up experiments will be conducted to ensure that the infants are in fact reacting to the stimuli in accordance with the patterns the triads display, rather than as merely lists of independent words.

difference in looking times between the two types of trial, when the difference was the crucial factor in determining preference for one type of trial over the other.

4.5 A Contradictory Result in the Literature: Seidl & Buckley (2005)

As mentioned above in section 1.2, the conclusions drawn from the results of this experiment would seem to contradict Seidl & Buckley's (2005) claim that their findings—9-month-old infants seem to show no more ease in learning phonetically motivated patterns than unmotivated ones—do not support the theory of a language-independent preference for phonetically motivated patterns over phonetically unmotivated patterns. However, only a much stronger version of the claim actually made here would pose such a contradiction: it is not proposed that phonetically unmotivated patterns are impossible to learn, nor that there exists a universal bias against them that is strong enough to show its influence on the learning faculty under all circumstances. Rather, it is hypothesized that a language-independent bias in favor of phonetically motivated patterns does exist, but that it is only detectable when prior input has been insufficient to override the bias. Of course, the ultimate goal of research in this area is to arrive at a theory that is able to account for both the results reported here and those from Seidl & Buckley (2005). In the absence of such a theory, the hypothesis put forth here seems a reasonable first step.

4.6 Conclusion

Thus, this experiment has contributed evidence that both 4.5-month-olds and 10.5-month-olds are sensitive to patterns based on their motivation, or lack thereof, by the phonetic principle of ease of articulation. The 4.5-month-olds displayed a language-

independent preference for phonological patterns that are motivated by the phonetic principle of ease of articulation. Their results further indicate that they might find it easier to learn patterns which are so motivated.

In contrast, the 10.5-month-olds displayed a preference for phonological patterns that are not motivated by ease of articulation, and their results indicated that they might be able to learn the unmotivated patterns more easily, as well. This is here tentatively interpreted as the result of a lower boredom threshold, rather than a reversal of the language-independent preference displayed by the 4.5-month-olds.

