UNIVERSITY OF CALIFORNIA

Los Angeles

Phonetic Motivation as a Learning Bias in Phonological Acquisition: An Experimental Study

A thesis submitted in partial satisfaction

of the requirements for the degree of Master of Arts

in Linguistics

by

Victoria Anne Thatte

2007

Table of Contents

List of Figures and Tables

Acknowledgments

I would like to thank Colin Wilson for introducing me to this project and supporting my progress in it; Bruce Hayes and Megha Sundara for their invaluable comments; Henry Tehrani, the designer and builder of the essential custom hardware that controlled the physical peripherals necessary to the experiment; Brook Lillehaugen for recording the versatile stimuli; and of course Lauren Varner for doing the pioneering work in this experiment.

I would also like to give a warm thanks to all the parents who took the time and energy, both of which are in such short supply with an infant as part of the household, to bring their children in to UCLA to participate in the study.

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 infants[1] 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 changes[3] 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 intervocalically 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 experiment[6]—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 fricative[7] of syllable B to create B', as in (1) below.

(1)	A	B	AB'
	[pi]	[**s**i]	[pi**z**i]

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

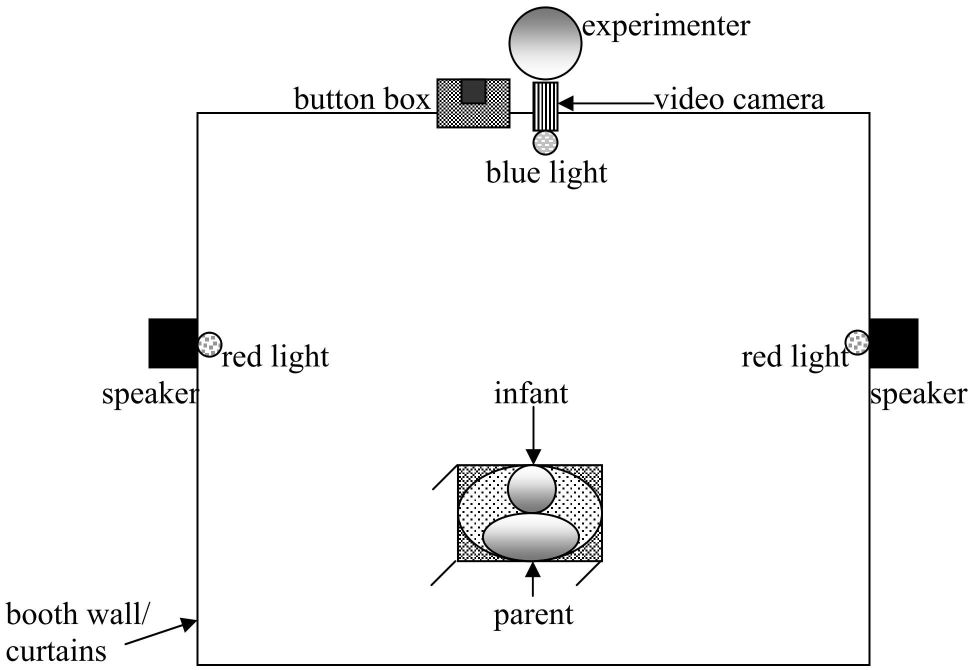

Figure 1: Headturn Preference Procedure Setup

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	*df*	*F*	η^a	*p*
		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. [a]Partial 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	*M (s)*	*SD (s)*	Pair[a]	*t*	*p*
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. [a]n = 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

Z-Scores

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

Note. Values enclosed in parentheses represent mean square errors. S = subject.*p < .10. **p < .05

These results are reflected visually in Figure 2 below:

