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The role of lexical frequency, telicity & phonological factors on past tense production in children with SLI & their typically developing peers

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THE ROLE OF LEXICAL FREQUENCY, TELICITY & PHONOLOGICAL FACTORS ON PAST TENSE PRODUCTION IN CHILDREN WITH SLI & THEIR TYPICALLY DEVELOPING PEERS

by

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

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has been approved by the Examining Committee for the thesis requirement for the Master of Arts degree in Speech Pathology and Audiology at the May 2010 graduation.

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ABSTRACT

Limited research is available about how lexical and phonological verb properties interact with past tense production by children. Frequency of the inflected form and phonotactic probability might serve as input-driven alternatives to previously-studied factors such as lexical aspect and coda composition.

Archival elicited production data from 4-9 year old children with typical language (N = 24) and specific language impairment (N=14) using 108 two-clause complex sentences/85 different verbs were analyzed for past tense use, coda composition, telicity, phonotactic probability (Vitevitch & Luce, 2004), and lexical frequency (CHILDES; MacWhinney, 2000).

Several regression models were considered, including one with only categorical factors (e.g. obstruent/continuant ending), one with only continuous factors (e.g. average biphone probability), one with only phonological factors, one with only lexical factors, and several mixed models.

Diagnostic status and verb regularity accounted for the majority of the variance. The combination of lexical frequency of the inflected form with residuals of stem lexical frequency was the best lexical model. Place and manner information for the final consonant of the stem comprised the best phonological model. These two models combined into a final overall predictive model.

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CHAPTER I

INTRODUCTION

Difficulty using past tense verb forms is one of the signature characteristics of children diagnosed with specific language impairment (Rice & Wexler, 1996). Research that focuses on the details of this characteristic and investigates the specific lexical and grammatical factors that contribute to these errors could aid us in understanding why this is such a problematic area for children with SLI. As the description of the past tense deficit in children with SLI becomes more detailed, the profile of the disorder can be better defined so that SLI can be more clearly diagnosed. Clinicians could more easily diagnose SLI by assessing a child’s past tense production in the most applicable lexical conditions.

In general, an investigation into past tense production of children with typical language can provide insight into typical language use and development. A child's success or difficulty with specific conditions of producing past tense is an outward representation to how their brain is processing the factors that influence their production. A lexical or grammatical characteristic of a production condition that a typical child has difficulty with could indicate how their language systems are interacting and the degree to which characteristics weigh into that interaction. The difference between the conditions that facilitate past tense production for typically developing children and children with SLI could further develop the profile of SLI.

In addition to providing more information about children with typical and disordered language, a more detailed past tense profile could also benefit the decision-making process for therapy for children with SLI. For example, clinicians could target the specific past tense needs of children with SLI by selecting optimal targets that would facilitate the most growth in this area of deficit. We know from work on principles of error-free (or 'error-less') learning in many areas of communication and learning research (e.g. Jokel, Rochon, & Anderson, 2010; da Silva & Sunderland, 2010) that creating a successful learning environment can facilitate task and skill learning success. The underlying principles of this learning approach are that stimuli should be carefully selected and introduced in an order so that the learner is highly successful with productions at every progressive task level. This allows the learner to practice with accurate repetitions and, as they build toward more difficult tasks, to continue to produce and learn from their own accurate productions. With added detail about specific facilitative factors of past tense production for children with SLI, it is possible that this learning approach could be applied successfully to this population.

Telicity has been shown to facilitate the production of past tense by typical children (Johnson & Fey, 2006; Leonard, et al., 2007). Lexical frequency (Marchman, Wulfeck, & Weismer, 1999), phonological composition (Marshall & van der Lely, 2007), and phonotactic probability (Marshall and van der Lely, 2006) also influence production of past tense by children with SLI. In the following sections, we review the information about how each of these types of factors relate to past tense production and discuss the evidence surrounding interaction between these factors.

Lexical Aspect

Lexical aspect appears to have close ties to the production of tense markers by children. As suggested by the aspect before tense hypothesis, progressive actions co-occur with the use of –ing; completed events co-occur with the use of –ed, forming logical connections between form and meaning (Li & Shirai, 2000). This seems to bootstrap the acquisition of tense in young typically developing children. For instance, Johnson and Fey (2006) investigated the relationship between lexical aspect and accurate use of tense. Verbs were classified by whether or not they represented a durative, dynamic, and telic action. If a verb is considered durative, its action takes time to unfold. A verb that is not durative represents an action that occurs completely within an instant.

An action is dynamic if it requires energy and results in a changed state once it has occurred. Finally, a third factor of aspect is if the action is telic, or is an event with an inherent endpoint. Using an imitation task, typically developing children were asked to produce verbs that were categorized by having various combinations of these telic properties and the resulting relationship with tense usage. The sentences only differed with regard to whether or not its endpoint was shown within the clip or if it appeared to be an ongoing event. Children imitated more accurately when the tense corresponded to the aspectual properties of the verbs. The children's use of past tense was most successful with verbs that were associated with an action that had an inherent property of completion. However, the children's accuracy of producing past progressive verbs to describe atelic actions was not found to be statistically significant. This suggests that telicity may be facilitative for the production of past tense verbs by children with typical language.

Leonard, Deevy, Kurtz, Chorev, Owen, Polite, et al. (2007) extended the examination of lexical aspect to the use of the simple past –ed, as well as progressive –ing, in both children with SLI and children with typically-developing language (TD). They asked whether lexical aspect would influence accurate tense marker use for TD children and children with SLI in a similar fashion. The children completed tasks that required them to describe a scene they had just seen using a set of either telic or atelic verbs that had been matched for frequency and phonotactics. For the TD group, the authors found a relationship between lexical aspect and verb form. As might be expected by the situations for which we typically use these types of verbs, the use of –ed was correlated to telic events, while –ing success was related to atelic actions. The SLI participants did not demonstrate this pattern. They used both –ed and –ing less accurately overall than their TD peers and used –ed and –ing at similar rates regardless of the aspectual properties of the events. This study furthered the theory of lexical aspect being used as a cue for inflection by typically-developing children, while supporting the need for continued investigation into the divergent performance by the children with SLI.

Lexical Frequency

One possibility is that lexical aspect may be particularly facilitative for past tense because telic, completed verbs may be heard often in their past tense form. To examine this, frequency information should also be considered as another lexical influence on past tense production. Previous research has looked at the role lexical frequency plays in past tense production and if its effects are different for regular and irregular verbs and for children with and without SLI.

A study of elementary children with and without SLI (Marchman, Wulfeck, & Weismer, 1999) found several correlations between lexical frequency and success with past tense marking. Children looked at pictures of people performing various actions, which an examiner's prompt told them happened in the past. The participants were then cued to finish a sentence about what the person did. Both the SLI and TD groups produced more errors on the items with lower-frequency verbs. Van der Lely and Ullman (2001) completed a similar study with young school-aged children. Participants played a word game in which they changed present tense sentences containing either a regular or irregular verb into past tense. For the irregular verbs, higher frequency verbs were more accurately inflected by both the SLI and TD groups. For the regular verbs, the participants with SLI were again better at the higher frequency verbs, yet the TD group had no frequency effect.

Both of these previous studies found that both TD children and children with SLI were affected by verb frequency when inflecting irregular verbs. The difference between the groups was seen in lexical frequency's influence on the inflection of regular verbs. TD children were unaffected by frequency when producing past tense regular verbs. However, children with SLI were more accurate as frequency increased frequency for the regular verbs just as it was for the production of the irregular verbs. This suggests that TD children produce inflection via aspectual cues, while children with SLI produce inflection via frequency information.

Phonological Complexity

The phonological complexity of the inflected form and the phonotactics of a verb have been considered as phonological influences of past tense inflection accuracy. Previous research has suggested that these phonological influences might have a different effect than that of the lexical factors do on each of the participant groups. Furthermore, within the phonological factors, there may be a difference between the effects on each of the participant groups.

A variety of previous research has cited the increased articulation complexity of consonant clusters. This includes that mastery of production of these clusters occurs later than their singleton components (Smit, Hand, Freilinger, Bernthal, & Bird, 1990). One study, by Kirk and Demuth (2005), compared accuracy and development of a variety of consonant clusters in the word-initial and word-final positions. Their typically-developing 2-year-old participants produced single words that contained one of these types of clusters. While they did not examine every combo of consonant clusters, because they limited their stimuli to age-appropriate vocabulary, they did find significant differences in production accuracy levels. Most relevant to this past tense discussion are their findings that word-final consonant clusters in which the second/final consonant was a stop were less accurately produced than other word-final clusters, including nasal + /z/ and stop + /s/. This suggests that for typical children, even within the overall developmental difficulty of consonant cluster production, some of the cluster properties common at the end of past tense inflected forms are even more difficult.

While Kirk and Demuth's study (2005) is just one record of the difference between the accuracy of production of different consonant clusters and of overall difficulty in production of clusters by developing TD children, the phonological productions of children with SLI have been studied as well. Bortolini and Leonard (2000) analyzed speech samples from preschoolers with SLI and their MLU-matched TD peers. They found that the participants with SLI had more difficulty than these TD peers with a variety of phonological productions, including word-final consonants and word-final consonant clusters. These errors and increased difficulty is of particular concern because these two phonological production skills are important for inflectional morphemes.