Appendix A: Stimulus Blocks

Block 1		Block 2		Block 3	
List 1		List 2		List 4	
<u>Voicing</u>	<u>Devoicing</u>	<i>Voicing</i>	<i>Devoicing</i>	<u>Voicing</u>	<u>Devoicing</u>
pi fi pivi	pi vi pifi	pi si pizi	pi zi pisi	pi θi piði	pi ði piθi
be θe beðe	be ðe beθe	be ʃe beʒe	be ze befe	be se beze	be ze bese
ta sa taza	ta za tasa	ta fa tava	ta va tafa	ta ʃa taʒa	ta ʒa taʃa
du ʃu duʒu	du zu duʃu	du θu duðu	du ðu duθu	du fu duvu	du vu dufu
ke ʃe keʒe	ke ze keʃe	ke θe keðe	ke ðe keθe	ke fe keve	ke ve kefe
ga fa gava	ga va gafa	ga sa gaza	ga za gasa	ga θa gaða	ga ða gaθa
mu θu muðu	mu ðu muθu	mu ʃu muʒu	mu zu muʃu	mu su muzu	mu zu musu
ni si nizi	ni zi nisi	ni fi nivi	ni vi nifi	ni ʃi niʒi	ni zi niʃi
List 3		List 5		List 6	
<u>Voicing</u>	<u>Devoicing</u>	<i>Voicing</i>	<i>Devoicing</i>	<i>Voicing</i>	<i>Devoicing</i>
pe se peze	pe ze pese	pe θe peðe	pe ðe peθe	pe ʃe peʒe	pe ze peʃe
ba ʃa baza	ba ʒa bafa	ba sa baza	ba za basa	ba fa bava	ba va bafa
tu fu tuvu	tu vu tufu	tu ʃu tuʒu	tu zu tuʃu	tu θu tuðu	tu ðu tuθu
di θi diði	di ði diθi	di fi divi	di vi difi	di si dizi	di zi disi
ka θa kaða	ka ða kaθa	ka fa kava	ka va kafa	ka sa kaza	ka za kasa
gu su guzu	gu zu gusu	gu θu guðu	gu ðu guθu	gu ʃu guʒu	gu zu guʃu
mi ʃi mizi	mi zi miʃi	mi si mizi	mi zi misi	mi fi mivi	mi vi mifi
ne fe neve	ne ve nefe	ne ʃe neʒe	ne ze nefe	ne θe neðe	ne ðe neθe
List 9		List 7		List 8	
<u>Voicing</u>	<u>Devoicing</u>	<u>Voicing</u>	<u>Devoicing</u>	<u>Voicing</u>	<u>Devoicing</u>
pu ʃu puʒu	pu zu puʃu	pu fu puvu	pu vu pufu	pu su puzu	pu zu pusu
bi fi bivi	bi vi bifi	bi θi biði	bi ði biθi	bi ʃi biʒi	bi zi biʃi
te θe teðe	te ðe teθe	te se teze	te ze tese	te fe teve	te ve tefe
da sa daza	da za dasa	da ʃa daʒa	da za daʃa	da θa daða	da ða daθa
ki si kizi	ki zi kisi	ki ʃi kiʒi	ki zi kiʃi	ki θi kiði	ki ði kiθi
ge ʃe geʒe	ge ze geʃe	ge fe geve	ge ve gefe	ge se geze	ge ze gese
ma fa mava	ma va mafa	ma θa maða	ma ða maθa	ma ʃa maʒa	ma ʒa maʃa
nu θu nuðu	nu ðu nuθu	nu su nuzu	nu zu nusu	nu fu nuvu	nu vu nufu
List 11		List 12		List 10	
<u>Voicing</u>	<u>Devoicing</u>	<u>Voicing</u>	<u>Devoicing</u>	<u>Voicing</u>	<u>Devoicing</u>
pa θa paða	pa ða paθa	pa ʃa paʒa	pa za paʃa	pa fa pava	pa va pafa
bu su buzu	bu zu busu	bu fu buvu	bu vu bufu	bu θu buðu	bu ðu buθu
ti ʃi tizi	ti zi tiʃi	ti θi tiði	ti ði tiθi	ti si tizi	ti zi tisi
de fe deve	de ve defe	de se deze	de ze dese	de ʃe deʒe	de ze defe
ku fu kuvu	ku vu kufu	ku su kuzu	ku zu kusu	ku ʃu kuzu	ku zu kuʃu
gi θi giði	gi ði giθi	gi ʃi giʒi	gi zi giʃi	gi fi givi	gi vi gifu
me se meze	me ze mese	me fe meve	me ve mefe	me θe meðe	me ðe meθe
na ʃa naʒa	na ʒa naʃa	na θa naða	na ða naθa	na sa naza	na za nasa

Appendix B: Phonotactic Probabilities of Stimuli

Location	Motivated Voicing			Unmotivated Devoicing		
	Triad	Probability Score		Triad	Probability Score	
		CELEX	PPC		CELEX	PPC
Block 1						
List 1		(.0236) ^a	(.0241)		(.0171)	(.0169)
	pi, fi, pivi	.0033	.0042	pi, vi, pifi	.0032	.0033
	be, θe, beθe	.0019	.0017	be, ðe, beθe	.0020	.0019
	ta, sa, taza	.0014	.0044	ta, za, tasa	.0011	.0023
	du, ʃu, duʒu	.0016	.0019	du, ʒu, duʃu	.0009	.0017
	ke, ʃe, keʒe	.0068	.0027	ke, ʒe, keʃe	.0063	.0020
	ga, fa, gava	.0024	.0039	ga, va, gafa	.0016	.0030
	mu, θu, muðu	.0007	.0008	mu, ðu, muθu	.0006	.0007
	ni, si, nizi	.0055	.0045	ni, zi, nisi	.0014	.0020
List 3		(.0438)	(.0409)		(.0412)	(.0338)
	pe, se, peze	.0053	.0044	pe, ze, pese	.0046	.0026
	ba, ʃa, baʒa	.0020	.0045	ba, ʒa, baʃa	.0018	.0039
	tu, fu, tuvuvu	.0159	.0024	tu, vu, tufu	.0158	.0021
	di, θi, diði	.0075	.0039	di, ði, diθi	.0073	.0032
	ka, θa, kaða	.0027	.0166	ka, ða, kaθa	.0027	.0166
	gu, su, guzu	.0021	.0027	gu, zu, gusu	.0003	.0005
	mi, ʃi, miʒi	.0020	.0028	mi, ʒi, miʃi	.0018	.0020
	ne, fe, neve	.0063	.0036	ne, ve, nefe	.0070	.0029

Note. Table is divided so lists are not split. ^aParentheses indicate summed list probabilities.