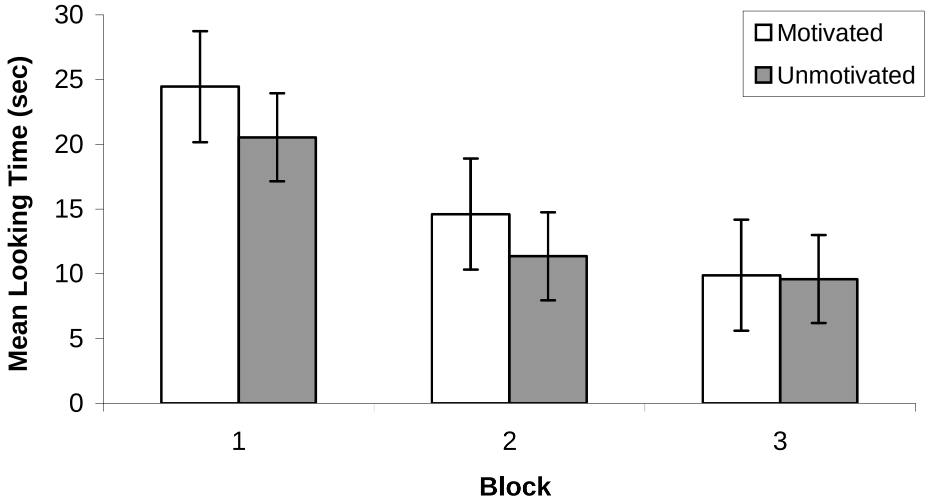

Figure 2. Mean Looking Times (±*SE*) by Block and Condition for 4.5-Month-Olds.

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

	Descriptives			*T*-Test Results		
Initial Test Condition	Condition	*M (s)*	*SD (s)*	*df*	*t*	*p*
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.

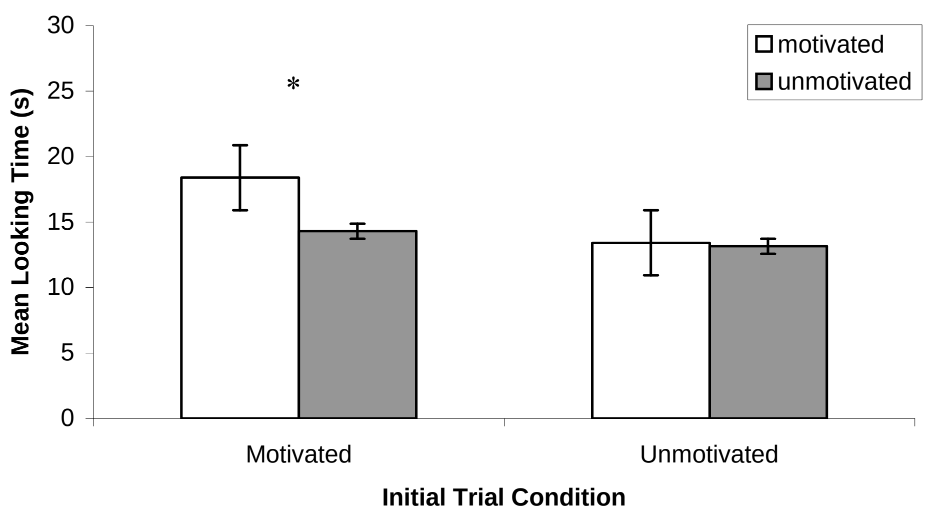

Figure 3. Mean Looking Times (±*SE*) by Initial Test Condition for 4.5-Month-Olds.

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

Analysis of Variance for 10.5-Month-Old Looking Times

Source	*df*	*F*	η	*p*
	Between Subjects			
Initial Test Condition (I)	1	1.52	.28	.28
Subject (S) within-group error	4	(38.52×10^6)		
	Within Subjects			
Condition (C)	1	13.93**	.78	.02
C x I	1	14.41**	.78	.02
C x S within-group error	4	(3.26×10^6)		
Block (B)	2	4.11*	.51	.06
B x I	2	.09	.02	.92
B x S within-group error	8	(77.69×10^6)		
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	(32.59×10^6)		

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

These results are reflected visually in Figure 4 below:

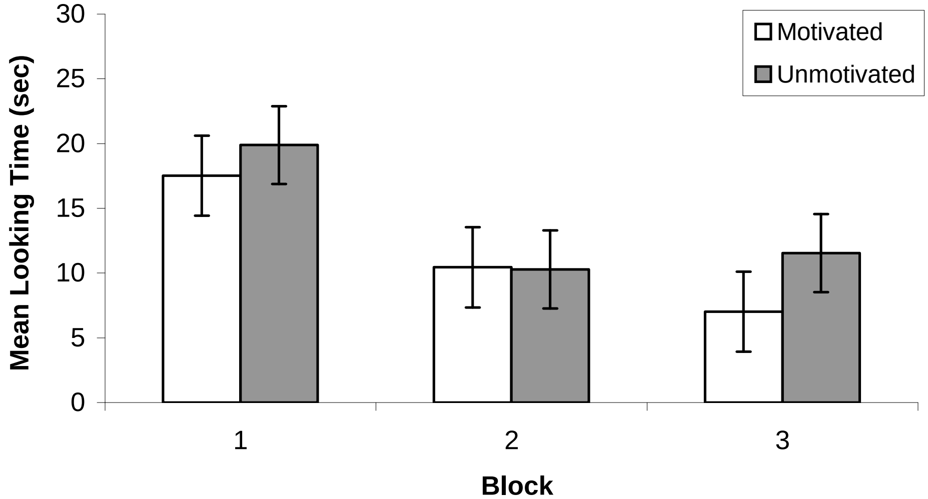

Figure 4. Mean Looking Time (± *SE*) by Block and Condition for 10.5-Month-Olds

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

	Descriptives			*T*-Test Results		
Initial Test Condition	Condition	*M (s)*	*SD (s)*	*df*	*t*	*p*
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.

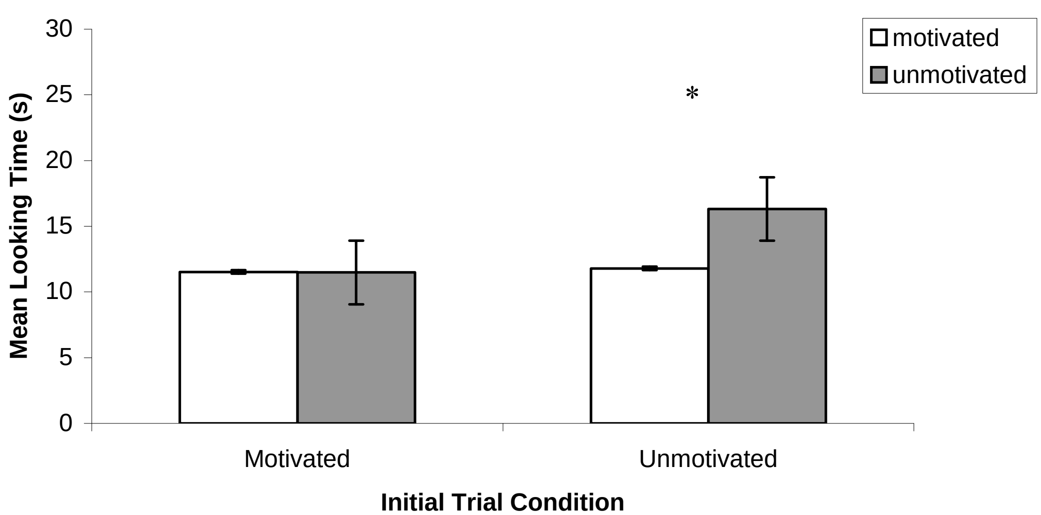

Figure 5. Mean Looking Times (±*SE*) by Initial Test Condition for 10.5-Month-Olds

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 language[11] (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	Japanese: 17	7	–[b]
10	[a]	9	Spanish: 6-10
16	Spanish: 0.5	14	Swahili: 1
17	Spanish: 30	25	
20		35	
26		38	
27			
28	Greek: 5		
29	Spanish: 40		
33	French: 1 Spanish: 3		
34	Spanish: 5		
37			

Note. [a]Blank cells indicate no relevant exposure.
[b]Language 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	*df*	*t*	*p*
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

Stimulus Phonotactic Probabilities

	Descriptives		*T*-Test Results	
Calculation Method	Mean List Sum	*SD*	*t*	*p*
CELEX			7.75**	.00
Motivated[a]	.3260	.0017		
Unmotivated	.2711	.0014		
PPC			5.00×10^{6}**	.00
Motivated	.3564	.0030		
Unmotivated	.2700	.0030		

Note. [a]n = 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) [ˈo͡ʊ**v**ɹ̩] "o**v**er" [ˈso͡ʊ**f**ə] "so**f**a"

(9) [ˈʌ**ð**ɹ̩] "o**th**er" [ˈɔ**θ**ɹ̩] "au**th**or"

(10) [ˈklɑ**z**ɨt] "clo**s**et" [ˈfɔ**s**ɨt] "fau**c**et"

(11) [ˈvɪ**ʒ**ən] "vi**s**ion" [ˈvɪ**ʃ**əs] "vi**c**ious"

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.