In a study on the potential influence of the phonological composition of verbs, that focused on the inflected form's ending (Marshall & van der Lely, 2007), researchers found that a TD group was equally accurate with verbs that did and did not have a final consonant cluster. However, as might be predicted from other phonological studies discussed above, the children with SLI were less accurate with more phonologically complex verb endings. Given that they controlled for the children's phonological abilities in non-morphological contexts, we can see that even beyond the above-discussed difficulty with word-final consonant clusters that TD children have, these complex phonological forms appear to be even more difficult for children with SLI.

Phonotactic Probability

In an earlier study (Marshall & van der Lely, 2006) two types of clusters were introduced at the ends of nonsense words: monomorphemically legal and illegal ones. In their study, a monomorphemically legal cluster was defined as one that was created at the end of an inflected regular past tense verb but also appears in other non-verb or non-inflection occurrences in English (e.g. the /st/ in *crossed* and *frost*). Because they occur in a variety of words and word positions, monomorphemically legal clusters are generally higher frequency phoneme combinations. A monomorphemically illegal cluster was one that occurs only in regular past tense productions but not in other non-verb or noninflected words (e.g. the /md/ in *slammed).* Monomorphemically illegal clusters are limited to the final position of inflected verbs, and they represent combinations of phonemes that occur less frequently than monomorphemically legal clusters. They found that the TD children were not influenced by phonotactics, but the SLI group was. The children with SLI were more accurate at inflecting past tense for the highly frequent verbs that used monomorphemically legal clusters.

A second way to examine the influence of phonotactic probability is to use whole-word phonotactic measures. The stimuli used in the previous study were selected based on the frequency, or legality, of the word-final cluster. However, in a study of SLI, MLU-matched, and age-matched participants, Leonard, Davis, and Deevy (2007) considered the influence of the phonotactic probability of the entire word on participants' abilities to inflect novel verbs accurately. Using 12 CVC non-words, that included 6 high phonotactic probability/high neighborhood density verbs and 6 low phonotactic probability/low neighborhood density verbs, the children watched a short scene and were told that they would need to pay attention to the actions with funny names. The participants were taught the actions as one character used each of the verbs three times in contextual sentences with a matching action, and the children were given a prompt that required an –ed response. Not only were the participants in the SLI group less likely than the typically-developing groups to provide a scorable response because their responses were not phonologically accurate uses (of any form) of the novel verb, but they also produced –ed significantly more with high probability novel verbs that with the low probability ones. In addition, the SLI group performed significantly worse on the low probability verbs than the MLU-matched TD group. This suggests that the SLI participants' performance was facilitated when the verbs contained more frequent sounds, while the TD groups were less affected by frequency. However their findings were limited by the small number of productions by all groups.

Lexical and Phonological Factors Combined

Very few studies have ventured into combinations of possible contributors. Marchman, Wulfeck, and Weismer (1999) studied the interaction between lexical frequency and phonological composition. In this study, school-aged children with typical language and others with SLI responded to prompts in an elicitation task designed to elicit past tense productions of regular and irregular verbs. Verbs were coded for several different properties, including lexical frequency and phonological composition, defined here as the place of production of the final consonant of the verb stem. Past tense production was facilitated for both participant groups for the verbs with higher lexical frequencies and alveolar stem endings. This effect of the stem phonological composition was found to be significantly greater for the SLI group, and only this group showed more errors on the non-alveolar stem endings.

Johnson and Morris (2007) considered the interaction of the characteristics of lexical aspect, as described above, with a simple consideration of the phonological properties of the end of the verb. In their study of typically developing toddlers, the authors found that interaction between factors to be successful, and that the combination a non-obstruent ending with a telic verb was the most challenging. The TD children's performance was improved when the verbs contained either one or two facilitative factors – telicity and/or having a non-obstruent ending. This study also included a single case study of a child with SLI, and the findings were different from those of the typically-developing language group. The child with SLI had significantly more success with telic verbs that ended in a non-obstruent phoneme. The child with SLI appeared to need both of the facilitating factors, as he had only moderate accuracy with just one factor and was even less accurate without either of the facilitating factors. The relative contributions of the factors were not considered. This case study promotes the need for additional investigation into the impact of an interaction of factors on the productions of children with SLI, as well as expanding these interactions to include other facilitative variables that were previously examined singularly.

Present Study

While lexical and phonological factors have largely been examined individually, additional research on the influence of their combinations is warranted. We are interested in what happens when combinations of properties of lexical aspect, lexical frequency, phonological complexity, and phonotactics are used predict the accuracy of past tense production. In what ways do these factors best combine to predict past tense production? Do we see that combinations are independent and additive as observed in Johnson and Morris (2007) suggest from their case study data? Or does the addition of any single factor boost performance to the extent that other factors are not able to further improve a child's accuracy?

Within these four main categories factors, we are also interested in which variables stand out as the most predictive of past tense accuracy. The same sort of information has been studied in a variety of ways. For instance, Marshall and van der Lely (2006) considered legal and illegal clusters while Leonard, Davis, and Deevy (2007) looked at phonotactic probability of the word. Both studies found similar results, but it is not clear which is the more appropriate way to consider such information. To that end, we ask, do continuous factors that appear to be closely related and almost measures of their categorical counterparts account for more variance in the prediction of past tense inflection than categorical ones do? Are categorical classifications detailed enough to accurately represent the factors that they measure? Or will the most predictive model be one with continuous variables, suggesting that a specific continuum of information in which each data point has a set relationship to another is required to account for variance in past tense accuracy? That is, is lexical frequency (Marchman, Wulfeck, & Weismer, 1999) more predictive than lexical aspect (Leonard et al., 2007), and are phonotactic properties (Leonard, Davis, & Deevy, 2007) more predictive than the categorical measures of phonological complexity such as the presence of a word-final cluster (Bortolini & Leonard, 2000)?

Finally, we predict that the factors that stand out as most predictive of past tense accuracy for TD children will not exactly match those that are predictive for the group of children with SLI. We predict that lexical frequency (van der Lely & Ullman, 2001) and phonotactic probability (Leonard, David, & Deevy, 2007; Marshall & van der Lely, 2006) will be more facilitative for the SLI group, while phonological complexity will be non-facilitative (Bortolini & Leonard, 2000). Furthermore, lexical aspect will be more facilitative for past tense production by the TD group (Leonard et al, 2007).

CHAPTER II

METHODS

Participants

This study uses archival data from a prior study focused on complex syntax (Owen, in press). Thirty-eight school-age children participated in this study. Fourteen children had a diagnosis of specific language impairment (5;0-8;1); 13 typically developing (TD) children were age-matched to each of the children in the SLI group; and 11 four-year-old children were matched to the SLI group participants by having a comparable mean length of utterance (MLU; +/- 0.35 words in a 100-utterance language sample) and expressive vocabulary (+/- 5 points of raw score on the Expressive Vocabulary Test). All children in all three groups had typical hearing, nonverbal IQ scores on the KBIT-II Matrices subtest above 83, and normal social abilities according to parental report, ensuring that children met standard exclusionary criteria for a study of SLI.

Participants in the SLI group met two or more of the following four criteria: (1) scored below the 10^{th} percentile on the *Structured Photographic Expressive Language Test-II* (Werner & Kresheck, 1974); (2) obtained a standard score below 7 on the non-word repetition subtest of the *NEPSY* (Korkman, Kirk, & Kemp, 1998); (3) received a composite standard score $\leq$ 85 on the *Test of Narrative Language* (Gillam & Pearson, 2004); (4) were receiving speech, language, or reading services at the time they participated in the study. The TD children scored within or above the normal score range on all of the measures given to the other participants and had no history of receiving speech or language intervention services. All participants were administered the *Peabody Picture Vocabulary Test-III Form B* (Dunn & Dunn, 1997) to document their receptive vocabulary skills. A summary of the children's performance on the assessments mentioned above can be found in Table 1.

Table 1. Summary of participants' performance on assessments

			Group		
Assessment	Score Type	Average Range	Age – matched	MLU-matched	SLI
SPELT-II	Percentiles	16-84	72.4 (17.8)	81.2 (16.7)	10.22 (8.9)
TNL Index	SS	85-115	109.5 (16.3)	-	83.3 (14.9)
NEPSY: NWR	SS	7-13	12.3 (2.6)	-	7.3 (1.8)
KBIT-2	SS	85-115	99.6 (9.37)	106.2 (8.08)	97.4(11.97)

Note: SS = standard score. Scores listed are the mean for each participant group. Numbers in parentheses are the standard deviations.

Previous Study

Past tense production was elicited via an enactment paradigm. Participants watched a short puppet scene and then were prompted to recount what happened in the scene to an outside character that had missed the action. Thirty-six sentences were elicited in each of three conditions – coordinate, subordinate, and adjunct. For each condition, the prompts were designed to produce a sentence with two clauses, both of which were designed so that the target verb would be most likely to be produced in the simple past tense. The coordinate condition elicited two coordinated clauses (e.g. *Piglet listened and Frog hid.*). The subordinate condition, elicited a main clause followed by a complement clause (e.g. *Ratty guessed Genie fell*). Finally, the temporal adverbial condition elicited a main clause followed by a temporal clause (e.g. *The aliens exercised while Minnie danced.*).