<i>Location</i>	<i>Motivated Voicing (continued)</i>			<i>Unmotivated Devoicing (continued)</i>		
	<i>Triad</i>	<i>Probability Score</i>		<i>Triad</i>	<i>Probability Score</i>	
		<i>CELEX</i>	<i>PPC</i>		<i>CELEX</i>	<i>PPC</i>
List 9		(.0224)	(.0262)		(.0159)	(.0190)
	pu, fu, pužu	.0009	.0004	pu, zu, pužu	.0002	.0002
	bi, fi, bivi	.0026	.0041	bi, vi, bivi	.0025	.0032
	te, θe, teđe	.0052	.0012	te, đe, teđe	.0053	.0014
	da, sa, daza	.0008	.0045	da, za, dasa	.0006	.0024
	ki, si, kizi	.0052	.0034	ki, zi, kisi	.0011	.0009
	ge, fe, geze	.0031	.0019	ge, ze, geze	.0026	.0012
	ma, fa, mava	.0040	.0083	ma, va, mafa	.0032	.0074
	nu, θu, nuđu	.0005	.0024	nu, đu, nuđu	.0004	.0023
List 11		(.0189)	(.0274)		(.0163)	(.0203)
	pa, θa, pađa	.0028	.0078	pa, đa, pađa	.0028	.0078
	bu, su, buzu	.0029	.0035	bu, zu, busu	.0012	.0013
	ti, fi, tiži	.0019	.0020	ti, zi, tiži	.0018	.0012
	de, fe, deve	.0045	.0034	de, ve, defe	.0051	.0027
	ku, fu, kuvu	.0007	.0010	ku, vu, kufu	.0006	.0007
	gi, θi, giđi	.0003	.0010	gi, di, giđi	.0001	.0003
	me, se, meze	.0050	.0046	me, ze, mese	.0043	.0028
	na, fa, naža	.0007	.0041	na, za, naža	.0005	.0035

<i>Location</i>	<i>Motivated Voicing (continued)</i>		<i>Unmotivated Devoicing (continued)</i>	
	<i>Probability</i>		<i>Probability</i>	
	<i>CELEX</i>	<i>PPC</i>	<i>CELEX</i>	<i>PPC</i>
Block 2				
List 2	(.0236)	(.0256)	(.0171)	(.0169)
pi, si, pizi	.0065	.0051	pi, zi, pisi	.0024 .0026
be, fe, beze	.0025	.0024	be, ze, befe	.0020 .0017
ta, fa, tava	.0020	.0041	ta, va, tafa	.0012 .0032
du, θu, duðu	.0010	.0018	du, ðu, duθu	.0009 .0017
ke, θe, keðe	.0062	.0020	ke, ðe, keθe	.0062 .0022
ga, sa, gaza	.0018	.0042	ga, za, gasa	.0015 .0021
mu, fu, muzu	.0013	.0024	mu, zu, mufu	.0006 .0007
ni, fi, nivi	.0024	.0036	ni, vi, nifi	.0023 .0027
List 6	(.0459)	(.0421)	(.0393)	(.0349)
pe, fe, peze	.0038	.0033	pe, ze, pefe	.0033 .0026
ba, fa, bava	.0029	.0058	ba, va, bafa	.0020 .0049
tu, θu, tuðu	.0158	.0022	tu, ðu, tuθu	.0157 .0021
di, si, dizi	.0115	.0058	di, zi, disi	.0074 .0033
ka, sa, kaza	.0031	.0188	ka, za, kasa	.0029 .0167
gu, fu, guzu	.0009	.0006	gu, zu, gufu	.0002 .0004
mi, fi, mivi	.0029	.0039	mi, vi, mifi	.0028 .0030
ne, θe, neðe	.0050	.0017	ne, ðe, neθe	.0050 .0019

