The Influence of Prosodic Stress Patterns and Semantic Depth on Novel Word Learning in Typically Developing Children

Allison Gladfelter and **Lisa Goffman**
Purdue University

Abstract

The goal of this study was to investigate the effects of prosodic stress patterns and semantic depth on word learning. Twelve preschool-aged children with typically developing speech and language skills participated in a word learning task. Novel words with either a trochaic or iambic prosodic pattern were embedded in one of two learning conditions, either in children's stories (semantically rich) or picture matching games (semantically sparse). Three main analyses were used to measure word learning: comprehension and production probes, phonetic accuracy, and speech motor stability. Results revealed that prosodic frequency and density influence the learnability of novel words, or that there are prosodic neighborhood density effects. The impact of semantic depth on word learning was minimal and likely depends on the amount of experience with the novel words.

Introduction

Children can comprehend a new, unfamiliar word and infer its relationship with a novel referent following a single exposure through a process known as fast mapping (Carey & Bartlett, 1978; Dollaghan, 1987). Because fast mapping tasks provide limited exposures to a novel word, only minimal semantic representations of the word may be established (Capone & McGregor, 2005). Recent studies have demonstrated that even in early mappings of a new word, detailed characteristics, such as multiple types of frequency effects, play a role in learning. That is, a highly frequent sequence of segments is more easily learned than an infrequently occurring sequence (Storkel, 2001). Lexical organization, or neighborhood density (i.e., the frequency of words that are phonetically similar to a specific word), also plays a role in word learning (Heisler, 2004; Storkel, 2004). Interestingly, the specific contributions of phonotactic probability and neighborhood density change as the lexicon expands, suggesting an interaction between semantic knowledge and segmental frequency effects (e.g., Hollich, Jusczyk, & Luce, 2002; Storkel, 2001). However, less is known about the potential role that frequency of occurrence of prosodic patterns has on word learning, or how the slow mapping components (such as semantic depth) may influence learnability. The goal of this study was to investigate the effect of prosodic stress patterns and semantic depth on word learning in preschool-aged children, relying on word learning principles that have been observed at the segmental level. While we include comprehension as a measure of word learning, this study places an emphasis on production, both using standard and novel paradigms.

Segmental Frequency Effects on Word Learning

Segmental frequency effects vary as a function of the representation of a word, with phonotactic frequency influencing sublexical aspects of production. Storkel (2001) assessed

Correspondence should be addressed to Allison Gladfelter, Purdue University, SLHS Department, Heavilon Hall, Room B-11, 500 Oval Drive, West Lafayette, IN 47907. agladfel@purdue.edu.

the influence of phonotactic probability on word learning in preschool-aged children by presenting novel words of either high or low phonotactic probability in stories and then collecting measures of learning following varying amounts of exposure. The results suggested that sound sequences with high phonotactic probability are learned more rapidly than those with low phonotactic probability.

Phonotactic probability is not the only segmental phenomenon that influences word learning in children. Neighborhood density, or the number of words that differ from a given word by a phoneme addition, deletion, or substitution also effects word learning (Storkel & Morrisette, 2002). Dense neighborhoods, which have many words differing by a single phoneme, and sparse neighborhoods, or words with relatively few similar words within their neighborhoods, were compared in a word learning task with infants (Hollich, Jusczyk, & Luce, 2002). The number of exposures influenced the role of neighborhood density. With only a few exposures, high-density words were learned more readily than low-density words. However, as the number of exposures increased, thus inducing lexical competition, word learning was inhibited for the words within dense neighborhoods. In other words, with increased exposure to novel words, infants learned words from sparse neighborhoods more effectively than those from dense neighborhoods. These findings are consistent with those of Coady and Aslin (2003), who showed that dense neighborhoods have a beneficial effect on word acquisition in three-year-old children; however, this facilitative influence of dense neighborhoods decreases as the developing lexicon includes more words with more infrequent sound combinations. This may explain why, as children reach school age, words in sparse neighborhoods are more rapidly processed than those in dense neighborhoods (Munson, Swenson, & Manthei, 2005). It appears that, in early word learning (i.e., fast mapping), dense neighborhoods function similarly to high phonotactic probabilities until the mental lexicon contains more competing word forms, at which point the effects of dense neighborhoods becomes more inhibitory. For children, this transition from facilitative to inhibitory processes appears to apply to both comprehension and production.

These interactions between phonology and the lexicon in language acquisition are summarized in a review article by Storkel and Morrisette (2002) describing the two-representation connectionist model of word processing. Within this model, the two types of representation are lexical and phonological. Depending on different lexical and phonological characteristics between connections, these representations vary in their activation thresholds during language processing tasks. The strength of these connections depends on the degree of associations between words, such as through word frequency, phonotactic probability, and neighborhood density. The lexical status of the stimulus item determines which type of representational processing, either phonological or lexical, dominates the language learning task. Following this model, for words with deep lexical representation, or real words, neighborhood density will have a greater influence in processing, such as for words established within the learner's lexicon. For words with minimal lexical representation, or non-words, phonotactic probability will play a greater role in processing. This allows the model to predict whether the inter-related phonological or lexical processing will ultimately be inhibitory or facilitory.

Possible Prosodic Frequency Effects on Word Learning

The two- representation connectionist model (Storkel & Morisette, 2002) focuses on how segmental and lexical factors show an interaction in word learning. Less is known about prosody. It may be that, similar to segmental phonology, prosodic aspects of phonology influence word learning. If this is the case, then words with a trochaic stress pattern, the more frequently occurring pattern in American English (85% according to Cutler and Carter, 1987), would likely enhance the early phases of word learning, as is the case in words with high phonotactic probability. It could be predicted that, during the initial phases of learning,

words with a highly frequent trochaic pattern would show similar facilitative effects to words with high phonotactic probability. Correspondingly, the less frequent iambic stress pattern may be particularly learnable in semantically rich contexts, as is the case in words from sparse segmental neighborhoods. Competition effects may arise once the lexicon is more established. It could be predicted that prosodic aspects of phonology will behave similarly to segmental aspects in the acquisition of a word. Neighborhood density may apply to prosodic as well as to segmental components of phonology.

Segmental frequency effects are observed regardless of prosodic features, and similarly, this notion of prosodic frequency may be viewed independently of segmental aspects of phonology. Iambs and trochees may be construed as binary categories, with trochees occurring in highly dense and iambs in sparse neighborhoods. Analogous to segmental neighborhood density, prosodic neighborhood density may be dependent on the number of neighbors that share the stress pattern of the target word. It is the objective of the present study to examine the independent influence of prosodic frequency on learning while holding constant segmental variables, such as phonotactic probability and neighborhood density.

While it is established that iambs are produced with more errors than trochees (e.g., Gerken, 1994), there is very little work on the learnability of these forms. One possibility is that the increased difficulty in producing an iamb renders learning more challenging. Alternately, low frequency and sparse prosodic neighborhood density may result in increased learnability. In the present study, we incorporate standard transcription and comprehension measures as well as speech kinematics to evaluate the learnability of novel iambic and trochaic word forms. We manipulate semantic depth to assess whether the sort of learning that occurs in fast mapping is sufficient, or if the inclusion of increased semantic detail enhances learning.

Quantifying Prosodic Effects in Word Learning Paradigms

Traditionally, a word is ascertained to be learned when children show improvement in phonetic accuracy or in comprehension (Munson et al., 2005; Storkel, 2001). However, often accuracy levels do not vary, either because they are already at ceiling or because children's speech patterns are sufficiently entrenched to preclude changes in a short timeframe. Measures of articulatory change, such as those revealed through acoustic or kinematic analysis, provide a complement to more traditional transcription based and comprehension measures. Such fine grained analyses may provide an index of learning that cannot be captured by transcription or by behavioral responses.

Variations in speech motor skill have been shown to provide a sensitive index of more implicit learning, for example when a phonetic form is fast mapped and becomes a word. In fact, some current accounts of language production posit that there is interactivity between lexical and articulatory levels of processing (Goldrick & Blumstein, 2006; McMillan, Corley, & Lickley, 2009), as evidenced by shifts in articulatory variables as a function of lexical parameters, such as wordlikeness. McMillan and colleagues' (2009) electropalatographic data showed that nonwords were more kinematically variable than words, suggesting a direct link between articulation and lexical processing. Measures of speech motor variability may be used to assess interactions between lexical and articulatory levels during word learning (Goffman, 1999; Goldrick & Blumstein, 2006; Heisler, Goffman, & Younger, 2010; McMillan, Corley, & Lickley, 2009).