In the temporal and coordinate conditions, all thirty-six verbs in the first clause were regular and intransitive. The verbs in the first clause of the subordinate conditions were all mental or communication verbs. Seven were regular and three were irregular. Eight of these ten verbs were repeated three times each and two of these verbs were repeated six times each for a total of thirty-six items. For the second clause, the targeted verbs were selected to include both regular and irregular past tense forms equally. The word-level properties examined in the present study were not controlled for during the selection of the stimuli items. A list of the verbs employed for each condition can be found in Appendix A in Owen (in press).

Results from this previous study showed that the sentence frame and the location of the verb in the sentence influence the likelihood of past tense inflection using a tense marker. Because large random effects remained for the individual items, additional analyses of properties at the word level were warranted. Although the word-level properties were not controlled for, a sufficient range in each of the categories of factors chosen for the present study, telicity, lexical frequency, phonological composition, and phonological probability, allowed us to test the influence of these word-level factors.

Present Study

Unlike the prior study's focus on the influence of sentence-level factors such as clausal complexity, here we focus on word-level factors. Therefore, while only two-clause productions were retained in the analysis of the data in the original study, one-clause productions were included in the present study to maximize the number of responses available for analysis. Because of this decision, all productions were considered independent of the clause order or sentence type in which it was originally produced. Given the inclusion of both 1 and 2 clause responses, 8208 tokens were elicited from children. 2259 verbs were discarded for a variety of reasons described below and shown in Table 2.

Each child's production was categorized for the type of inflection. The productions were classified as being a bare stem, correct regular past tense inflection, correct irregular past tense production, or irregular form that was incorrectly inflected using 'ed'. Past progressive and present progressive productions were eliminated from the final data set because they have a different telicity and inflection pattern than simple past productions. These productions accounted for approximately 13.8% of the children's overall productions, or the elimination of 1131 responses. A very small set of additional incorrect productions, such as third person singular present tense or past perfect, were also eliminated from the analyzed data set (N=357) given our focus on simple past.

Some participants used a verb in their sentence that was not the target verb used by the puppet or researcher in that scene. If the verb the child used matched a target verb that was used elsewhere in the prompts (N=1003), it was retained in the data set. These verbs were retained for analysis even when they were not the targets for that particular item because the participants' inflection of these verbs outside the specifically targeted context still provides information about the inflection of that verb. If the verb the child produced was not a target verb for that item or for another item in the study, it was excluded from the final data set (N = 419) due to the low individual frequencies in the data set. Without sufficient productions for the particular lexical item, analysis of the other contributing factors was difficult. The three exceptions to this exclusion rule were *go*, *do*, and *want* (N = 412), which were included in the analyzed data set even though they were not in the verb stimuli set because they each occurred as, if not more, frequently than most of the targeted verbs.

The remaining verbs produced in the simple past in the previous study (N=5649) were re-coded for telicity, lexical frequency, and phonological characteristics that are described below. To summarize, the analyses completed below involved 5949 tokens of 85 verb types. 2259 tokens were excluded because of being a non-target verb, being produced as progressive, or being otherwise unscorable or unintelligible. A breakdown of the data that were retained and eliminated in the final data set can be viewed in Table 2.

Table 2. Summary of eliminated and retained data points

	Eliminated	Retained
Past and present progressive productions	1131	
Other incorrect responses*	357	
Infrequent, non-target verbs	419	
Unintelligible responses or responses without verbs	652	
Total eliminated items	**2559**	
Frequent, non-target verbs (*do*, *go*, *want*)		412
Productions that did not match target, but were targets elsewhere		1003
Productions that matched target, not excluded for above reasons		4234
Total retained items		**5649**

*Includes productions that were present tense, past perfect, or were inflected with multiple incorrect inflectional morphemes

Lexical Aspect

Although lists of highly telic and highly atelic verbs do exist, there are no well-established measures of lexical aspect. Telicity is only partially related to the verb and may be better characterized as being an expression of the entire verb phrase (such as, he walked *around* vs. he walked *to the table*). With this in mind, the lexical aspect of each verb was determined via adult ratings of the elicitation scenarios. A group of eight undergraduate and graduate speech language pathology students scored each verb on a scale of 1-4 on the dimensions of dynamic, telicity, and continuity (Leonard et al., 2007). The scorers were given the descriptions of the three dimensions of lexical aspect shown in Table 3. They were asked to score one factor at a time for the entire list of verbs for all three scenarios before moving on to the next factor. A higher score indicated that a verb was more representative of that dimension of lexical aspect.

Table 3. Telicity dimensions

Factor	Description	Mean z-score	SD
Dynamic	A lower score on this factor indicates that the verb represents an action that is static, or unchanging. A higher score on this dimension indicates that the verb situation is dynamic, or changing.	0.03	0.63
Clear Endpoint	A lower score on this factor indicates that the verb represents an action that does not have an inherent or clear end to its action. A higher score represents an action with a clear, inherent endpoint.	-0.00055	0.64
Punctual	A lower score on this factor indicates that the verb represents an action that is inherently continuous or takes time to occur. A higher score represents an action that is completed within a short duration, if not instantaneously.	-0.51	0.69

Note: SD = standard deviation

For each verb (meaning every production of a verb across all three conditions), the mean score and standard deviation was calculated for each dimension. A z-score, comparing the mean score of each verb to the distribution of mean scores of all the verbs on that characteristic, was used to classify the verb as either being representative of the characteristic (T), *not* being representative of the characteristic (A), or falling somewhere in between those classifications (N). A verb with a z-score less than -0.5 was coded as being atelic (A), a z-score between -0.5 and 0.5 was coded as being neutral (N), and a z-score greater than 0.5 was coded as telic (T) for each of the three dimensions. An overall category for telicity was then determined from the codes for each characteristic. A verb was labeled as being overall telic if two or three of the dimensions were telic, as atelic if two or three of the dimensions were atelic, and as neutral otherwise. Because the telicity rating of each verb varied by its prompt situation, there were no telicity ratings for the cases where the child produced a different verb than the targets for that scenario. The z-scores for each dimension and final classifications of each verb are listed in Appendix A.

Lexical Frequency

Lexical frequency is an indicator of an individual's relative exposure to hearing one word compared to other words and the corresponding experience with the word's lexical information that such exposure could provide. When a child gains lexical information, he expands his schema of the ways in which that verb can be used, how it changes in different lexical situations, its position relative to other lexical forms, etc. The following lexical frequency variables were calculated from the parental lexical frequency information in the CHILDES database (MacWhinney, 2000): stem frequency, frequency of the child's production, and total frequency. Stem frequency for *walk* indicates how often 'walk' occurred in the database. The frequency of the child’s production would have meant, for example, that 728 was listed as the frequency of use. The total lexical frequency for all forms of each verb in the CHILDES database was calculated for this variable. For example, the total for *walk*, a regular verb, includes the frequencies for *walk*, *walked*, *walks*, and *walking.* This total also includes the frequency of productions that are not grammatically correct, when they were also present in the database. For example, the total lexical frequency for *think*, an irregular verb, includes *think*, *thinks*, *thinking*, *thought*, *thinked*, and *thoughted.* No attempt was made to distinguish between nouns (e.g. the *thought*, a *walk*) and verbs (e.g. he *thought*, I *walk*) since exposure to the word in all lexical scenarios is thought to add to an individual's knowledge of that word's lexical information. All frequency variables were log transformed to standardize their distribution. Appendix B lists the lexical frequency information for each verb.

Phonological Complexity

The articulatory difficulty of the child's production was determined by its final cluster characteristics and articulatory manner of production. Each child's production was coded for the presence or absence of a word-final consonant cluster at the end of the inflected form (Marshall & van der Lely, 2007). Here, a word-final consonant cluster was defined as the production of more than one consecutive consonant sound after the last vowel of the production. For verbs that had a word-final consonant cluster, the number of consonants in that cluster was noted. Therefore, each production was labeled 0, 1, 2, or 3, depending on the number of consonants at the end of the word. The second measure of articulatory difficulty was the manner of production of the final consonant of the verb stem. Each stem was coded as having either a continuant or obstruent ending. Johnson and Morris (2007) have shown that obstruents depress past tense accuracy, presumably because it is more difficult to inflect a word with a /-t/ or /-d/ if the word ends in a stop, fricative, or affricate than if it ends in a liquid or glide. While differences in manner might be the source of the non-facilitating nature of obstruent endings, place of production could also be a factor affecting articulatory complexity (Marchman, Wulfeck, & Weismer, 1999). Thus we also coded for the place of the final consonant on the stem of the verb, front, mid, and back, and verbs that ended in vowels were coded as a separate category.

Phonotactic Probability

While lexical frequency represents familiarity with the use and form of a verb, phonotactic probability represents a likelihood of familiarity with the sounds and sound combinations within a word. Phoneme positional probability is a measurement of the likelihood a phoneme occurs in a particular position of a word regardless of word length (Vitevitch & Luce, 2004). It may be considered to be an indicator of the relative familiarity an individual has with the sounds used to produce this word. Likewise, biphone positional probability focuses on the occurrence of a pairing of sounds in a specific word position. Biphone probability is more of an indicator of a relative familiarity with how sounds combine within English words.

An online phonotactic probability calculator (Vitevitch & Luce, 2004) was used to determine the phonological probability of both the stem and past tense productions of each of the target verbs. This calculator is a database that provides data about the likelihood of two sound segments occurring together within a word, biphone positional probability, and the likelihood that a phoneme occurs in a particular position in the word, phoneme positional probability. The probability data for the calculator came from pronunciations of the entries in the 1964 Merriam-Webster Dictionary.