		<i>Motivated Voicing (continued)</i>		<i>Unmotivated Devoicing (continued)</i>		
		<i>Probability</i>		<i>Probability</i>		
<i>Location</i>	<i>Triad</i>	<i>CELEX</i>	<i>PPC</i>	<i>Triad</i>	<i>CELEX</i>	<i>PPC</i>
List 8		(.0203)	(.0250)		(.0177)	(.0179)
	pu, su, puzu	.0021	.0025	pu, zu, pusu	.0003	.0003
	bi, ʃi, biʒi	.0017	.0030	bi, ʒi, biʒi	.0015	.0022
	te, fe, teve	.0065	.0031	te, ve, tefe	.0072	.0024
	da, θa, daða	.0004	.0023	da, ða, daθa	.0004	.0023
	ki, θi, kiði	.0012	.0015	ki, ði, kiθi	.0010	.0008
	ge, se, geze	.0046	.0030	ge, ze, gese	.0039	.0012
	ma, ʃa, maʒa	.0031	.0070	ma, ʒa, maʒa	.0029	.0064
	nu, fu, nuvu	.0006	.0026	nu, vu, nufu	.0005	.0023
List 10		(.0210)	(.0286)		(.0144)	(.0214)
	pa, fa, pava	.0039	.0097	pa, va, pafa	.0031	.0088
	bu, θu, buðu	.0011	.0013	bu, ðu, buθu	.0010	.0012
	ti, si, tizi	.0061	.0040	ti, zi, tisi	.0019	.0015
	de, ʃe, deʒe	.0037	.0022	de, ʒe, deʒe	.0032	.0015
	ku, ʃu, kuʒu	.0012	.0009	ku, ʒu, kuʒu	.0005	.0007
	gi, fi, givi	.0011	.0020	gi, vi, givi	.0010	.0011
	me, θe, meðe	.0029	.0028	me, ðe, meθe	.0029	.0030
	na, sa, naza	.0010	.0057	na, za, naza	.0007	.0036

<i>Location</i>	<i>Motivated Voicing (continued)</i>		<i>Unmotivated Devoicing (continued)</i>		
	<i>Probability</i>		<i>Probability</i>		
	<i>CELEX</i>	<i>PPC</i>	<i>CELEX</i>	<i>PPC</i>	
List 5	(.0459)	(.0421)	(.0393)	(.0349)	
pe, θe, peθe	.0032	.0026	pe, ðe, peθe	.0032	.0028
ba, sa, baza	.0022	.0061	ba, za, basa	.0020	.0040
tu, ʃu, tuʒu	.0164	.0023	tu, zu, tuʒu	.0157	.0021
di, fi, divi	.0083	.0049	di, vi, difi	.0083	.0040
ka, fa, kava	.0038	.0185	ka, va, kafa	.0029	.0176
gu, θu, guθu	.0003	.0005	gu, ðu, guθu	.0002	.0004
mi, si, mizi	.0061	.0048	mi, zi, misi	.0020	.0023
ne, ʃe, neʒe	.0056	.0024	ne, ze, neʒe	.0051	.0017
List 7	(.0203)	(.0250)	(.0177)	(.0179)	
pu, fu, puvu	.0005	.0005	pu, vu, pufu	.0003	.0002
bi, θi, biθi	.0018	.0031	bi, ði, biθi	.0015	.0024
te, se, teze	.0074	.0030	te, ze, tese	.0066	.0012
da, ʃa, daʒa	.0006	.0029	da, za, daʒa	.0004	.0023
ki, ʃi, kizi	.0011	.0014	ki, zi, kifi	.0010	.0006
ge, fe, geve	.0038	.0031	ge, ve, gefe	.0045	.0024
ma, θa, maθa	.0029	.0064	ma, ða, maθa	.0029	.0064
nu, su, nuzu	.0023	.0046	nu, zu, nusu	.0005	.0024