It is important to consider how articulatory variability is measured to assess within individual learning effects. One analytic approach is to record lip and jaw movements and to calculate their variability (Smith, Zelaznik, Ying, & McGillem, 1995). Patterning variability changes as a function of development, with young children showing increased articulatory

variability as compared to older children and adults (e.g., Smith & Goffman, 1998; Smith & Zelaznik, 2004). Within individual differences in articulatory variability may also be observed; these shifts in variability may index the relative difficulty of a task (e.g., production of iambs vs. trochees; Goffman, 1999; 2004) or learning over time (Walsh, Smith, & Weber-Fox, 2006). A major advantage of including fine grained kinematic analysis is that it provides a quantitative index of change that is independent of segmental accuracy.

Speech motor variability decreases as a function of motor practice (Sasisekaran, Smith, Sadagopan, & Weber-Fox, 2010; Walsh, Smith, & Weber-Fox, 2006). Children who are 9 and 10 years old show decreases in articulatory variability when imitating complex novel words, even across only 10 productions. More critically for the investigation of word learning, articulatory variability decreases when a nonword is provided with a visual referent, similar to a fast mapping task (Heisler, Goffman, & Younger, 2010). Using kinematic measures of articulatory variability, Heisler and colleagues (2010) found that 4-year-old children showed decreased articulatory variability when they produced novel word forms that were paired with a visual referent. Children first produced nonwords while looking at a checkerboard pattern on a screen. In a learning phase, some nonwords were then presented with a visual referent (i.e., a novel object, such as a squeeze ball on a turkey baster). Other nonwords were presented auditorily an equivalent number of times, but were not paired with a visual referent. Only those forms that were paired with a visual referent showed decreased articulatory variability. Heisler et al. concluded that some aspect of lexical or semantic processing positively influenced articulatory components of production, independent of phonetic accuracy.

These results provide further evidence that lexical and articulatory levels of representation are closely associated in word learning tasks. In another study, phonotactic frequency was shown to influence articulatory variability, with less frequent forms produced with more variability (Heisler, 2004). Kinematic variability may index important aspects of word learning, related to both frequency and to lexical content. This same method may be utilized to measure the influence of prosody on word learning, for example quantifying whether iambic or trochaic words become increasingly stable as a function of motor practice or of depth of semantic knowledge.

Another advantage of kinematic analysis is that it allows for direct measurement of what differentiates stressed and unstressed syllables. Weak syllables are produced with smaller and shorter movements than strong ones (Goffman, 1999; 2004), especially when those syllables are unfooted, or occur in an initial weak position. Compared with iambs, trochees are more frequently occurring and are produced accurately earlier in development. In prior work, perhaps surprisingly, iambs were actually found to be produced with more speech motor stability than trochees (Goffman & Malin, 1999). In keeping with the points raised in the previous section, perhaps this increased stability occurs because iambic words occur in sparser prosodic neighborhoods than trochaic words; it may be that the construct of neighborhood density applies to prosodic as well as segmental aspects of phonology.

Hypotheses

The hypotheses of the present study were threefold. First, since iambs are proposed to reside in sparse prosodic neighborhoods, similar to observations of segmental effects, decreased competition would also enhance learning of iambic compared with trochaic word forms. Second, increased semantic depth would further enhance the learning effects that occur once a word is lexicalized (Heisler, Goffman, & Younger, 2010). Both traditional accuracy and comprehension measures as well as kinematic variability measures would reveal that increased semantic depth facilitates word learning as higher processing levels are engaged.

Finally, additional enhancement of learning would occur in the more semantically elaborated conditions; iambs in a semantically rich condition are predicted to be the most learnable forms.

Method

Participants

The participants in this study included 12 preschool children (six female) between the ages of 4;0 and 5;0 with typical language development, as indicated by performance within expected levels on the *Peabody Picture Vocabulary Test* (PPVT; Dunn & Dunn, 1997), the *Expressive Vocabulary Test* (EVT; Williams, 1997), and the *Structured Photographic Expressive Language Test-3rd Edition* (SPELT-3; Dawson, Stout, & Eyer, 2003). Speech production skills were measured using the *Bankson Bernthal Test of Phonology* (Bankson & Bernthal, 1990). One child performed with a standard score of 80, placing him just below expected levels. However, his language skills were at expected levels and all of his speech production errors were developmentally appropriate. Thus, there were no significant concerns that a speech or language disorder was present, and his data were included. All participants responded to pure-tones presented bilaterally at 20 dB at 500, 1000, 2000, and 4000 Hz, and were monolingual English speakers. Two additional children were excluded; one because of an inability to respond to the demands of the task and the other was identified as a child who stutters. In addition, for the kinematic variability analyses, two participants were excluded from some conditions, one because of omission of initial weak syllables and a second because of selection of the wrong lexical target.

Procedure

Stimuli—Eight two-syllable nonsense words, half trochees and half iambs, were presented in a novel word learning task. These words were: /fʌʃpəm/, /fəʃpʌm/, /pʌvgəb/, /pəvgʌb/, /bʌpkəv/, /bəpkʌv/, /mʌfpəm/, and /məfpʌm/. To allow for the analysis of lip and jaw movement it was essential to constrain the words to labial consonants in initial, medial, and final word positions. The stimuli were divided into two groups, with the iambic and trochaic versions of each word presented in two experimental sessions that were separated by at least a week. Therefore, phonetically, each stimulus set was identical for both experimental sessions, with the exception of the prosodic stress pattern. For example, during the first experimental session, the words [fʌʃpəm] and [pʌvgəb] had trochaic stress patterns; however, during the second session, they constituted iambic stress patterns ([fəʃpʌm] and [pəvgʌb]), allowing the two sessions to serve as prosodic mirror images of each other. Within each session, words were counterbalanced for stress pattern (iambic or trochaic) and semantic depth (rich or sparse). In other words, of the eight nonwords, four were used in each session, two of these trochaic and two iambic. One trochee and one iamb were used in the semantically rich context (i.e., children's story) and one trochee and one iamb were used in the semantically sparse context (i.e., picture matching game). The stimulus sets were counterbalanced across children.

Because phonotactic probability and neighborhood density have been shown to influence the learnability of novel words (e.g., Hollich, Jusczyk, & Luce, 2002; Storkel 2001), and because words with low phonotactic probability and low neighborhood density are most likely to demonstrate word learning effects in children (Heisler, 2004), all words had low phonotactic probability and low neighborhood density to control segmental influences on word learning in the present study. Phonotactic probability and neighborhood density were calculated using the child mental lexicon: neighborhood density, phonotactic probability, and word frequency online calculator (CMLC) (Storkel, Hoover, & Kieweg, 2008). To determine the number of neighbors that constitute low neighborhood density, the mean

number of neighbors (12) and standard deviation (6) from the Munson, Swenson, and Manthei (2005) study were used. While none of the bisyllabic stimuli had any neighbors, the number of neighbors for each monosyllable was also calculated to make certain that all possible components met similar low-density criteria. Low phonotactic probability was defined based on Storkel (2001). All positional segment frequencies for all words were lower than 0.1072, and all biphone frequencies were lower than 0.0066.

Instrumentation—Participants were positioned approximately 8 feet in front of an Optotrak movement tracking camera. Stimuli were delivered using Microsoft PowerPoint from a notebook computer connected to a thirty inch Dell monitor. The auditory stimuli were digitized on a computer using Praat (Boersma, & Weenink, 2010), and the visual stimuli consisted of pictures developed by Storkel (2001, 2004, 2006). A set of external speakers was placed six-feet in front of the participant. Pictures of the referents were printed on cardstock for the participants to select and label during the comprehension and production measures. For later transcription of child productions, high quality acoustic recordings were obtained using a Marantz Professional CD recorder CDR300.

Kinematic data were collected using the Optotrak (Northern Digital Inc., Waterloo, Ontario, Canada), a commercially available system designed to record human movement in 3-dimensions. Eight infrared light emitting diodes (IREDs) were placed on each participant's face. Five of these IREDs were stationary and were used as a frame of reference to subtract for head movement. Of the five calibration IREDs, two were aligned on either side of the lips, two on either side of the eyes, and one was placed on the forehead. The three moving IREDs were placed on the lower lip, the upper lip, and on a small splint on the jaw. The kinematic signal was collected at a sampling rate of 250 cycles/second and a time locked acoustic signal, at a sampling rate of 16,000 cycles/second.