Phoneme positional probability is calculated by finding the sum of the probabilities that each individual phoneme occurs in that position of the word. Position is determined by counting from left to right. For example, the word /stæmp/ has five phonemes. Its phoneme positional frequency value of 0.2070 is the sum of the probability that /s/ occurs in the first position of a word, the probability that /t/ occurs in the second position, and so on. Likewise, the value which represents biphone positional probability is the sum of the probability of each of the pairs of phonemes occurs in that position of a word. In the verb /stæmp/, the biphone probabilities are 0.0177 for /st/ in the first position, 0.0023 for /tæ/ in the second position, and so on. Therefore, 'stamp' has an overall biphone frequency of 0.0237, the sum of those values. The phoneme positional probability of the stem and inflected form of the child's production both were calculated. Biphone positional frequency for both the child's stem form and inflected production also were calculated. These data were adjusted for the differences in the word length of the verbs according to the standardization procedure described by Storkel (2004).

CHAPTER III

RESULTS

To test the ability of each of the variables described above to predict correct past tense use, several regression models were evaluated. The dependent measure was correct past tense inflection. Over-regularizations (e.g., *goed*) and incorrect productions of irregular (e.g., *brung*) and regular (e.g., *jumped-id*) past tense were counted as incorrect. Given that previous work has shown them to be critical, all regression models contained variables reflecting participant group and regularity. The independent lexical variables consisted of telicity, stem lexical frequency, total lexical frequency, inflected lexical frequency, and ratio of inflected lexical frequency to stem lexical frequency. The independent phonological variables included number of consonants at the end of the inflected form, manner of production of the final consonant of the stem, place of production of the final consonant of the stem, stem positional probability, stem biphone probability, inflected form positional probability, and inflected form biphone probability.

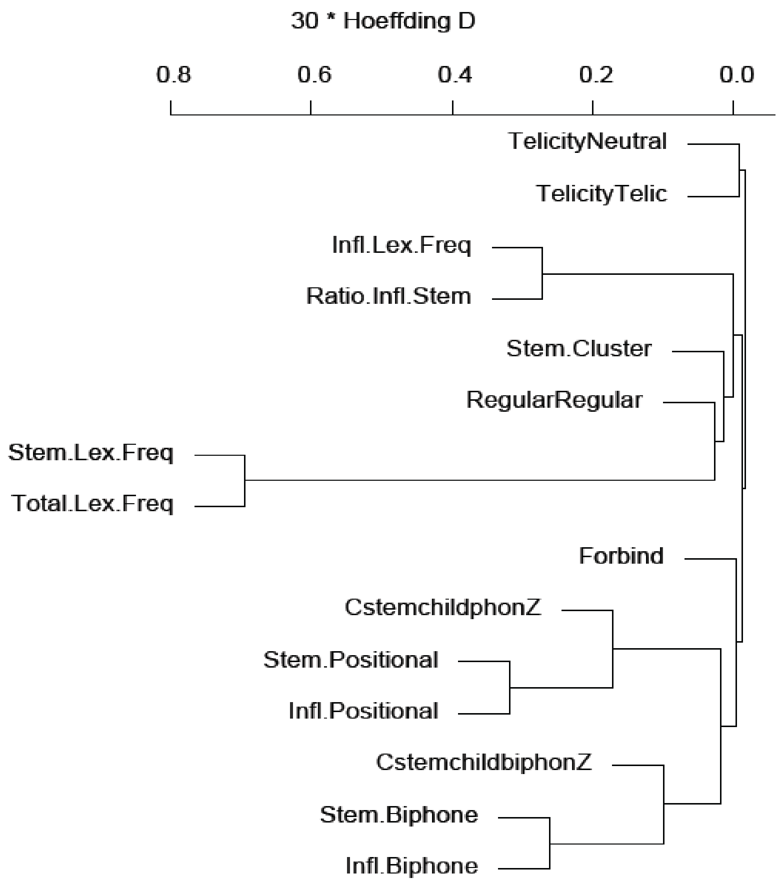
Relationship between predictor variables

One concern in designing a model of the verbs here was that many of the variables were collinear with each other, as can be seen in Table 4. A cluster analysis measure, Hoeffding's d, was utilized to initially group the variables. Hoeffding's d is a measure of dependence that analyzes the co-linearity of variables. It groups variables according to how related they are, as determined by a series of rankings and re-rankings based on how dependant the variables are on each other, resulting in pairings and groupings. Figure 1 shows the graph of this analysis, a physical grouping of the similar variables. Appendix C contains the data from the Hoeffding's d analysis. We selected one variable from each grouping to be considered for our initial model. Following this step, each variable was regressed against the others in its group, to allow us to determine how much accuracy it predicted over each of the other variable members of that group. For instance, because the results of Hoeffding's d indicated that the stem lexical frequency and total lexical frequency were closely related (d = 0.69), only stem lexical frequency was chosen from that pair to be included in the lexical model. Thus, the lexical model was initially built by entering the lexical frequency of the inflected form and then including the residuals of what the bare stem frequency predicted beyond the inflected frequency. Total lexical frequency was not included at all due to the high degree of co-linearity.

Table 4. Correlation coefficients of continuous variables

Variable	1	2	3	4	5	6	7	8	9
1. Stem positional probability	1.00	0.59	0.82	0.59	-0.15	0.19	0.17	0.05	-0.10
2. Stem biphone probability	–	1.00	0.48	0.71	-0.15	0.16	0.13	-0.01	-0.07
3. Inflected positional probability	–	–	1.00	0.70	0.04	0.13	0.15	0.13	0.05
4. Inflected biphone probability	–	–	–	1.00	-0.10	0.25	0.25	0.20	0.00
5. Number of consonants in cluster at the end of stem	–	–	–	–	1.00	0.40	-0.42	-0.35	-0.04
6. Stem lexical frequency	–	–	–	–	–	1.00	0.97	0.69	-0.11
7. Total lexical frequency	–	–	–	–	–	–	1.00	0.78	0.06
8. Inflected lexical frequency	–	–	–	–	–	–	–	1.00	0.46
9. Ratio of inflected to stem	–	–	–	–	–	–	–	–	1.00

Figure 1. Graph of groupings created by Hoeffding's d analysis



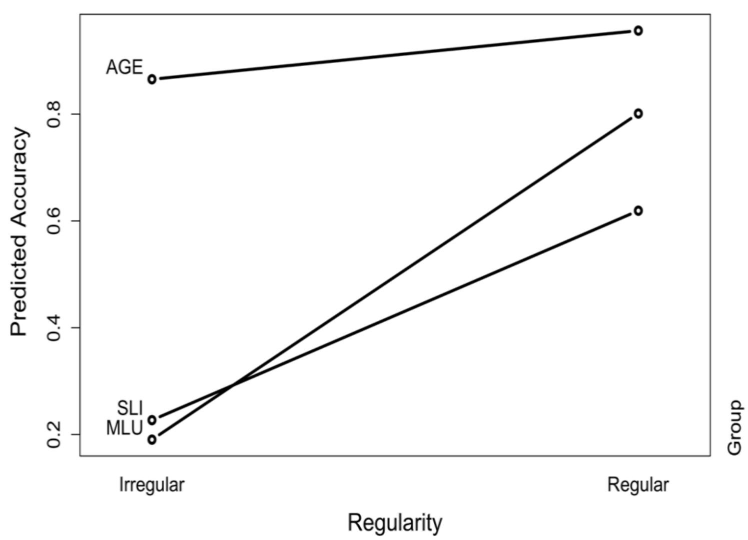
The analysis proceeded in this manner, with additional residuals being added in as predictors, with the goal that each additional factor we chose for our model would contribute additional information above and beyond the information provided by the factors already chosen for the model. Each of the following models' ability to predict past tense accuracy was compared to how group and verb regularity can predict accuracy alone. The details of this reduced model can be viewed in Table 5 and Figure 2.

Table 5. Basic participant group and regularity regression model

	Variance	SD		
Random Factors				
Stem	0.61	0.78		
Participant	1.69	1.30		
	Coefficient	SE	z-value	p-value
Fixed Factors				
Intercept	3.21	0.44	7.27	< 0.01*
Regularity (reference category = Irregular)				
Regular	-0.27	0.27	-0.97	0.33
Participant Group (reference category = Age)				
MLU Group	-1.72	0.58	-2.97	< 0.01*
SLI Group	-2.80	0.55	-5.10	< 0.01*
Regularity*Group (reference category = Irregular, Age)				
Regular*MLU	0.21	0.24	0.89	0.38
Regular*SLI	0.35	0.23	1.50	0.13

Note: SD = standard deviation; SE = standard error

Figure 2. Graph of model with regularity and participant group only



Lexical Models

The lexical variables were considered in three separate models. The telicity information was considered for the categorical lexical model, while the lexical frequency information was evaluated for a model of continuous data. After each of the individual models was constructed, the telicity and lexical frequency information was combined into a single model.

Telicity Model

Accuracy of past tense production was examined by telicity categorization. Only verbs that had an assigned value based on adult ratings were included in this analysis. The neutral irregular verbs tended to be less accurately inflected than the atelic verbs ($\beta = -1.13$, $p = 0.07$). Neutral regular verbs were slightly more accurate ($\beta = 1.76$, $p = 0.01$). Although this coefficient in the model did not attain significance, telic verbs were more likely to be inflected correctly for regular verbs only ($\beta = 1.50$, $p = 0.11$). Telicity was not a significant predictor for the irregular verbs telic: ($\beta = -0.80$, $p = 0.30$). There were relatively few irregular telic verbs, given our criteria for selection as telic. Significant interactions were not found between group and regularity or group and telicity, as were found in previous studies (Leonard et al, 2007).