<i>Location</i>	<i>Motivated Voicing (continued)</i>			<i>Unmotivated Devoicing (continued)</i>		
	<i>Triad</i>	<i>Probability</i>		<i>Triad</i>	<i>Probability</i>	
		<i>CELEX</i>	<i>PPC</i>		<i>CELEX</i>	<i>PPC</i>
List 12		(.0189)	(.0265)		(.0163)	(.0203)
	pa, ʃa, paʒa	.0030	.0084	pa, ʒa, paʃa	.0028	.0078
	bu, fu, buvu	.0013	.0015	bu, vu, bufu	.0011	.0012
	ti, θi, tiði	.0020	.0021	ti, ði, tiθi	.0018	.0014
	de, se, deze	.0053	.0033	de, ze, dese	.0045	.0015
	ku, su, kuzu	.0024	.0030	ku, zu, kusu	.0006	.0008
	gi, ʃi, giʒi	.0002	.0009	gi, ʒi, giʃi	.0000	.0001
	me, fe, meve	.0042	.0047	me, ve, mefe	.0049	.0040
	na, θa, naða	.0005	.0035	na, ða, naθa	.0005	.0035
Block 3						
List 4		(.0215)	(.0229)		(.0189)	(.0158)
	pi, θi, piði	.0025	.0032	pi, ði, piθi	.0022	.0025
	be, se, beze	.0041	.0035	be, ze, bese	.0033	.0017
	ta, ʃa, taʒa	.0011	.0028	ta, ʒa, taʃa	.0009	.0022
	du, fu, duvu	.0012	.0020	du, vu, dufu	.0010	.0017
	ke, fe, keve	.0075	.0039	ke, ve, kefe	.0082	.0032
	ga, θa, gaða	.0013	.0020	ga, ða, gaθa	.0013	.0020
	mu, su, muzu	.0025	.0030	mu, zu, musu	.0007	.0008
	ni, ʃi, niʒi	.0014	.0025	ni, ʒi, niʃi	.0013	.0017

Appendix C: Partial Data Included in Analysis

Subject	Age	Anomalous Trial(s)	Corresponding Trial(s) Removed	Reason
9	10.5	7	8	experimenter error
10	4.5	3, 9	1, 12	experimenter error
14	10.5	7, 12	6, 9	experimenter error
26	4.5	4, 6	3, 5	experimenter error
28	4.5	2	1	experimenter error
29	4.5	8	6	experimenter error
33	4.5	9, 10	– ^a	fussy
35	10.5	2	4	experimenter error

Note. ^aThe anomalous trials were already balanced in condition.

Works Cited

- Aslin, R., Pisoni, D., Hennessy, B., & Perey, A. (1981). Discrimination of voice onset time by human infants: New findings and implications for the effects of early experience. *Child Development*, *52*, 1135-1145.
- Baayen, R., Piepenbrock, R., & Rijn, H.V. (1993). The CELEX lexical database (Release 1) [CD-ROM]. University of Pennsylvania, Distributor. Philadelphia, PA: Linguistic Data Consortium.
- Best, C., McRoberts, G., & Sithole, N. (1988). Examination of the perceptual reorganization for speech contrasts: Zulu click discrimination by English-speaking adults and infants. *Journal of Experimental Psychology: Human Perception and Performance*, *14*, 345-360.
- Bever, T. (1970). The cognitive basis for linguistic structures. In J. Hayes (Ed.), *Cognition and the Development of Language* (pp. 279-352). New York: Wiley.
- Blevins, J. (2004). *Evolutionary Phonology: The Emergence of Sound Patterns*. New York: Cambridge University Press.
- Bosch, L., & Sebastián-Gallés, N. (1997). Native-language recognition abilities in 4-month-old infants. *Cognition*, *65*, 33-69.
- Christiansen, M., & Devlin, J. (1997). Recursive inconsistencies are hard to learn: A connectionist perspective on universal word order correlations. In *Proceedings of the Nineteenth Annual Conference of the Cognitive Science Society*, *25* (pp. 113-118). Hillsdale, NJ: Erlbaum
- Echols, C., Crowhurst, M., Childers, J. (1997). The perception of rhythmic units in speech by infants and adults. *Journal of Memory and Language*, *36*, 202-225.
- Ellefson, M., & Christiansen, M. (2000). Subjacency constraints without universal grammar: Evidence from artificial language learning and connectionist modeling. In *Proceedings of the 22nd Annual Conference of the Cognitive Science Society* (pp. 645-650). Hillsdale, NJ: Erlbaum
- Friederici, A., & Wessels, J. (1993). Phonotactic knowledge and its use in infant speech perception. *Perception & Psychophysics*, *54*, 287-295.
- Gomez, R., & Gerken, L. (1999). Artificial grammar learning by 1-year-olds leads to specific and abstract knowledge. *Cognition*, *70*, 109-135.
- Harris, J. (1969). *Spanish Phonology*. Cambridge, MA: MIT Press.