Kinematic records were collected in 90 second trials, during which the participants produced multiple words. Following data collection, kinematic trajectories were analyzed using the Matlab signal processing program (Mathworks, 1993). Displacement data were low pass filtered using a Butterworth filter with a cutoff frequency of 10 Hz (both forward and backward). The superior-inferior movements of the lower and upper lips were the focus of the kinematic analysis.

Session structure—To test the influence of prosodic stress patterns on word learning, a paradigm adapted from Storkel (2001) and Heisler, Goffman, and Younger (2010) was used. Initially, to assess how the children produced the stimuli without semantic representations, they repeated the nonsense words 12 times each. Picture matching games were used to present the stimuli with sparse semantic representation, whereas stories had the stimuli embedded within them to establish a richer semantic representation. Children participated in two word learning sessions in order to acquire the nonsense words. Sessions were counterbalanced for story and game and for iamb and trochee. Each session lasted approximately 30 minutes, which included the time necessary for IRED placement. The structure of a sample session is shown in Table 1.

Pre-test—Participants were instructed to look at a large computer monitor and repeat what they heard. The monitor had a blank white screen as each auditory stimulus item was delivered. Each of the two stimulus items were presented twelve times in quasi-random order (total of 24 items; no more than two consecutive productions of any particular item). The experimenter controlled the timing of stimulus presentation to fit the response rate of the participant so they could speak at their natural rate. Each participant's imitations of the stimuli during the pre-test were used for kinematic measures of speech motor variability and phonetic accuracy prior to the exposure phase.

Exposure phase—Half of the novel words and their referents were embedded into children's stories presented as slides on Microsoft PowerPoint on the large monitor. Stories were derived from Storkel (2001), and an example is presented in Appendix A. Two novel words were presented in each story, with one story presented in each session. Each story was divided into three episodes, in which the first episode contained one exposure to the novel words and their referents, and the second and third episodes each contained three exposures to the novel words and referents. After each episode, comprehension and production accuracy were assessed.

The other half of the novel words were presented in a game format. The game was presented as slides on Microsoft PowerPoint on the large monitor. Similar to the stories, two novel words were presented in each game, and one game was played in each session. To keep the same number of exposures as the stories, each game was divided into three episodes, with the first episode containing one exposure to the novel words and their referents, and the second and third episodes each containing three exposures to the novel words and referents. Game scripts contained approximately the same number of words as the stories, but provided minimal semantic content. Unlike the story condition, the games included an interactive component, in which the participants were asked to find the picture that matched the visual referent on the screen. The majority of participants found this task highly engaging. An example game script is presented in Appendix B. The stories and games were prerecorded and presented via Microsoft PowerPoint as described in the *Instrumentation* section above.

Post-test—The post-test was identical to the pre-test. Akin to the pre-test, each participant's imitations of the stimuli during the post-test were used for kinematic measures of speech motor variability and phonetic accuracy, now subsequent to the exposure phase.

Analyses

Evidence of learning within the exposure phase—The comprehension and production learning measures were derived from Storkel (2001). These included referent identification and picture naming. Learning probes occurred following exposure one, exposure four, and exposure seven of the Exposure Phase.

Comprehension probe—Comprehension was measured using a referent identification task. A digital recording of the novel word was presented to the participant while showing a field of four pictures. The participant then selected the picture that corresponded to the novel word's referent. In the array of four pictures, one item was the trochaic referent, one was the corresponding iambic referent, and the remaining two pictures were random foils that had the same visual exposure time as the target referents. The participants' responses during the referent identification were analyzed by comparing the ratio of correct responses to total responses, to derive a percent accuracy score.

Production probe—Semantic production accuracy was measured using a picture naming task, in which the participant was presented with a picture of the referent, and was then asked to name it. Similar to the semantic comprehension analyses, the participants' responses during the picture naming task were analyzed by comparing the ratio of correct responses to total responses, to derive a percent accuracy score. Specifically, in the exposure phase, responses with a percent of consonants correct (PCC) score of 75% or higher were considered correct.

Evidence of learning from pre- to post-test—During the pre- and post-test, 12 productions of each novel word were obtained in direct imitation. In the pre-test, no visual

referents were provided. The post-tests occurred after the exposure to the visual referents within either the story or the game; however, no visual referents were provided during the post-test itself. Thus, the critical measures for learning were the changes in phonetic accuracy and articulatory stability from the pre- to the post-test.

Criteria for inclusion—In the pre- and post-test, productions of novel words judged to be disfluent, or containing laughter, whispering, singing, or yawning were excluded. To be consistent across participants, the first 10 (out of a possible 12) usable productions of each lexical type meeting all of the inclusionary criteria were selected for analysis.

Phonetic accuracy—Digital audio recordings were phonetically transcribed for all words produced by each child during the pre-test and the post-test. Accuracy was measured using PCC. Omission and substitution errors were weighted equally. For example, an omission error, such as /pʌvgə*/ for /pʌvgə**b**/ would be scored the same as the substitution error of /pʌvgə**v**/ for /pʌvgə**b**/. Consistent with prior work, the initial syllables of iambs were produced with marginally more errors than trochees across the pre- and post-tests, $F(1, 11) = 3.13$, $p = 0.10$; Trochees, $M = 82.81$, $SE = 2.65$; Iambs, $M = 78.75$, $SE = 2.85$.

Kinematic analyses—Upper lip, lower lip, and jaw signals were recorded and lip aperture was derived. Kinematic records of participants' novel word productions were collected in a series of three trials with eight productions per trial (24 total productions, 12 of each novel word). For each novel word, the same 10 productions were used for kinematic analysis and phonetic transcription analysis.

Extraction of movement sequences—The movement sequences associated with the target words were extracted from the long data files. For word onset, the lip closure at the beginning of the word was selected (e.g., for the word [bʌpkəv], the onset was the peak velocity following the lip closure for the initial [b]). Movement offsets also corresponded with peak velocity, now for the final consonant (e.g., for the [v]). Movement onsets and offsets were initially selected by visual inspection of the displacement and velocity records. An algorithm then determined the peak movement velocity that occurred within a 25-point (100-ms) window of the experimenter-selected point. Synchronized acoustic signals were used to confirm selections of the kinematic records. The top panel of Figure 1 shows 10 overlying records selected with this algorithm.

Kinematic correlates of stress—The rhythmic structure of individual stressed and unstressed syllables were analyzed using point measures of movement amplitude and duration. These amplitude and duration values were used to confirm that iambs and trochees were differentiated in movement output. Over pre- and post-test productions, the initial syllables of trochees were produced with greater amplitude than iambs, $F(1, 10) = 25.82$, $p = 0.0005$; Trochees, $M = 8.22$ mm, $SE = 0.24$; Iambs, $M = 7.16$ mm, $SE = 0.21$, and with longer duration, $F(1, 10) = 11.57$, $p = 0.007$; Trochees, $M = 0.31$ sec, $SE = 0.006$; Iambs, $M = 0.29$ sec, $SE = 0.007$. These findings were consistent with previous studies of kinematic correlates of stress, in which weak syllables showed smaller movements and shorter durations than strong syllables (e.g., Goffman, 1999), and thus confirmed that the participants were producing the targeted prosodic patterns.

Movement patterning variability—The spatiotemporal index (STI; Smith, Goffman, Zelaznik et al., 1995) was used to assess changes in variability as a function of prosodic structure and of semantic depth. The analytic purpose of the STI was to quantify the stability of underlying movement patterns when absolute differences in duration (e.g., rate) and amplitude (e.g., loudness) were eliminated. Movement trajectories corresponding to the

entire nonword were initially linearly amplitude- and time- normalized. Amplitude-normalization was accomplished by subtracting the mean and dividing by the standard deviation of each displacement record. For time normalization, a spline function (Mathworks, 1993) was used to interpolate each displacement record onto a time base of 1000 points (for a detailed description of this analysis, see Smith, Goffman, Zelaznik et al., 1995; Smith et al., 2000). Following normalization, standard deviations were computed at 2% intervals across all of the time- and amplitude-normalized displacement records. The STI was the sum of these 50 standard deviations. A higher STI value indicated increased variability. For the present study, the velocity records were used to determine the selection points for calculating the STI values.