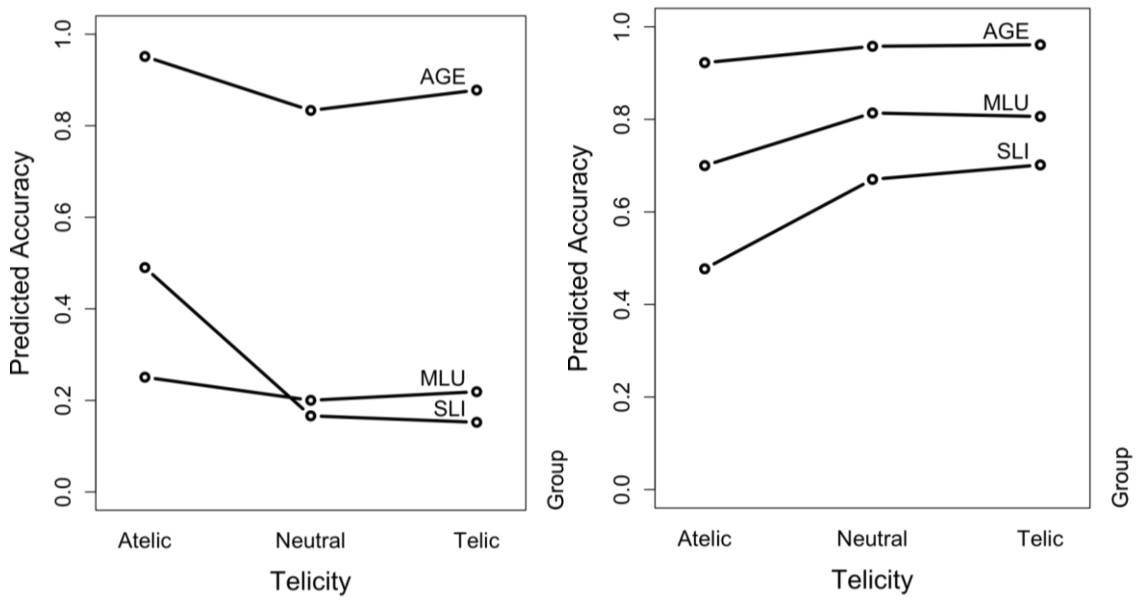
The model shows that telicity and regularity are equally predictive for all groups as demonstrated by the lack of any significant interactions with group. A logistic regression model that included interactions between telicity, group, and regularity was found to have the strongest fit to the data, despite the fact that the two-way interactions did not attain significance, χ^2 (12) = 25.09, p = 0.01. Table 6 contains the details of this regression which is also pictured in Figure 3.

Table 6. Telicity regression model

	Variance	SD		
Random Factors				
Stem	0.52	0.72		
Participant	1.71	1.31		
	Coefficient	SE	z-value	p-value
Fixed Factors				
Intercept	4.07	0.68	5.98	< 0.01*
Regularity (reference category = Irregular)				
Regular	-1.62	0.63	-2.57	0.01*
Participant Group (reference category = Age)				
MLU Group	-1.70	0.77	-2.22	0.03*
SLI Group	-3.20	0.71	-4.51	< 0.01*
Telicity (reference category = Atelic)				
Neutral	-1.13	0.63	-1.78	0.07
Telic	-0.80	0.77	-1.03	0.30
Participant Group*Regularity (reference category = Age, Irregular)				
MLU*Regular	0.19	0.60	0.31	0.75
SLI*Regular	0.63	0.55	1.15	0.25
Regularity*Telicity (reference category = Irregular, Atelic)				
Regular*Neutral	1.76	0.71	2.47	0.01*
Regular*Telic	1.50	0.95	1.58	0.11
Participant Group*Telicity (reference category = Age, Atelic)				
MLU*Neutral	0.06	0.60	0.10	0.92
SLI*Neutral	0.50	0.54	0.93	0.35
MLU*Telic	-0.46	0.72	-0.64	0.52
SLI*Telic	0.45	0.67	0.67	0.50
Regularity*Participant Group*Telicity(reference category = Irregular, Age, Atelic)				
Regular*MLU*Neutral	-0.08	0.67	-0.11	0.91
Regular*SLI*Neutral	-0.37	0.62	-0.61	0.54
Regular*MLU*Telic	0.32	0.89	0.36	0.72
Regular*SLI*Telic	-0.28	0.84	-0.33	0.74

Note: SD = standard deviation; SE = standard error

Figure 3. Telicity regression model



Lexical Frequency Model

The continuous data, or the lexical frequency information, was formed into the second lexical model using a logistic regression. As can be seen in Table 7 and viewed in Figure 4, overall, the accuracy of past tense production increased when the frequency of the inflected form increased (β = 1.02, $p < 0.01$). Additionally, accuracy tended to increase with the stem frequency residuals for irregulars (β = 0.69, $p = 0.08$) and clearly decreased as stem frequency residuals increased for regular verbs (β = -1.22, $p < 0.01$). Consider the verb *squish*, which has a lower stem frequency than one would predict given its inflected frequency. Because *squish* has a large negative residual, this increases accuracy for *squish* (log freq of the inflected form = 1.11; stem form = 0.30), compared to another verb like *answer*, which has a similar inflected frequency (log freq of the inflected form = 1.14) but a stem frequency that is closer to what would be predicted from the inflected form frequency (2.09). Note that despite being lower than *squish*, *answer* is still more accurately inflected than a verb with a much lower frequency of the inflected form, like *float.* The same holds true in the opposite direction when we think about cases in which a verb has a higher stem frequency than we would predict from its inflected frequency.

When group was taken into account along with inflected form lexical frequency, accuracy for both the SLI group and the MLU-matched group tended to increase more slowly as compared to the TD group, although this result was only marginal (p = 0.11 and 0.15, respectively). The role of stem frequency as compared to inflected form frequency was significant for both of these groups. Residuals of stem frequency were less influential for these two groups than was seen for the age-matched group. In fact, when all coefficients were summed, the stem residuals for regular verbs actually had a positive beta coefficient for the MLU matched group, which means that as the stem form frequency declined relative to the inflected form frequency, this group's accuracy also declined. This is the opposite of what we saw for the age-matched group and the SLI group.

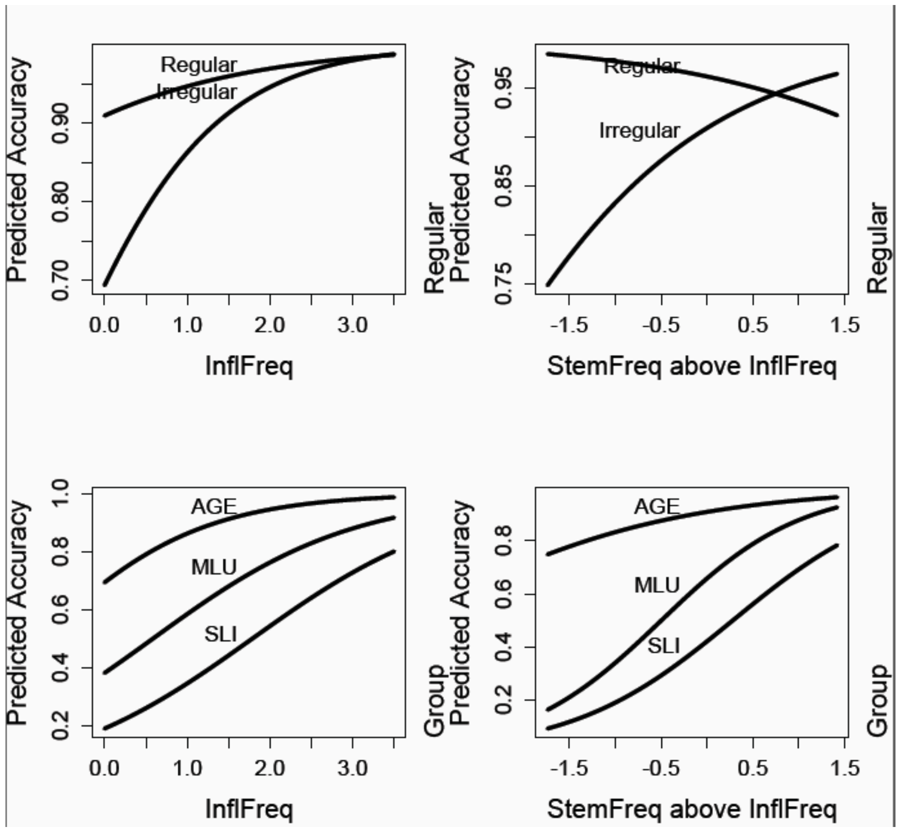
A chi-squared test was used to test the goodness-of-fit to the data set, and suggested that this model was a better representation of the data than the regression that contained just group and regularity alone, $\chi^2(6) = 35.11$, $p < 0.01$ and than a model that contained group and regularity and inflected form frequency $\chi^2(6) = 18.1$, $p < 0.01$.