Furthermore, just like Spanish (see section 4.2 above), English lacks regular intervocalic voicing—especially in careful speech, which is the register in which our stimuli was recorded. Moreover, even if the infants had managed to pick up a tendency toward intervocalic voicing in casual speech, there is no reason to expect them to generalize from casual to careful speech.

4.4 Possible Objections to Interpretation of Results: Stimulus Level

To back up the claim that it is the final AB' member of the triad which is the key to the infants' recognition of the triads as a voicing or devoicing process, two follow-up experiments will be run in the coming months using the same procedure as that detailed in section 2.3 above, using the same stimuli as described in section 2.1 and appendix A. The crucial and sole difference between the experiment discussed in this paper and the proposed follow-ups will be that part of each triad will be omitted from the stimuli. In follow-up 1, the final bisyllabic member of the triads will be omitted so that stimulus lists will consist of only pairs of single syllables. Examples are as in (12) and (13) below, the follow-up 1 counterparts of (2) and (5) from section 2.2 above, where the crossed-out syllables are the final triad member present in the original experiment but omitted in the follow-up:

(12)	A		B		~~AB'~~
	pi	*(500ms)*	*fi*	~~*(500ms)*~~	~~*pivi*~~
(13)	A		B		~~AB'~~
	pi	*(500ms)*	*vi*	~~*(500ms)*~~	~~*pifi*~~

Follow-up experiment 2 will be the reverse of follow-up 1: in this experiment, the two single syllable members of the triad will be omitted. Thus the stimuli will consist only of the final bisyllabic forms from the present experiment, as in (14) and (15) below:

(14) ~~A B~~ AB'
~~*pi (500ms) fi (500ms)*~~ *pivi*

(15) ~~A B~~ AB'
~~*pi (500ms) vi (500ms)*~~ *pifi*

If the infants were indeed using the third member of the triads to identify the patterns as either voicing or devoicing, then the truncated triads used in the follow-up experiments should not elicit the same preference as the full triads did, since they are lacking the crucial third member in follow-up 1, and the input or underlying syllables in follow-up 2.

Another objection could be the fact that [ð] and [ʒ] were used word-initially in the second syllable ("B") of the unmotivated triads, when the former only shows up initially in function words and the latter only shows up in a handful of borrowings (e.g., [ˈʒɑnɹə], [ˈmɛʒɹ̩], [gəˈɹɑʒ]). This is of course a drawback, but use of these fricatives was necessary to allow for the variety of stimuli needed for the experiment. Even including the two pairs of fricatives which include the two above, there are only four pairs of fricatives in English: [f]/[v], [θ]/[ð], [s]/[z], [ʃ]/[ʒ]. As it is, each fricative pair had to be utilized twice a list to make each list eight items long: it was feared that if the lists were only four triads long, the ceiling effect would interfere with data collection—i.e., the lists would be so short that the infants would not have time to lose enough interest within a trial and so would attend uninterruptedly throughout all 12 entire trials. This would obscure any 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

List 1

Voicing			Devoicing		
pi	fi	pivi	pi	vi	pifi
be	θe	beðe	be	ðe	beθe
ta	sa	taza	ta	za	tasa
du	ʃu	duʒu	du	ʒu	duʃu
ke	ʃe	keʒe	ke	ʒe	keʃe
ga	fa	gava	ga	va	gafa
mu	θu	muðu	mu	ðu	muθu
ni	si	nizi	ni	zi	nisi

List 3

Voicing			Devoicing		
pe	se	peze	pe	ze	pese
ba	ʃa	baʒa	ba	ʒa	baʃa
tu	fu	tuvu	tu	vu	tufu
di	θi	diði	di	ði	diθi
ka	θa	kaða	ka	ða	kaθa
gu	su	guzu	gu	zu	gusu
mi	ʃi	miʒi	mi	ʒi	miʃi
ne	fe	neve	ne	ve	nefe

List 9

Voicing			Devoicing		
pu	ʃu	puʒu	pu	ʒu	puʃu
bi	fi	bivi	bi	vi	bifi
te	θe	teðe	te	ðe	teθe
da	sa	daza	da	za	dasa
ki	si	kizi	ki	zi	kisi
ge	ʃe	geʒe	ge	ʒe	geʃe
ma	fa	mava	ma	va	mafa
nu	θu	nuðu	nu	ðu	nuθu