- Hayes, B. (1999). Phonetically-driven phonology: The role of optimality theory and inductive grounding. In M. Darnell, E. Mravcsik, M. Noonan, F. Newmeyer, & K. Wheatly (Eds.), *Functionalism and Formalism in Linguistics, Volume 1: General Papers* (pp. 243-285). Amsterdam: John Benjamins.
- Hayes, B. (2004). Phonological acquisition in optimality theory: The early stages. In R. Kager, J. Pater, & W. Zonneveld (Eds.), *Constraints in Phonological Acquisition* (pp. 158-201). Cambridge, England: Cambridge University Press.
- Hayes, B., & Steriade, D. (2004). Introduction: The phonetic basis of phonological markedness. In B. Hayes, R. Kirchner, & D. Steriade (Eds.), *Phonetically-Based Phonology* (pp. 1-55). Cambridge, England: Cambridge University Press.
- Hayes, B., & Wilson, C. (in press). A maximum entropy model of phonotactics and phonotactic learning. To appear in *Linguistic Inquiry*.
- Hunter, M., & Ames, E. (1988). A multifactor model of infant preferences for novel and familiar stimuli. In C. Rovee-Collier, & L. P. Lipsitt (Eds.), *Advances in Infancy Research, Volume 5* (pp. 69-95). NJ: Ablex Publishing Corporation.
- Johnson, E., Jusczyk, P. (2001). Word segmentation by 8-month-olds: When speech cues count more than statistics. *Journal of Memory and Language, 44*, 584-567.
- Jun, J. (1995). Perceptual and articulatory factors in place assimilation: An optimality theoretic approach. University of California, Los Angeles, Ms.
- Jusczyk, P., Cutler, A., & Redanz, N. (1993a). Infants' preference for the predominant stress patterns of English words. *Child Development, 64*, 675-687.
- Jusczyk, P., Friederici, A., Wessels, J., Svenkerud, V., & Jusczyk, A. (1993b). Infants' sensitivity to the sound patterns of native language words. *Journal of Memory and Language, 32*, 402-420.
- Jusczyk, P., Goodman, M., & Baumann, A. (1999). Nine-month-olds' attention to sound similarities in syllables. *Journal of Memory and Language, 40*, 62-82.
- Jusczyk, P., Kemler Nelson, D., Hirsh-Pasek, K., Kennedy, L., Woodward, A., & Piwoz, J. (1992). Perception of acoustic correlates of major phrasal units by young infants. *Cognitive Psychology, 24*, 252-293.
- Jusczyk, P., Luce, P., & Charles-Luce, J. (1994). Infants' sensitivity to phonotactic patterns in the native language. *Journal of Memory and Language, 33*, 630-645.
- Jusczyk, P., Smolensky, P., & Allocco, T. (2002). How English-learning infants respond to markedness and faithfulness constraints. *Language Acquisition, 10*, 31-73.