Table 7. Lexical frequency regression model

	Variance	SD		
Random Factors				
Stem	0.41	0.64		
Participant	1.71	1.31		
	Coefficient	SE	z-value	p-value
Fixed Factors				
Intercept	0.76	0.71	1.08	0.28
Regularity (reference category = Irregular)				
Regular	1.58	0.61	2.61	0.01*
Participant Group (reference category = Age)				
MLU Group	-1.35	0.59	-2.30	0.02*
SLI Group	-2.30	0.56	-4.14	< 0.01*
Lexical Frequency				
Inflected	1.02	0.27	3.85	< 0.01*
Stem Residuals	0.69	0.39	1.78	0.08
Participant Group*Lexical Frequency (reference category = Age)				
MLU*Inflected	-0.19	0.14	-1.44	0.15
SLI*Inflected	-0.21	0.13	-1.62	0.11
MLU*Stem Residuals	0.62	0.20	3.14	< 0.01*
SLI*Stem Residuals	0.43	0.19	2.33	0.02*
Regularity*Lexical Frequency (reference category = Irregular)				
Regular*Inflected	-0.45	0.28	-1.58	0.11
Regular*Stem Residuals	-1.22	0.40	-3.03	< 0.01*

Note: SD = standard deviation; SE = standard error; Stem Residuals = residuals of the stem lexical frequency regressed linearly against the inflected form

Figure 4. Lexical frequency regression model



Final Lexical Model

Finally, the categorical and continuous data were considered for a single, combined model of lexical information. This combined model was better at predicting accuracy than the telicity-only model (χ^2 (12) = 62.16, $p < 0.0001$). However, the combined model was not better than the model with only lexical frequency information (χ^2 (12) = 14.6, p = 0.26). So, telicity does not add to the prediction of lexical frequency in past tense inflection. With this in mind, the best characterization of the lexical information is the continuous model which is already provided in Table 7 above. This suggests that frequency information, as captured in how often the verb appears in the past tense form in child-directed speech, captures the information provided by classifying verbs as telic/neutral/and atelic.

Phonological Models

In the same way as the models with only lexical information, the phonological information was considered for three different models. The phonological composition information formed a categorical phonological model, and the phonotactics data formed the continuous phonological model. A combined categorical and continuous data model followed the separate models.

Phonological Composition Model

Information that was considered for the phonological composition model included the place and manner of production of the final phoneme of the verb stem and the number of consonants after the final vowel in the inflected form. All models that included the number of final consonants were not statistically significant, suggesting that the previous reports of difficulty consonant clusters are better captured by other metrics. Therefore, this factor was rejected for all of the phonological models. The combined place + manner model was a better fit than the place-only model, χ^2 (6) = 14.11, $p = 0.03$, and the manner-only model, χ^2 (18) = 38.67, $p < 0.01$. Table 8 shows the results of the regressions of the phonological composition variables.

Examination of the model coefficients showed that all of the children seemed to be less accurate at inflecting verbs with stems that ended in mid consonants (*s, z, sh, dz, t, d, n, r, l*) than back consonants (*k, g, ng*). This effect was only significant for the SLI group ($\beta = -1.21$, $p = 0.01$). Front consonants (*f, v, p, b, m, th*) also seemed to be more difficult than back consonants based on examination of beta-coefficients and graphs. However none of these factors actually attained significance, with all except the marginal interaction between SLI, Front, Regular (β = -1.74, $p = 0.06$) having p-values > 0.36. Thus we can conclude that this effect is not reliable for either typical group.

With regard to manner, the negative influence of obstruent endings in regular verbs was much more reliable than the effects of place (p's < 0.08). The combination of two- and three- way interactions initially makes it appear as if the children with SLI and the MLU-matched group do better with regular verbs with obstruent endings than their age-matched peers (SLI: β = 1.53, $p = 0.01$; MLU: β = 1.50, $p = 0.01$). However, in many ways this effect simply offsets the two way interaction for manner and regularity (β = -1.52, $p = 0.08$). The detrimental role of obstruents was amplified for both the SLI group (β = -0.89, $p = 0.06$) and the MLU groups (β = -0.87, $p = 0.08$) as compared to typical age-matched children. When all coefficients are considered together, accuracy of all three groups was lower for regular verbs that ended in an obstruent. This effect appeared to be amplified for the age-matched group, but this was likely significant because any change within the already high level of accuracy of this group is more noticeable within the statistical model we are using.

For irregular verbs, the MLU-matched group and SLI group were less accurate on obstruent-final verbs much like they were on regular verbs, suggesting again that these groups may be less accurate with verbs with this final manner but not that their performance here is different between regular and irregular verbs.

Taking the model as a whole, this additional difficulty for the SLI group with front/mid consonants may be due to the fact that front/mid phonemes are articulated in the same way as the regular past tense –ed marker, and that this combination of two similar sounds is more difficult, such as in verbs like *kissed* or that irregular verbs that end in mid consonants fit the pattern of verbs that are already inflected (*bite, hide*). In general, accuracy of both SLI and MLU-matched groups was particularly increased when the target verbs were regular and ended in continuants, and they were far less accurate with regular and front/mid verbs. Phonological composition appeared to have a more limited influence on irregular verbs. Because the phonological forms of regular verbs are much more similar than irregular forms, it makes sense that several significant interactions with regularity were observed.

Table 8. Phonological composition regression model

	Variance	SD		
Random Factors				
Stem	0.42	0.65		
Participant	1.74	1.32		
	Coefficient	SE	z-value	p-value
Fixed Factors				
Intercept	2.77	0.63	5.37	< 0.01*
Regularity (reference category = Irregular)				
Regular	0.96	0.72	1.34	0.18
Participant Group (reference category = Age)				
MLU Group	-0.86	0.74	-1.16	0.25
SLI Group	-1.74	0.69	-2.52	0.01*
Place of Production (reference category = Back)				
Front	-0.32	0.82	-0.39	0.69
Mid	-0.23	0.54	-0.44	0.66
Vowel	0.96	0.69	1.39	0.17
Manner of Production (reference category = Continuant)				
Obstruent	0.58	0.52	1.10	0.27
Participant Group*Regularity (reference category = Age, Irregular)				
MLU*Regular	-0.96	0.72	-1.34	0.18
SLI*Regular	-0.62	0.67	-0.92	0.36
Participant Group*Place (reference category = Age, Back)				
MLU*Front	0.67	0.81	0.82	0.41
SLI*Front	0.70	0.77	0.91	0.36
MLU*Mid	-0.59	0.51	-1.15	0.25
SLI*Mid	-1.21	0.47	-2.55	0.01*
MLU*Vowel	-0.75	0.69	-1.09	0.27
SLI*Vowel	-0.26	0.64	-0.40	0.69

Participant Group*Manner (reference category = Age, Continuant)				
MLU*Obstruent	-0.87	0.50	-1.74	0.08
SLI*Obstruent	-0.89	0.47	-1.88	0.06
Regularity*Place (reference category = Irregular, Back)				
Regular*Front	0.70	0.97	0.72	0.47
Regular*Mid	-0.22	0.71	-0.31	0.76
Regular*Vowel	-1.09	1.12	-0.98	0.33
Regularity* Manner (reference category = Irregular, Continuant)				
Regular*Obstruent	-1.52	0.60	-2.51	0.01*
Participant Group*Regularity*Place (reference category = Age, Irregular, Back)				
MLU*Regular*Front	-0.91	0.97	-0.93	0.35
SLI*Regular*Front	-1.74	0.92	-1.89	0.06
MLU*Regular*Mid	0.55	0.69	0.79	0.43
SLI*Regular*Mid	0.77	0.65	1.17	0.24
MLU*Regular*Vowel	0.61	1.12	0.55	0.58
SLI*Regular*Vowel	0.78	1.09	0.72	0.47
Participant Group*Regular*Manner (reference category = Age, Irregular, Continuant)				
MLU*Regular*Obstruent	1.50	0.58	2.58	0.01*
SLI*Regular*Obstruent	1.53	0.55	2.78	0.01*

Note: SD = standard deviation; SE = standard error

Phonotactic Probability Model

The final phonotactic probability model was one with an interaction between group, regularity, and inflected biphone probability. Recall that all phonotactic measures were normed, following Storkel (2004). As such, the possible range is from -3 to 3, with less frequent combinations having negative numbers. The age-matched group was near ceiling for both irregular ($\beta = 3.17$, $p < 0.01$) and regular ($\beta = -0.20$, $p = 0.49$) verbs before the contributions of phonotactic probability are considered, as such no differences were noticeable for this group although the graphs make it appear as if increased phonotactic probability is reduces accuracy (Effect of biphone probability for irregular verbs: $\beta = 0.10$, $p = 0.69$; for regular verbs: $\beta = -0.33$, $p = 0.24$).

For the SLI and MLU groups, however, phonotactic probability was influential. For regular verbs, the overall effect was one of increasing accuracy with increasing inflected biphone probability for both of these groups (SLI β = 0.87, $p < 0.01$; MLU β = 0.76, $p < 0.01$). For the irregular verbs, the opposite effect was seen. As inflected form biphone probability increased, past tense irregular verb accuracy decreased (SLI β = -0.53, $p = 0.01$; MLU β = -0.47, $p = 0.03$). It is possible that lower accuracy on irregular forms was due to both of these groups simply being more likely to overregularize past tense irregular verbs, and this was may have been exaggerated here by the difference between mean biphone probabilities for each of the verb classes (irregular = 0.69; regular = -0.01). Reanalysis with over-regularizations counted as correct may be helpful for understanding this effect.