Statistical Analysis

For the analyses associated with the exposure phase, the ratio of correct responses during the production and comprehension probes were assessed in a 2 (rich vs. sparse semantic representation) X 2 (trochee vs. iamb) repeated measures ANOVA. Two analyses were completed on the pre- and post-test productions, one kinematic (i.e., the STI) and a second transcription (i.e., PCC). These two analyses employed a 2 (rich vs. sparse semantic representation) X 2 (trochee vs. iamb) X 2 (set1 vs. set 2) X 2 (pre- vs. post-test) repeated measures ANOVA. In addition to raw STI and PCC values, difference scores, or the numerical difference from the post-test STI to the pre-test STI, were used to evaluate the extent of change during learning. For the ANOVA, a .05 level was considered significant.

Phonetic Transcription Reliability

For 25% of the sessions, an independent coder phonetically transcribed the pre- and post-test productions and the production probes from the exposure phase tasks. The phonetic transcription agreement between the first author and the independent coder for the pre- and post-test productions was 99.7%, and for the production probes was 99.5%.

Session Effects and Number of Exposures

Because the novel words used in this study were phonetically minimal pairs that differed only in lexical stress, a minimum of a week was required between sessions. Because of prior findings demonstrating long term learning (Storkel, 2001), a repeated measures ANOVA was used to compare the results from session 1 to session 2. An analysis of the kinematic data revealed that children did not change in their movement variability from session 1 to session 2, although they trended toward lower STIs, $F(1, 9) = 3.88$, $p = 0.08$. There were no interactions between pre-vs. post-test measures and session, $F(1, 9) = 1.08$, $p = 0.33$. STI difference scores also revealed no session effects, $F(1, 9) = 1.08$, $p = 0.33$.

The transcription data were also analyzed by session. PCC scores were overall higher in the second session than the first, $F(1, 11) = 6.57$, $p = 0.03$. However, there was no interaction between session and pre- vs. post-test, $F(1, 11) = 0.40$, $p = 0.54$. Difference scores also revealed no session effects, $F(1, 11) = 0.44$, $p = 0.53$. While an overall improvement in accuracy occurred from the first session to the second, the actual level of change from pre-test to post-test within each session was equivalent, indicating that the critical learning measure was not influenced by session. Therefore, the results from both sessions were combined for all further analyses.

Because it may be predicted that children's productions would change as a function of increased exposure to the novel word, a preliminary analysis was completed to assess whether comprehension or production accuracy improved throughout the exposure phase. A repeated measures ANOVA revealed no significant effect of the number of exposures on production probe accuracy, $F(1, 12) = 0.21$, $p = 0.81$, or on comprehension probe accuracy,

$F(2, 22) = 1.06$, $p = .36$. Because no significant differences were found based on the number of exposures, the comprehension and production probe results were collapsed for subsequent analyses.

Results

The results are organized into sections associated with comprehension and production probes obtained in the exposure phase, phonetic accuracy (PCC) results in the pre- and post-test, and kinematic results in the pre- and post-test. Within each section, the following hypotheses are assessed: (1) Iambic words are more learnable than trochaic (main effect of prosody); (2) Words embedded in semantically rich stories are more learnable than those embedded in games (main effect of semantic condition); (3) Iambs are particularly learnable in stories (interaction between prosodic and semantic factors).

Exposure Phase

Production probes in the exposure phase—A 2 (trochee vs. iamb) X 2 (story vs. game) repeated measures ANOVA was used to assess differences in production based on prosodic stress pattern and semantic status. In the production probes, iambs showed higher levels of accuracy than trochees, $F(1, 11) = 5.31$, $p = 0.04$; iambs, $M = 0.55$, $SE = 0.05$; trochees, $M = 0.37$, $SE = 0.06$, $p < 0.06$. As predicted, there was an iambic advantage in the acquisition of these novel words. However, there was no advantage for story over game, with production probes showing no differences in accuracy between the semantically rich learning condition (children's story) and the semantically sparse learning condition (matching game), $F(1,11) = 1.11$, $p = 0.31$; game, $M = 0.49$, $SE = 0.05$; story, $M = 0.42$, $SE = 0.06$. There was no interaction between prosodic and semantic variables, $F(1, 11) = 1.59$, $p = 0.23$. Production scores did not correlate with expressive vocabulary performance based on the EVT (range of correlations from −.22 to .14, all ns).

Comprehension probes in the exposure phase—Iambs and trochees showed similar levels of accuracy in the comprehension probes, $F(1, 11) = 0.08$, $p = 0.78$; iambs, $M = 0.56$, $SE = 0.06$; trochees, $M = 0.57$, $SE = 0.05$, $p > 0.05$. Comprehension probes revealed no differences between the story and the game conditions, with novel words embedded in games and stories comprehended similarly, $F(1, 11) = 1.96$, $p = 0.19$; game, $M = 0.64$, $SE = 0.06$; story, $M = 0.49$, $SE = 0.04$). While there was a trending interaction between the prosodic and semantic conditions, $F(1, 11) = 4.57$, $p = 0.06$, the pattern of performance did not conform to the hypothesis that iambs would be particularly learnable in the story condition. In fact, children were slightly more accurate in the game condition, especially in their production of iambic words. Comprehension scores did not correlate with receptive vocabulary performance based on the PPVT-3 (range of correlations from −.08–.23, all ns).

To summarize the results from the exposure phase, an iambic advantage was observed when levels of processing associated with production were invoked; this advantage did not appear when words were merely recognized in a comprehension probe. Semantic context had no influence on either the comprehension or the production of novel words that were taught during the fast mapping phase of this experiment.

Transcription Results in the Pre- and Post-test

Phonetic accuracy—A 2 (story vs. game) X 2 (iamb vs. trochee) X 2 (set 1 vs. set 2) X 2 (pre- vs. post-test) repeated measures ANOVA revealed that children demonstrated improvements in phonetic accuracy in the post- compared with the pre-test, $F(1, 11) = 9.40$, $p = 0.01$ (see Figure 2). Iambs and trochees showed similar improvement in PCC, $F(1, 11) = 0.33$, $p = 0.58$. In this imitation task, both prosodic forms improved, but not differentially.

This result from the pre- and post-tests differed from the elicited responses obtained during the production probes in the exposure phase, in which the iambs were learned more effectively.

There was no difference in the overall PCC for stories vs. games, $F(1, 11) = 1.53$, $p = 0.24$, indicating that words were produced with similar degrees of phonetic accuracy in both learning conditions. To ascertain that there were no inherent differences in accuracy prior to the exposure phase, a follow-up ANOVA revealed that, in the pre-test phases, nonwords were produced with similar levels of accuracy for both game and story conditions, $F(1, 11) = 0.19$, $p = 0.67$. These results indicated that neither condition was initially at an advantage. Although it was predicted that the influence of the iambic stress pattern would be enhanced within the semantically rich condition, no such interactions were observed based on PCC, $F(1, 11) = 0.31$, $p = 0.59$.

Difference scores (or the numerical change in PCC from pre- to post-test) provide a more direct index of learning within specific prosodic and semantic conditions. For PCC, difference scores showed no significant effects for prosodic condition, $F(1, 11) = 0.77$, $p = 0.40$, semantic condition, $F(1, 11) = 0.61$, $p = 0.45$, and no interactions, $F(1, 11) = 0.33$, $p = 0.58$. However, visual examination of the difference scores (Figure 3) suggested that phonetic accuracy improved for both iambs and trochees in the story condition but not the game condition. A follow-up ANOVA confirmed this observation, with phonetic accuracy showing improvement in the story condition, $F(1, 11) = 8.08$, $p = 0.02$, but not the game condition, $F(1, 11) = 0.63$, $p = 0.44$. This observation suggests that word learning may benefit from increased semantic detail, though these results are preliminary and follow-up studies are needed.

In summary, children showed improvements in phonetic accuracy following the exposure phase, or in the post-test. However, inconsistent with our predictions, this learning was not increased in iambs. The semantic condition results are a bit more complex, in that follow-up ANOVAs suggested that increased phonetic accuracy may occur in the story but not the game condition, though future research is needed to verify these findings.

Kinematic Results in the Pre- and Post-test

Articulatory variability—A 2 (story vs. game) X 2 (iamb vs. trochee) X 2 (set 1 vs. set 2) X 2 (pre- vs. post-test) repeated measures ANOVA was used to evaluate differences in articulatory variability between iambs and trochees and between stories and games in pre- and post-test conditions. As shown in Figure 4, speech motor learning effects were observed in all prosodic and semantic contexts, with the STI decreasing from pre- to post-test, $F(1, 11) = 11.58$, $p = 0.006$. There were no overall differences in articulatory movement variability between iambs and trochees, $F(1, 11) = 0.83$, $p = 0.38$. In addition, there were no differences in articulatory variability between words learned in the story vs. the game conditions, $F(1, 11) = 0.20$, $p = 0.66$. There was no significant interaction between prosodic stress pattern and semantic depth, $F(1, 11) = 0.57$, $p = 0.47$.