List 11

Voicing			Devoicing		
pa	θa	paða	pa	ða	paθa
bu	su	buzu	bu	zu	busu
ti	ʃi	tiʒi	ti	ʒi	tiʃi
de	fe	deve	de	ve	defe
ku	fu	kuvu	ku	vu	kufu
gi	θi	giði	gi	ði	giθi
me	se	meze	me	ze	mese
na	ʃa	naʒa	na	ʒa	naʃa

Block 2

List 2

Voicing			*Devoicing*		
pi	si	pizi	pi	zi	pisi
be	ʃe	beʒe	be	ʒe	beʃe
ta	fa	tava	ta	va	tafa
du	θu	duðu	du	ðu	duθu
ke	θe	keðe	ke	ðe	keθe
ga	sa	gaza	ga	za	gasa
mu	ʃu	muʒu	mu	ʒu	muʃu
ni	fi	nivi	ni	vi	nifi

List 5

Voicing			*Devoicing*		
pe	θe	peðe	pe	ðe	peθe
ba	sa	baza	ba	za	basa
tu	ʃu	tuʒu	tu	ʒu	tuʃu
di	fi	divi	di	vi	difi
ka	fa	kava	ka	va	kafa
gu	θu	guðu	gu	ðu	guθu
mi	si	mizi	mi	zi	misi
ne	ʃe	neʒe	ne	ʒe	neʃe

List 7

Voicing			Devoicing		
pu	fu	puvu	pu	vu	pufu
bi	θi	biði	bi	ði	biθi
te	se	teze	te	ze	tese
da	ʃa	daʒa	da	ʒa	daʃa
ki	ʃi	kiʒi	ki	ʒi	kiʃi
ge	fe	geve	ge	ve	gefe
ma	θa	maða	ma	ða	maθa
nu	su	nuzu	nu	zu	nusu

List 12

Voicing			Devoicing		
pa	ʃa	paʒa	pa	ʒa	paʃa
bu	fu	buvu	bu	vu	bufu
ti	θi	tiði	ti	ði	tiθi
de	se	deze	de	ze	dese
ku	su	kuzu	ku	zu	kusu
gi	ʃi	giʒi	gi	ʒi	giʃi
me	fe	meve	me	ve	mefe
na	θa	naða	na	ða	naθa

Block 3

List 4

Voicing			Devoicing		
pi	θi	piði	pi	ði	piθi
be	se	beze	be	ze	bese
ta	ʃa	taʒa	ta	ʒa	taʃa
du	fu	duvu	du	vu	dufu
ke	fe	keve	ke	ve	kefe
ga	θa	gaða	ga	ða	gaθa
mu	su	muzu	mu	zu	musu
ni	ʃi	niʒi	ni	ʒi	niʃi

List 6

Voicing			*Devoicing*		
pe	ʃe	peʒe	pe	ʒe	peʃe
ba	fa	bava	ba	va	bafa
tu	θu	tuðu	tu	ðu	tuθu
di	si	dizi	di	zi	disi
ka	sa	kaza	ka	za	kasa
gu	ʃu	guʒu	gu	ʒu	guʃu
mi	fi	mivi	mi	vi	mifi
ne	θe	neðe	ne	ðe	neθe

List 8

Voicing			Devoicing		
pu	su	puzu	pu	zu	pusu
bi	ʃi	biʒi	bi	ʒi	biʃi
te	fe	teve	te	ve	tefe
da	θa	daða	da	ða	daθa
ki	θi	kiði	ki	ði	kiθi
ge	se	geze	ge	ze	gese
ma	ʃa	maʒa	ma	ʒa	maʃa
nu	fu	nuvu	nu	vu	nufu

List 10

Voicing			Devoicing		
pa	fa	pava	pa	va	pafa
bu	θu	buðu	bu	ðu	buθu
ti	si	tizi	ti	zi	tisi
de	ʃe	deʒe	de	ʒe	deʃe
ku	ʃu	kuʒu	ku	ʒu	kuʃu
gi	fi	givi	gi	vi	gifi
me	θe	meðe	me	ðe	meθe
na	sa	naza	na	za	nasa

Appendix B: Phonotactic Probabilities of Stimuli

	Motivated Voicing			Unmotivated Devoicing		
		Probability Score			Probability Score	
Location	Triad	CELEX	PPC	Triad	CELEX	PPC
Block 1						
List 1		(.0236)[a]	(.0241)		(.0171)	(.0169)
	pi, fi, pivi	.0033	.0042	pi, vi, pifi	.0032	.0033
	be, θe, beðe	.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, tuvu	.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. [a]Parentheses indicate summed list probabilities.