Figure 5. Phonotactic probability regression model

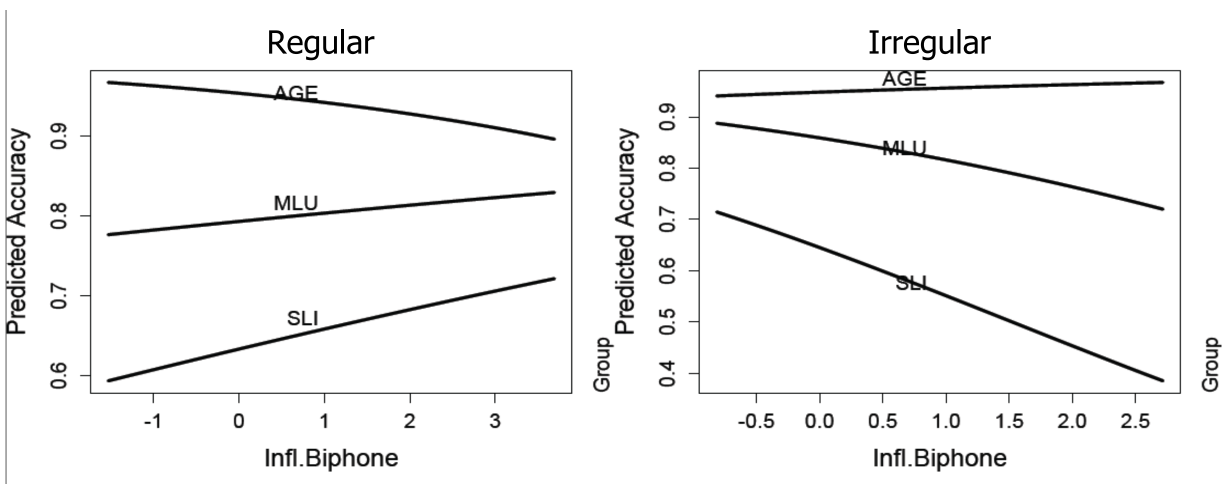


Table 9. Phonotactic probability regression model

	Variance	SD		
Random Factors				
Stem	0.59	0.77		
Participant	1.71	1.39		
	Coefficient	SE	z-value	p-value
Fixed Factors				
Intercept	3.17	0.46	6.97	< 0.01*
Regularity (reference category = Irregular)				
Regular	-0.20	0.29	-0.69	0.49
Participant Group (reference category = Age)				
MLU Group	-1.50	0.59	-2.54	0.01*
SLI Group	-2.55	0.56	-4.58	< 0.01*
Phonotactic Probability				
Inflected Biphone	0.10	0.25	0.39	0.69
Regularity*Group (reference category = Irregular, Age)				
Regular*MLU	-0.03	0.26	-0.13	0.90
Regular*SLI	0.07	0.24	0.30	0.76
Group*Phonotactic Probability (reference category = Age)				
MLU*Inflected Biphone	-0.47	0.22	-2.16	0.03*
SLI*Inflected Biphone	-0.53	0.21	-2.52	0.01*
Regularity*Phonotactic Probability (reference category = Irregular)				
Regular*Inflected Biphone	-0.33	0.28	-1.17	0.24
Group*Regularity*Phonotactic Probability (reference category = Age, Irregular)				
MLU*Regular*Inflected Biphone	0.76	0.25	3.01	< 0.01*
SLI*Regular*Inflected Biphone	0.87	0.24	3.64	< 0.01*

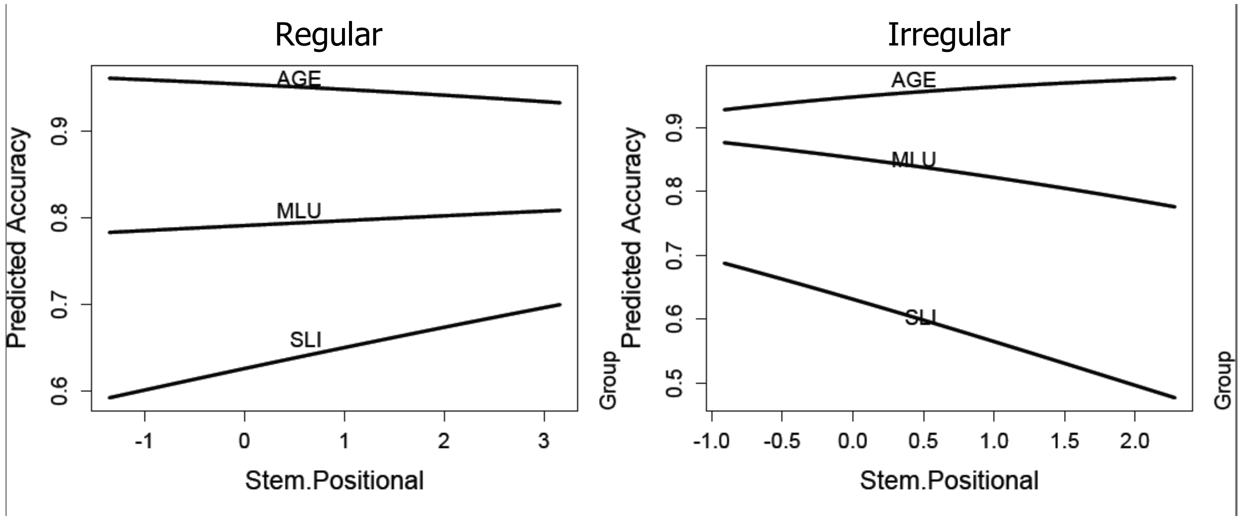
Note: SD = standard deviation; SE = standard error

Consideration of alternative models

Recall that we described a variety of ways of computing phonotactic probability in the methods section. Each of these different variables was considered for the phonotactics probability model. Each of the four phonotactic factors, stem positional probability, stem biphone probability, inflected positional probability, and inflected biphone probability, were considered alone as individual models, as well as in various combinations. Models that contained either only inflected biphone probability or only stem positional probability were both significant and very similar, as can be seen by comparing Figure 5 with Figure 6. However, the better phonotactics model was one with only inflected form biphone probability interacting with regularity and group, as judged by comparing AIC values (biphone AIC = 4207; positional AIC = 4215).

The addition of a second phonotactics variable was considered as well. Like the lexical models discussed above, each possible second variable was regressed against the first to ensure that it was adding unique information. For models that began with one of the biphone probabilities (e.g., inflected form biphone probability) the only variable that was significant was the residuals of the alternative way of computing biphone probability (e.g., stem biphone probability). The same was true for the positional probability models. That is, for models that began with positional probability of the stem, the only second variable that improved the model were the residuals of the positional probability of the inflected form. However, in order for a model that included the residuals of a second phonotactic variable to show significance, in could not include the interaction with group and regularity. Consideration of such a model seems illogical, since we already know that group and regularity contribute to past tense accuracy. Therefore, the simple inflected biphone probability-only model was retained as the phonotactics model, but the reader is encouraged to remember that the method of computing phonotactics does not seem to influence the outcome of the model greatly.

Figure 6. Alternative phonotactic probability regression model



Final Phonological Model

As with the lexical models, we attempted to build a phonological model that evaluated whether the phonotactic variable, biphone probability, and the categorical variables, place and manner, made unique contributions to the predication of past tense accuracy.   This model was a better fit than the phonotactics-only model χ^2 (24) = 54.83, p < 0.01 but was not a better fit than manner/place-only χ^2 (6) = 9.75, p = 0.14.   The categorical model is considered better given the marginal p-value when phonotactic probability was added and the large number of variables in this model.

Alternative Models

We speculated that these results may be due to the use of biphone probability as the phonotactic predictor. Stem positional probability is more likely to overlap with the categorical predictors than any of the other phonotactic variables. However similar comparisons made using positional probability instead yielded similar results. Adding manner and place of the final consonant to the model with positional probability improved model fit (χ^2 (24) = 58.96, p < 0.01) but adding positional probability to the model with manner and place did not (χ^2 (6) = 10.33, p = 0.11). With this in mind, the categorical phonological model is retained as the final model. Appendix D contains the results of this combined phonological regression that was considered and rejected.

In addition to considering whether our representation of phonotactic probability was valid, other alternative models were considered, including similar models without interactions between the categorical variables and group and regularity. This was done in attempt to reduce the complexity of this large model with its many two- and three- way interactions. One way we attempted to reduce the complexity of the final model was by eliminating one of the categorical phonological composition variables while retaining a phonotactic probability variable. Given the effects of obstruents above, we expected that dropping place from the model would have little effect. However, models that included Place led to a better fit and models with both were best, as can be seen by comparing BIC values (biphone probability + Place + Manner: AIC = 4200, BIC = 4451; biphone probability + Manner: AIC = 4195, BIC = 4327; biphone probability + Place: AIC = 4200, BIC = 4412).

Combined Lexical and Phonological Model

As a last step, we considered whether both lexical and phonological information were required to predict past tense well. The combined model of both lexical and phonological factors included inflected form lexical frequency, residuals of stem lexical frequency, place, and manner and is provided in Table 10. This final model was built with consideration of several combinations of the final factors from each of the overall lexical and overall phonological models. All four variables were necessary to accurately predict past tense use. Just like before with the final phonological model, a reduced model that did not include place and a reduced model that did not include manner were considered for the final lexical-phonological combined model. However, both place and manner appeared to contribute unique information and were retained together for this model (without place χ^2 (18) = 31.21, p = 0.03; without manner χ^2 (6) = 12.52, p = 0.05). This result could be expected after examination of the final phonological model, in which it was also seen that place and manner were contributing specific additional information about the production of the final phonemes of a word, which we know is important in the inflection of inflected forms.