- Kemler Nelson, D., Jusczyk, P., Mandel, D., Myers, J., Turk, A., & Gerken, L. (1995). The headturn preference procedure for testing auditory perception. *Infant Behavior and Development, 18*, 111-116.
- Kirchner, R. (2001). *An Effort-Based Approach to Consonant Lenition*. New York: Routledge.
- Kuhl, P. (1991). Human adults and human infants show a "perceptual magnet effect" for the prototypes of speech categories, monkeys do not. *Perception & Psychophysics, 50*, 93-107.
- Kuhl, P., Williams, K., Lacerda, F., Stevens, K., & Lindblom, B. (1992). Linguistic experiences alter phonetic perception in infants by 6 months of age. *Science, 255*, 606-608.
- Lindblom, B. (1983). Economy of speech gestures. In P. MacNeilage (Ed.), *The Production of Speech* (pp. 217-246). New York: Springer Verlag.
- Marcus, G., Vijayan, S., Bandi Rao, S., & Vishton, P. (1999). Rule learning by seven-month-old infants. *Science, 283*, 77-80.
- McCarthy, J., & Prince, A. (1995). Faithfulness and reduplicative identity. In J. Beckman, L. Dickey, & S. Urbanczyk (Eds.), *University of Massachusetts Occasional Papers in Linguistics 18: Papers in Optimality Theory* (pp. 249-384). Amherst, MA: GLSA, University of Massachusetts.
- Mugitani, R., Fais, L., Kajikawa, S., Werker, J., & Amano, S. (2007). Age-related changes in sensitivity to native phonotactics in Japanese infants. *Journal of the Acoustical Society of America, 122*, 1332-1335.
- Newport, E. (1982). Task specificity in language learning? Evidence from speech perception and American Sign Language. In E. Warner, & L. R. Gleitman (Eds.), *Language Acquisition: The State of the Art* (pp. 450-486). Cambridge, England: Cambridge University Press.
- Ohala, J. (1997). Comparison of speech sounds: Distance vs. cost metrics. In S. Kiritani, & H. Fujisaki (Eds.), *Speech Production and Language: In Honor of Osamu Fujimara* (pp. 261-270). Berlin: Mouton de Gruyter.
- Polka, L., & Werker, J. (1994). Developmental changes in perception of non-native vowel contrasts. *Journal of Experimental Psychology: Human Perception and Performance, 20*, 421-435.
- Saffran, J. (2002). Constraints on statistical language learning. *Journal of Memory and Language, 47*, 172-196.

- Saffran, J., Aslin, R., Newport, E. (1996). Statistical learning by 8-month-old infants. *Science*, *274*, 1926-1928.
- Saffran, J., Johnson, E., Aslin, R., Newport, E. (1999). Statistical learning of tone sequences by human infants and adults. *Cognition*, *70*, 27-52.
- Saffran, J., & Thiessen, E. (2003). Pattern induction by infant language learners. *Developmental Psychology*, *39*, 484-494.
- Saltzman, E., & Kelso, J. (1987). Skilled actions: A task dynamical approach. *Psychological Review*, *94*, 84-106.
- Saltzman, E., & Munhall, K. (1989). A dynamic approach to gestural patterning in speech production. *Ecological Psychology*, *14*, 333-382.
- Seidl, A., & Buckley, E. (2005). On the learning of arbitrary phonological rules. *Language Learning and Development*, *1*, 289-316.
- Steriade, D. (2001a). Directional asymmetries in place assimilation: A perceptual account. In E. Hume, & K. Johnson (Eds.), *The Role of Speech Perception in Phonology* (pp. 219-250). San Diego: Academic Press.
- Steriade, D. (2001b). The phonology of perceptibility effects: The P-map and its consequences for constraint organization. MIT, Ms.
- Tesar, B., & Smolensky, P. (1993). *The learnability of optimality theory* (Tech. Rep. CU-CS-678-93). Boulder, CO: University of Colorado, Department of Computer Science.
- Tesar, B., & Smolensky, P. (2000). *Learnability in optimality theory*. Cambridge, MA: MIT Press.
- Turk, A., Jusczyk, P., Gerken, L. (1995). Do English-learning infants use syllable weight to determine stress? *Language and Speech*, *38*, 143-158.
- Vitevitch, M. S., & Luce, P.A. (2004). A web-based interface to calculate phonotactic probability for words and nonwords in English. *Behavior Research Methods, Instruments, and Computers*, *36*, 481-487.
- Werker, J., & Lalonde, C. (1988). Cross-language speech perception: Initial capabilities and developmental change. *Developmental Psychology*, *24*, 672-683.
- Werker, J., & Tees, R. (1984). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development*, *7*, 49-63.

- Wilson, C. (2003). Experimental investigation of phonological naturalness: Nasal assimilation and dissimilation vs. random alternations. In M. Tsujimura, & G. Garding (Eds.), *WCCFL 22 Proceedings* (pp. 533-546). Somerville, MA: Cascadilla Press.
- Wilson, C. (2006). Learning phonology with substantive bias: An experimental and computational study of velar palatalization. *Cognitive Science*, *30*, 945-982.
- Wilson, C. (2007). UCLA Phonotactic Learner [Computer software and manual]. Retrieved from <http://www.linguistics.ucla.edu/people/hayes/Phonotactics/index.htm#software>