Difference scores (or the actual reduction in the STI from pre-test to post-test) were used as a more direct index of learning. As illustrated in Figure 5, when considering difference scores, iambs showed more improvement from pre- to post-test compared with trochees, $F(1, 11) = 4.67$, $p = 0.05$. In other words, while both prosodic patterns showed improvement, the iambic forms demonstrated more dramatic learning following the exposure phase than the trochaic forms.

Also as shown in Figure 5, a repeated measures ANOVA revealed no differences in change in articulatory movement variability between story and game conditions, $F(1, 11) = 2.39$, p

= 0.15. As previously reported, variability decreased in the post-test compared to the pre-test, indicating that learning occurred following the exposure phase. However, there was no evidence that the increased semantic depth in the story condition contributed to the articulatory learning beyond that of the game condition. Further, when comparing the difference scores from pre-test to post-test, no significant interactions between prosodic and semantic factors were observed, $F(1, 11) = 0.03$, $p = 0.87$.

To summarize the kinematic variability results, STI values decreased following the exposure phase, revealing that motor learning occurred from pre- to post-test phases. More direct measures of change, reflected in difference scores, indicated that there was an iambic advantage in speech motor learning regardless of whether the novel word was acquired in a story or game context during the exposure phase. However, there was no particular advantage for story over game. No prosodic and semantic interactions were observed, again suggesting that iambs were not especially learnable in the semantically richer story context.

Discussion

In the preschool years, multiple phonological and semantic factors influence how children learn words. Much prior work has focused on aspects of segmental frequency, including phonotactic probability and neighborhood density. The goal of the current study was to investigate two factors related to word learning, prosodic frequency and semantic depth, and their potential interaction. Specifically, we looked at whether the sorts of frequency and density effects observed in segmental phonology could also be used to predict the influence of prosodic stress patterns in a novel word learning paradigm. Additionally, we investigated the impact differing degrees of semantic depth (i.e., a semantically sparse game versus a semantically rich story) may have on a word's learnability, and the potential interaction of semantic factors with prosodic frequency. Three separate indices of learning were included. These were: comprehension and production probes, phonetic accuracy, and kinematic variability. The results contribute to an understanding of factors that influence word learning in preschool-aged children.

Prosodic Influences on Word Learning

Based on a standard measure of fast mapping, namely the confrontation naming task during the production probes, iambs were learned more effectively than trochees in both semantic conditions. Furthermore, an iambic advantage was observed in the kinematic results, as evidenced by greater decreases in movement variability in learning iambic compared with trochaic words. This iambic bias for speech motor learning in preschool-aged children is consistent with the findings from earlier kinematic studies comparing iambic and trochaic words (Goffman, 1999, 2004). In this earlier work, iambic words were produced with relatively high levels of motor stability, whereas it seemed that preschool-aged children still relied on a more frequent and earlier developing motor pattern to produce trochaic words. Iambs were produced with more articulatory precision than trochees.

In both traditional confrontation naming and kinematic measures, an iambic advantage was observed in the acquisition of new words. Prior studies have demonstrated that words with high segmental neighborhood density show increased lexical competition, potentially hindering word learning (Munson, Swenson, & Mathei, 2005). When considering prosody, the iambic advantage observed in the present study may be due to a similar reduction in competition, as iambs reside in a less dense prosodic neighborhood compared to trochees. Therefore, these data support the construct of prosodic neighborhood density.

While initially it seems counterintuitive that a less frequent prosodic form would be more learnable, this finding is consistent with other aspects of speech production. For example,

the benefits associated with the less commonly occurring iambic pattern are compatible with the inverse-preference pattern described in the literature on structural priming, in which the structures that were less common showed greater priming compared to those with a more frequent structure when using a neutral baseline (Ferreira & Bock, 2006). This finding is also consistent with the sound learning literature, in which learning is enhanced when more marked phonological features are targeted (in this case the iambic pattern) compared to unmarked targets (Dinnsen, Chin, & Elbert, 1992; Gierut, 2001; Gierut & Storkel, 2002;Tyler & Figurski, 1994).

Segmental frequency and neighborhood density have long been considered important phonological factors that contribute to word learning. In many ways, the influence of prosodic frequency and density appears to parallel that of segmental phonology in word learning paradigms in preschool-aged children. Therefore, future researchers should consider prosody as a contributing factor in word learning paradigms.

Semantic Influences on Word Learning

When new words are learned, semantic representations form connections around a lexical node within a neural network that spreads as deeper semantic representations are established (Bjorklund, 1987). In the present study, comprehension and production learning measures were obtained during a fast mapping task (the exposure phase), in which the participants were provided limited exposures to new lexical forms along with minimal semantic information. Therefore, the novel words learned in the fast mapping task were likely sparsely represented and presumably had few connections to other words within the lexicon. Although no distinctions between the different semantic learning conditions (i.e., games and stories) were evident within the fast mapping phase, this phase may have been crucial for learning new words because it established a word-referent pair, allowing later experiences of the novel words to enrich and solidify the semantic representations in what is known as the slow mapping phase (Capone & McGregor, 2005). The richer semantic representations then may facilitate word retrieval by increasing the activation of the lexical node being targeted (Bjorklund, 1987). While the semantic representation was richer in the story condition than the game condition, the opportunity for deeper connections to form within the fast mapping task was limited and thus not initially apparent. However, there was some inkling that these semantic differences may have begun to reveal themselves through phonetic changes during the post-test, or the slower mapping phase of the learning paradigm; during the post-test, words were produced with greater accuracy in semantically rich stories than in semantically sparse games.

The suggestion that semantic depth may influence word learning is preliminary, since the primary ANOVA did not reveal a statistically significant difference between the learnability of words presented in the semantically rich condition and the semantically sparse condition. The present findings may be explained by a couple of factors. First, the two novel words learned within each condition possessed numerous semantic similarities. Past research has demonstrated that word learning is slowed for novel words with similar semantic representations in preschool children (Storkel & Adlof, 2009). In the current study, both words in each semantic learning condition resided in the same semantic category (e.g., both candy machines, both toys), which may have caused competition effects during retrieval, and thus prevented any significant learning advantages to manifest across the two semantically varied learning conditions. Future research should include novel words from semantically distinct categories in order to investigate the impact of semantic depth on word learnability.

A second possible cause could be that within a fast mapping task, lexicalization, or achieving word status, may be sufficient to evoke improvements in articulatory stability. A

previous study by Heisler, Goffman, and Younger (2010) investigated the kinematic variability of novel phonetic strings given varying levels of semantic information within a fast mapping task. One set of phonetic strings was given a visual referent (lexicalization), a second was given a visual referent and a function (lexicalization and semantic information), and the third set remained only phonetic strings without a visual referent (nonword). Two key results from this study relate to the current study. First, the results revealed increased motoric stability for both of the phonetic sets paired with visual referents, but not for the set that did not attain full word status. Second, the inclusion of the added semantic depth associated with a function did not differentially affect articulatory stability. In other words, within a fast mapping task, it appeared that the linking between a novel word and a referent was sufficient to improve the motor stability of the speech productions.

It remains unclear whether higher levels of semantic and conceptual processing influence speech production processes. Because the results of the current study provide hints of an articulatory advantage for learning novel words within a semantically rich context following later exposures, as in the post-test phase, and because previous research has mostly manipulated semantic variation within a fast mapping task, future research investigating semantic depth should include a more elaborated slow mapping phase.

Interactions between Prosodic Stress and Semantic Depth in Word Learning

It was predicted that the iambs in the semantically rich condition would be the most learnable forms, resulting from a combination of increased activation due to elaborated semantic information (Bjorklund, 1987) and reduced competition due to a sparser prosodic neighborhood. However, in the present study, no statistical differences were observed between iambs produced in the semantically sparse compared to the semantically rich learning condition on any of the learning measures.