	Motivated Voicing (continued)			*Unmotivated Devoicing (continued)*		
		Probability Score			*Probability Score*	
Location	*Triad*	*CELEX*	*PPC*	*Triad*	*CELEX*	*PPC*
List 9		(.0224)	(.0262)		(.0159)	(.0190)
	pu, ʃu, puʒu	.0009	.0004	pu, ʒu, puʃu	.0002	.0002
	bi, fi, bivi	.0026	.0041	bi, vi, bifi	.0025	.0032
	te, θe, teðe	.0052	.0012	te, ðe, teθe	.0053	.0014
	da, sa, daza	.0008	.0045	da, za, dasa	.0006	.0024
	ki, si, kizi	.0052	.0034	ki, zi, kisi	.0011	.0009
	ge, ʃe, geʒe	.0031	.0019	ge, ʒe, geʃe	.0026	.0012
	ma, fa, mava	.0040	.0083	ma, va, mafa	.0032	.0074
	nu, θu, nuðu	.0005	.0024	nu, ðu, nuθu	.0004	.0023
List 11		(.0189)	(.0274)		(.0163)	(.0203)
	pa, θa, paða	.0028	.0078	pa, ða, paθa	.0028	.0078
	bu, su, buzu	.0029	.0035	bu, zu, busu	.0012	.0013
	ti, ʃi, tiʒi	.0019	.0020	ti, ʒi, tiʃi	.0018	.0012
	de, fe, deve	.0045	.0034	de, ve, defe	.0051	.0027
	ku, fu, kuvu	.0007	.0010	ku, vu, kufu	.0006	.0007
	gi, θi, giði	.0003	.0010	gi, ði, giθi	.0001	.0003
	me, se, meze	.0050	.0046	me, ze, mese	.0043	.0028
	na, ʃa, naʒa	.0007	.0041	na, ʒa, naʃa	.0005	.0035

	Motivated Voicing (continued)			*Unmotivated Devoicing (continued)*		
		Probability			*Probability*	
Location		*CELEX*	*PPC*		*CELEX*	*PPC*
Block 2						
List 2		(.0236)	(.0256)		(.0171)	(.0169)
	pi, si, pizi	.0065	.0051	pi, zi, pisi	.0024	.0026
	be, ʃe, beʒe	.0025	.0024	be, ʒe, beʃe	.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, ʃu, muʒu	.0013	.0024	mu, ʒu, muʃu	.0006	.0007
	ni, fi, nivi	.0024	.0036	ni, vi, nifi	.0023	.0027
List 6		(.0459)	(.0421)		(.0393)	(.0349)
	pe, ʃe, peʒe	.0038	.0033	pe, ʒe, peʃe	.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, ʃu, guʒu	.0009	.0006	gu, ʒu, guʃu	.0002	.0004
	mi, fi, mivi	.0029	.0039	mi, vi, mifi	.0028	.0030
	ne, θe, neðe	.0050	.0017	ne, ðe, neθe	.0050	.0019

	Motivated Voicing (continued)			*Unmotivated Devoicing (continued)*		
		Probability			*Probability*	
Location	*Triad*	*CELEX*	*PPC*	*Triad*	*CELEX*	*PPC*
List 8		(.0203)	(.0250)		(.0177)	(.0179)
	pu, su, puzu	.0021	.0025	pu, zu, pusu	.0003	.0003
	bi, ʃi, biʒi	.0017	.0030	bi, ʒi, biʃi	.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, maʃa	.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, deʃe	.0032	.0015
	ku, ʃu, kuʒu	.0012	.0009	ku, ʒu, kuʃu	.0005	.0007
	gi, fi, givi	.0011	.0020	gi, vi, gifi	.0010	.0011
	me, θe, meðe	.0029	.0028	me, ðe, meθe	.0029	.0030
	na, sa, naza	.0010	.0057	na, za, nasa	.0007	.0036

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

	Motivated Voicing (continued)			Unmotivated Devoicing (continued)		
		Probability			Probability	
Location	*Triad*	*CELEX*	*PPC*	*Triad*	*CELEX*	*PPC*
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. [a]The 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. Mravscik, 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