Boyle and Gerken (1997) investigated this potential interaction between semantic word knowledge (lexical familiarity) and prosodic stress (meter) by observing the omission patterns of object articles in speech productions of 2-year-old children. Replicating previous work, meter influenced omission patterns. More critically for the present purposes, within their imitated sentence production task, lexical familiarity also influenced omission patterns, with object articles preserved more frequently in front of familiar nouns than unfamiliar nouns. The influences of meter and lexical familiarity provided independent contributions to the object article omission patterns in children's speech production. Similar to the present results, no significant interaction between semantic knowledge and prosodic pattern was observed in children's speech productions.

In segmental phonology, there is an interaction observed between frequency and lexical-semantic effects, with improved learning of highly frequent forms at sublexical levels and of less frequent forms at lexical levels. It is important to consider differences between prosodic and segmental frequency. For example, segmental frequency varies in a graded fashion while, at least as conceptualized in the present study, prosodic distinctions are more binary, with iambic words low frequency in English and trochaic forms high frequency. Perhaps prosodic neighborhood density behaves differently from segmental neighborhood density, with increased independence between semantic and prosodic cues supporting word learning.

Conclusions

Numerous factors are thought to influence word learning in preschool-aged children, such as semantic depth, phonotactic probability and neighborhood density. In the current study, we explored the contributions of two word learning cues, one associated with semantic depth and a second with a new construct of prosodic neighborhood density. Semantic depth, as it

was studied here, had minimal effects, especially during early fast mapping phases of word learning. However, with increased production experience (i.e., during the post-test), novel words that were learned in a rich semantic context were produced more accurately than those learned in a sparse semantic context. While there are several possible explanations for why semantic depth may not have influenced word learning within the present fast mapping task, there was a glimmering of evidence for semantic effects over a more protracted timecourse.

The major result related to our proposal for a new construct of prosodic neighborhood density. Based on the results of the current study, neighborhood density can be applied to prosodic phonology. Past studies have indicated that while the mental lexicon is developing, words within dense segmental neighborhoods are initially acquired more easily, but as the lexicon expands, lower neighborhood density actually plays a more facilitative role in sound and word learning (Gierut, Morrisette, & Champion, 1999; Hollich, et al., 2002; Morrisette & Gierut, 2002; Storkel, 2004). Based on the results of the current study, the facilitative role of prosodic neighborhood density parallels that of segmental neighborhood density. The less prosodically dense iambic pattern demonstrated enhanced learnability compared to the more prosodically dense trochaic pattern.

Acknowledgments

References

Bankson, NW.; Bernthal, JE. Bankson-Bernthal Test of Phonology. Chicago, IL: Riverside Publishing Company; 1990.

Bjorklund DF. How age changes in knowledge base contribute to the development of children's memory: An interpretive review. Developmental Review. 1987; 7:93–130.

Boersma, P.; Weenink, D. Praat: doing phonetics by computer (Version 5.1.29) [Computer program]. 2010. Retrieved March 11, 2010, from http://www.praat.org/

Boyle MK, Gerken L. The influence of lexical familiarity on children's function morpheme omissions: A nonmetrical effect? Journal of Memory and Language. 1997; 36:117–128.

Capone NC, McGregor KK. The effect of semantic representation on toddlers' word retrieval. Journal of Speech, Language, and Hearing Research. 2005; 48:1468–1480.

Carey S, Bartlett E. Acquiring a single new word. Papers and Reports on Child Language Development (Stanford University). 1978; 15:17–29.

Coady JA, Aslin RN. Phonological neighbourhoods in the developing lexicon. Journal of Child Language. 2003; 30:441–469. [PubMed: 12846305]

Cutler A, Carter DM. The predominance of strong initial syllables in the English vocabulary. Computer Speech and Language. 1987; 2:133–142.

Dawson, J.; Stout, C.; Eyer, J. Structured Photographic Expressive Language Test. 3. Dekalb, IL: Janelle Publications Inc; 2003.

Dinnsen DA, Chin SB, Elbert M. On the lawfulness of change in phonetic inventories. Lingua. 1992; 86:207–222.

Dollaghan CA. Fast mapping in normal and language-impaired children. Journal of Speech and Hearing Disorders. 1987; 52:218–222. [PubMed: 3455444]

Dunn, LM.; Dunn, LM. Peabody Picture Vocabulary Test-III. Circle Pines, MN: American Guidance Service; 1997.

Ferreira VS, Bock K. The functions of structural priming. Language and Cognitive Processes. 2006; 21:1011–1029. [PubMed: 17710210]

Gerken LA. Young children's representation of prosodic structure: Evidence from English-speakers' weak syllable omissions. Journal of Memory and Language. 1994; 33:19–38.

Gierut JA. A model of lexical diffusion in phonological acquisition. Clinical Linguistics & Phonetics. 2001; 15:19–22. [PubMed: 21269092]

Gierut JA, Morrisette ML, Champion AH. Lexical constraints in phonological acquisition. Journal of Child Language. 1999; 26:261–294. [PubMed: 11706466]

Gierut JA, Storkel H. Markedness and the grammar in lexical diffusion of fricatives. Clinical Linguistics & Phonetics. 2002; 16:115–134. [PubMed: 11987493]

Goffman L. Prosodic influences on speech production in children with specific language impairment and speech deficits: Kinematic, acoustic, and transcription evidence. Journal of Speech, Language, and Hearing Research. 1999; 42:1499–1517.

Goffman L. Kinematic differentiation of prosodic categories in normal and disordered language development. Journal of Speech, Language, and Hearing Research. 2004; 47:1088–1102.

Goffman L, Malin C. Metrical effects on speech movements in children and adults. Journal of Speech, Language, and Hearing Research. 1999; 42:1003–1015.

Goldrick M, Blumstein SE. Cascading activation from phonological planning to articulatory processes: Evidence from tongue twisters. Language and Cognitive Processes. 2006; 21:649–683.

Heisler, L. Unpublished doctoral dissertation. Purdue University; West Lafayette: 2004. The influence of neighborhood density and phonotactic probability on representational and production factors in word learning.

Heisler L, Goffman L, Younger B. Lexical and articulatory interactions in children's language production. Developmental Science. 2010; 13:722–730. [PubMed: 20712738]

Hollich, G.; Jusczyk, P.; Luce, P. Lexical neighborhood effects in 17-month-old word learning. Proceedings of the 26th Annual Boston University Conference on Language Development; Boston, MA: Cascadilla Press; 2002. p. 314-323.

Mathworks, Inc. Matlab: High performance numeric computation and visualization software [computer program]. Natick, MA: Author; 1993.

McMillan CT, Corley M, Lickley RJ. Articulatory evidence for feedback and competition in speech production. Language and Cognitive Processes. 2009; 24:44–66.

Morrisette ML, Gierut JA. Lexical organization and phonological change in treatment. Journal of Speech, Language, and hearing Research. 2002; 45:143–159.

Munson B, Swenson CL, Manthei SC. Lexical and phonological organization in children: Evidence from repetition tasks. Journal of Speech, Language, and Hearing Research. 2005; 48:108–124.

Sasisekaran J, Smith A, Sadagopan N, Weber-Fox C. Nonword repetition in children and adults: Effects on movement coordination. Developmental Science. 2010; 13:521–532. [PubMed: 20443972]

Smith A, Goffman L. Stability and patterning of movement sequences in children and adults. Journal of Speech Language and Hearing Research. 1998; 41:18–30.

Smith A, Goffman L, Zelaznik HN, Ying G, McGillem CM. Spatiotemporal stability and the patterning of speech movement sequences. Experimental Brain Research. 1995; 104:493–501.

Smith A, Johnson M, McGillem C, Goffman L. On the assessment of stability and patterning of speech movements. Journal of Speech, Language, and Hearing Research. 2000; 43:277–286.

Smith A, Zelaznik HN. Development of functional synergies for speech motor coordination in childhood and adolescence. Developmental Psychobiology. 2004; 45:22–33. [PubMed: 15229873]

Storkel HL. Learning new words: Phonotactic probability in language development. Journal of Speech, Language, and Hearing Research. 2001; 44:1321–1337.

Storkel HL. Do children acquire dense neighborhoods? An investigation of similarity neighborhoods in lexical acquisition. Applied Psycholinguistics. 2004; 25:201–221.

Storkel HL, Adlof SM. The effect of semantic set size on word learning by preschool children. Journal of Speech, Language, and Hearing Research. 2009; 52:306–320.

Storkel HL, Armbruster J, Hogan TP. Differentiating phonotactic probability and neighborhood density in adult word learning. Journal of Speech, Language, and Hearing Research. 2006; 49:1175–1192.

Storkel, HL.; Hoover, JR.; Kieweg, D. The child mental lexicon: Neighborhood density, phonotactic probability, and word frequency online calculator. 2008. Available from the University of Kansas Word and Sound Learning Laboratory web site

Storkel HL, Morrisette ML. The lexicon and phonology: Interactions in language acquisition. Language, Speech, and Hearing Services in Schools. 2002; 33:24–37.

Tyler AA, Figurski GR. Phonetic inventory changes after treating distinctions along an implicational hierarchy. Clinical Linguistics & Phonetics. 1994; 8:91–107.

Walsh B, Smith A, Weber-Fox C. Short-term plasticity in children's speech motor systems. Developmental Psychobiology. 2006; 8:660–674. [PubMed: 17111401]

Williams, K. Expressive Vocabulary Test. Circle Pines, MN: American Guidance Service; 1997.

Appendix A. Sample Story

	Episode 1 (1 exposure)	Episode 2 (3 exposures)	Episode 3 (3 exposures)
Narrator	"We can go to the candy machines at the park, said Big Brother.	"I can eat more candy than you," said Big Brother.	"Let's eat our leftover candy before mom and dad come home," said Little Sister.
Trochaic Stress Pattern	"My favorite is the /'f ʌʃpəm /."	Big Brother ran to the /'fʌʃpəm/. He got candy from the /'fʌʃpəm/. He stuffed all the candy from the /'fʌʃpəm/ in his mouth. "Can you eat that much?"	Big Brother got his candy from the /'fʌʃpəm/. He ate all his candy from the /'fʌʃpəm/. "Mmm," he said, "the candy from the /'fʌʃpəm/ is really good."
Iambic Stress Pattern	Little Sister said, "My favorite is the /bəp'kʌv/."	Little Sister ran to the /bəp'kʌv/. She got candy from the /bəp'kʌv/. She stuffed all the candy from the /bəp'kʌv/ in her mouth. Then, they got more candy for later.	Little Sister got her candy from the /bəp'kʌv/. She ate all her candy from the /bəp'kʌv /. "Mmm," she said, "the candy from the /bəp'kʌv/ is really good."

Note. Story taken from Storkel (2001) with present study's novel words substituted.

Appendix B. Sample Game

|	Episode 1 (1 exposure)	Episode 2 (3 exposures)	Episode 3 (3 exposures)
Narrator	Look for the picture! It has a match. Listen. Now look for it. The picture is on the screen.	Now we will see the pictures again.	Now we will see the pictures again. Let's find all of the matches!
Trochaic Stress Pattern	This is a /'fʌʃpəm/.	This picture is the /'fʌʃpəm/. Look at the /'fʌʃpəm/. Here it is. It's a picture of a /'fʌʃpəm/ on the screen. Find the matching picture.	This picture is the /'fʌʃpəm/. Look at the /'fʌʃpəm/. Here it is. It's a picture of a /'fʌʃpəm/ on the screen. Find the matching picture.
Iambic Stress Pattern	This is a /bəp'kʌv/.	This picture is the /bəp'kʌv/. Look at the /bəp'kʌv/. Here it is. It's a picture of a /bəp'kʌv/ on the screen. Find the matching picture.	This picture is the /bəp'kʌv/. Look at the /bəp'kʌv/. Here it is. It's a picture of a /bəp'kʌv/ on the screen. Find the matching picture.
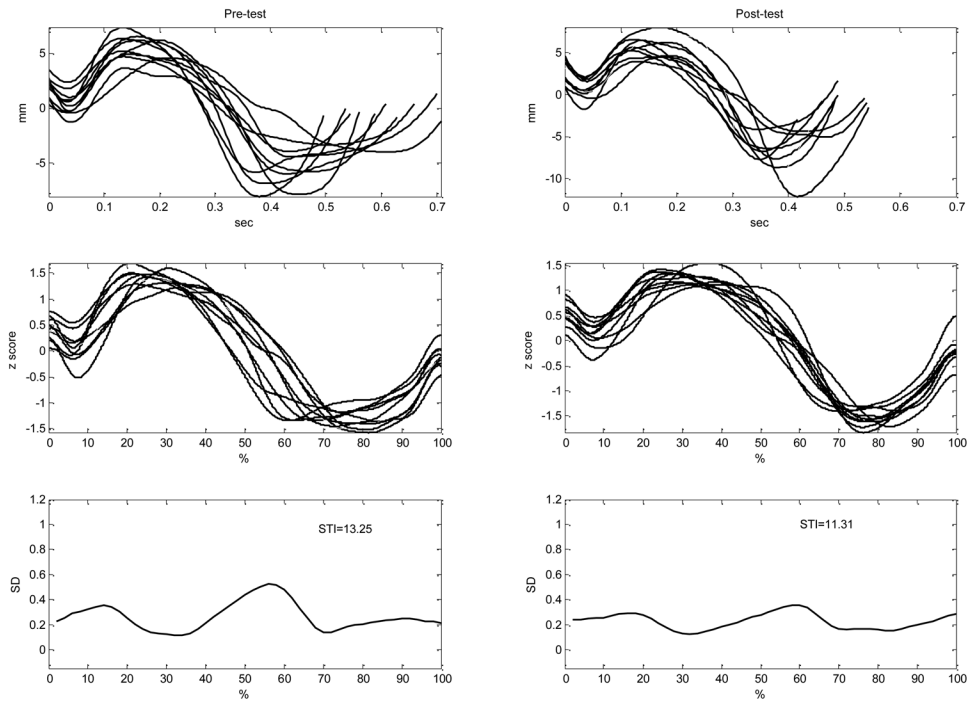
Figure 1.
Example of individual movement records showing time and amplitude normalization and the resulting spatiotemporal index (STI). Data are shown from one participant producing the weak strong (iambic) movement sequences for the novel word /m ə fp ʌ m/. The top panels for each column are the 10 non-normalized movement sequences. The middle panels show the same movement sequences time and amplitude normalized. The bottom panels show standard deviation values obtained at 2% intervals from the normalized records. The STI is the sum of these 50 SDs.
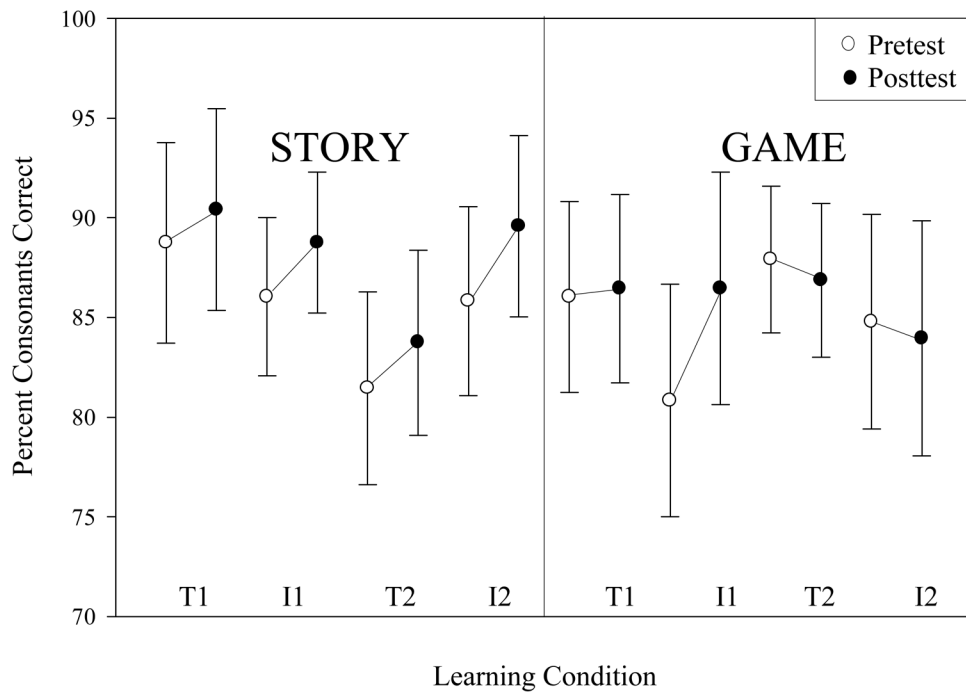
Figure 2.
Phonetic accuracy for pre-tests and post-tests. Labels at the bottom of the figure represent either the trochaic (T) or iambic (I) productions. The numbers 1 or 2 signify which version of the story or game the stimuli were presented. Error bars represent standard errors.
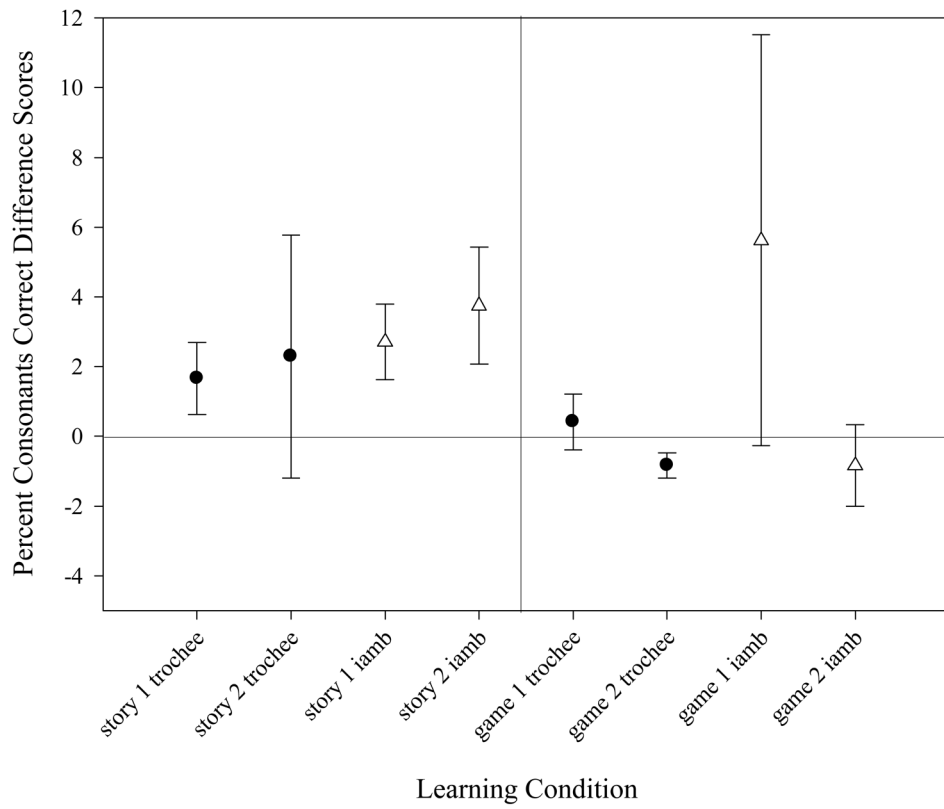
Figure 3.
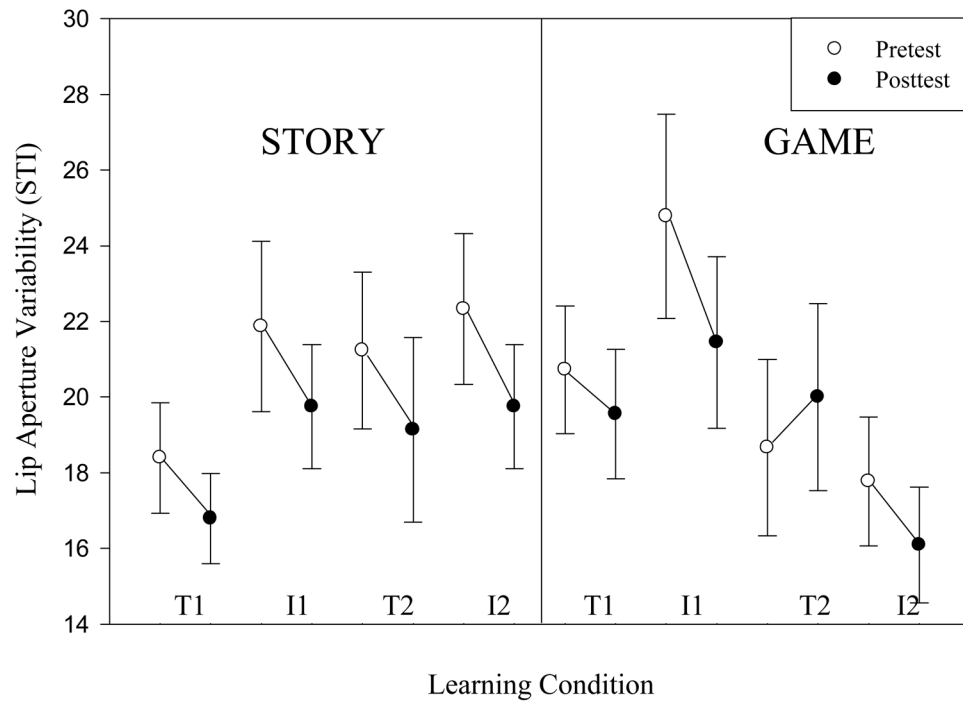Phonetic accuracy difference scores from pre-test to post-test. Error bars represent standard errors.

Figure 4.
Lip aperture variability scores using spatiotemporal index. Labels at the bottom of the figure represent either the trochaic (T) or iambic (I) productions. The numbers 1 or 2 signify which version of the story or game the stimuli were presented. Error bars represent standard errors.
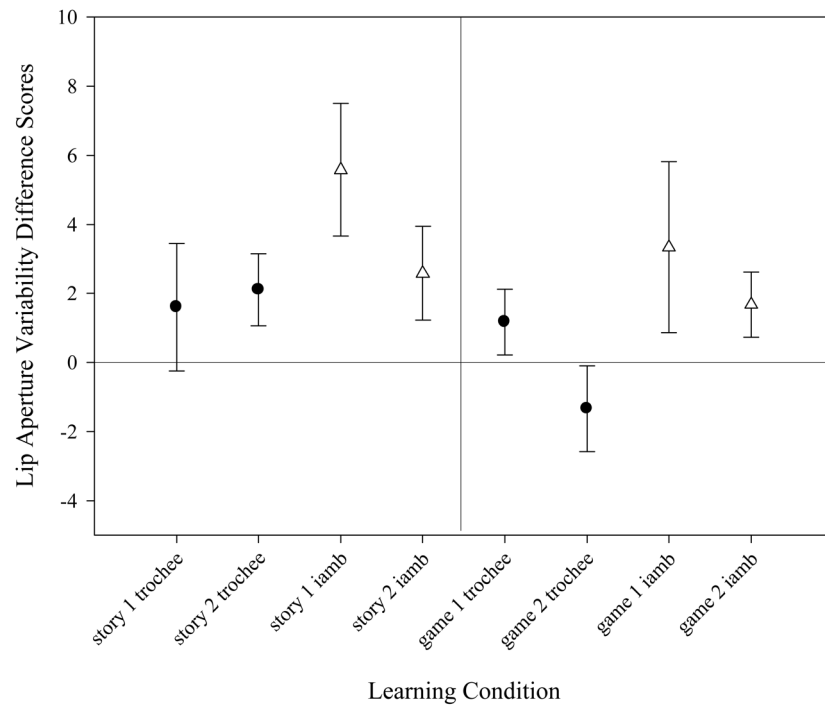
Figure 5.
Lip aperture variability difference scores using spatiotemporal index. Error bars represent standard errors.

Table 1

Detailed Layout of Session Structure and Corresponding Analyses: Story and Game Conditions are Counterbalanced

Session Phase	Task	Purpose	Analyses
Story Pre-Test Phase	12 productions of each stimulus item in direct imitation prior to visual referent exposure	Assess kinematic stability and transcription accuracy prior to word learning	STI (kinematic) and PCC (transcription)
Story Exposure Phase	Exposure to the visual referents associated with novel words embedded within a story, followed by traditional word learning measures	Assess fast mapping of novel words using picture referent identification and picture naming tasks	Accuracy in comprehension and production probes
Story Post-Test Phase	12 productions of each stimulus item in direct imitation subsequent to visual referent exposure	Assess kinematic stability and transcription accuracy post initial word learning	STI and PCC
Game Pre-Test Phase	12 productions of each stimulus item in direct imitation prior to visual referent exposure	Assess kinematic stability and transcription accuracy prior to word learning	STI and PCC
Game Exposure Phase	Exposure to the visual referents associated with novel words in a picture-matching game, followed by traditional word learning measures	Assess fast mapping of novel words using picture referent identification and picture naming tasks	Accuracy in comprehension and production probes
Game Post-Test Phase	12 productions of each stimulus item in direct imitation subsequent to visual referent exposure	Assess articulatory stability and accuracy post initial word learning	STI and PCC