Table 10. Combined lexical and phonological regression model

	Variance	SD		
Random Factors				
Stem	0.24	0.49		
Participant	1.76	1.32		
	Coefficient	SE	z-value	p-value
Fixed Factors				
Intercept	0.39	0.79	0.49	0.63
Participant Group (reference category = Age)				
MLU Group	-0.92	0.83	-1.11	0.27
SLI Group	-1.81	0.78	-2.33	0.02*
Regularity (reference category = Irregular)				
Regular	2.80	0.82	3.43	< 0.01*
Manner of Production (reference category = Continuant)				
Obstruent	0.28	0.48	0.59	0.56
Place of Production (reference category = Back)				
Front	0.44	0.76	0.58	0.56
Mid	-0.32	0.50	-0.63	0.53
Vowel	0.56	0.63	0.89	0.37
Lexical Frequency				
Inflected	1.17	0.26	4.50	< 0.01*
Stem Residuals	0.26	0.37	0.72	0.47
Participant Group*Regularity (reference category = Age, Irregular)				
MLU*Regular	-0.77	0.75	-1.03	0.30
SLI*Regular	-0.50	0.70	-0.71	0.48
Participant Group*Manner (reference category = Age, Continuant)				
MLU*Obstruent	-0.98	0.51	-1.92	0.05*
SLI*Obstruent	-1.00	0.49	-2.07	0.04*
Participant Group*Place (reference category = Age, Back)				
MLU*Front	0.65	0.82	0.79	0.43
SLI*Front	0.73	0.78	0.94	0.35
MLU*Mid	-0.36	0.52	-0.70	0.49
SLI*Mid	-1.08	0.49	-2.20	0.03*
MLU*Vowel	-0.80	0.69	-1.16	0.25
SLI*Vowel	-0.34	0.64	-0.52	0.60

Regularity* Manner (reference category = Irregular, Continuant)				
Regular*Obstruent	-1.14	0.55	-2.05	0.04*
Regularity*Place (reference category = Irregular, Back)				
Regular*Front	-0.10	0.89	-0.11	0.91
Regular*Mid	-0.06	0.65	-0.09	0.93
Regular*Vowel	-0.79	1.04	-0.76	0.44
Group*Lexical Frequency (reference category = Age)				
MLU*Inflected	-0.05	0.18	-0.28	0.78
SLI*Inflected	-0.02	0.18	-0.09	0.92
MLU*Stem Residuals	0.62	0.20	3.06	0.00*
SLI*Stem Residuals	0.35	0.19	1.80	0.07
Regularity*Lexical Frequency (reference category = Irregular)				
Regular*Inflected	-0.77	0.26	-2.99	< 0.01*
Regular*Stem Residuals	-0.73	0.37	-1.99	0.05*
Participant Group*Regular*Manner (reference category = Age, Irregular, Continuant)				
MLU*Regular*Obstruent	1.53	0.59	2.60	< 0.01*
SLI*Regular*Obstruent	1.62	0.56	2.90	< 0.01*
Participant Group*Regularity*Place (reference category = Age, Irregular, Back)				
MLU*Regular*Front	-0.87	0.98	-0.89	0.37
SLI*Regular*Front	-1.80	0.94	-1.92	0.05*
MLU*Regular*Mid	0.29	0.71	0.40	0.69
SLI*Regular*Mid	0.62	0.67	0.92	0.36
MLU*Regular*Vowel	0.44	1.13	0.39	0.70
SLI*Regular*Vowel	0.76	1.10	0.69	0.49

Note: SD = standard deviation; SE = standard error

Despite the fact that phonotactic probability was not informative in combination with place and manner, we were curious about the relationship between biphone probability and the lexical frequency information. The three variables were not highly correlated (biphone probability & inflected lexical frequency r = 0.20; biphone probability & stem lexical frequency: r = 0.25), suggesting that they could each make unique contributions to the prediction of past-tense use. When the combination of the lexical frequency and phonological frequency is compared to the lexical frequency-only model, the combined model does not account for more accuracy (χ^2 (1) = 1.47, $p = 0.23$). However the combined lexical and phonological frequency model is a better fit to the data than just the phonological frequency alone (χ^2 (2) = 16.47, $p < 0.01$). This suggests that, despite relatively low correlations, the information about past tense accuracy that phonotactic information provides is closely related to that which is accounted for by the lexical frequency information when we focus on the relationship between the inflected form and the stem form. Both factors provide information about an individual's familiarity with a verb, which includes familiarity of its semantic meaning, occurrence in an inflected form, and sound combinations. This relationship seems logical, that increased familiarity with the use of a word would be related to an increased familiarity with the phonemes combinations specific to that word.

CHAPTER IV

DISCUSSION

This study aimed to find the combination of lexical and phonological variables that best predicted past tense accuracy and to determine if this best-fit model differed between children with SLI and their TD peers. We also sought to examine whether categorical or continuous variables best represented factors that predict past tense accuracy. Place and manner combined to form the best phonological model. The inflected form lexical frequency and residuals of stem lexical frequency above the frequency of the inflected form were the best lexical predictors. These two models combined to account for the production of past tense across all three groups. Within these significant factors, several differences were found across the participant groups, suggesting that these factors influence production differently based on language experience (Age vs. MLU) and language ability (Age vs. SLI). We found that continuous variables were appropriate for the lexical model while the categorical measures were the best fit in the phonological factor model.

Lexical Factors

The results of our telicity model suggested that, for regular verbs, neutral verbs were less accurately inflected than atelic verbs. In addition, while telic verbs were more likely to be accurately inflected than atelic verbs, this result approached, but did not attain, significance. That this result was not significant was unexpected, considering the previous findings that when telicity is facilitative for a participant, it is telic verbs that are more accurately inflected (Johnson & Fey, 2006; Leonard et al., 2007; Li & Shirai, 2000). This is also why our finding that neutral telicity verbs were less accurately inflected than atelic verbs is particularly surprising. Finally, there were no differences between the effects of the telicity factors across any of the participant groups, a finding which differed from that of Leonard and colleagues (2007).

There are several possible reasons for these discrepancies. First, unlike the other studies described above, the target verbs from the original study were not selected with consideration for telicity, which resulted in a small amount of regular telic verbs in the final data set. It also resulted in a large amount of verbs that were coded as neutral, a telicity categorization that was not considered in these other studies, Johnson and Fey (2006) and Leonard et al. (2007). Both of these studies used verb events that were specifically designed to portray events that were clearly either telic or atelic. Therefore, verbs in this large neutral category, that created a telicity continuum for our telicity measurements, would have been classified differently under these researchers' telicity dichotomy. The choice to classify verbs as telic or atelic on the basis of z-scores across several rating measures is part of what led to so few verbs being classified as telic. This has the added problem of leading the logistic regression model to consider the coefficients for this variable as less reliable because it has fewer data points on which to base an estimate. It is unclear whether the lack of clear categories or the reduced number of items is at fault in this case. Reclassification of some neutral verbs as telic or atelic may improve the results.

With regard to the lack of group interactions with telicity, we may want to consider differences in the age of our participants. Our SLI participants were five through eight-year-olds. Our SLI and age-matched TD group, and as a result also the MLU group, were older than the participants in each of these studies. The SLI participants in the Leonard et al. study were four through six-year-olds, while Johnson and Fey's TD participants were only two-years-old. We did not see the increase in past tense accuracy when TD participants inflected telic regular verbs as in these studies, possibly because our participants had outgrown this effect. It is not clear if telicity cues are only beneficial while a child is in an earlier developing period and then they do not significantly rely on them after that point. Regardless, the fact that we only replicated others' results in a limited fashion calls into question our approach for determining telicity. Future work should identify more quantitative approaches to classifying verbs as telic and atelic.

For the lexical frequency model, the initial finding that as the frequency of the inflected form increased, so did the overall accuracy, is unsurprising. The results that as the stem frequency residuals increased so did irregular verb accuracy while regular verb accuracy decreased is more difficult to explain, but may be attributable to what we know about frequency differences between irregular and regular verbs. Irregular verbs, highly frequent forms by definition, tend to be highly frequent in both their stem and inflected forms. However, the lexical frequency of regular verbs covers a wide range of frequent to infrequent, and therefore it is possible that hearing the stem form interferes with the accurate past tense inflection of these forms that all follow the same past tense inflection pattern. Therefore, that accuracy increases when stems of irregular verbs are heard more often could possibly be that this increased frequency is helping to reinforce the alternative inflected form of the irregular. Another plausible source of the inflated effect for irregular verbs is the calculation of frequency in the CHILDES database. For a few of our irregular verbs which have stem forms that are also nouns, including *fall, ring, fly*, their listing included both noun and stem count. These elevated numbers could have slightly inflated the effect of lexical frequency on irregular verb inflection, and it is possible that we may have seen slightly different results if only the stem verb forms had been counted in these cases.

Although the SLI group was consistently lower than the other two groups, the sole significant interaction with group in the lexical frequency model across the participant groups was that the MLU-matched group's accuracy increased along with the stem residuals for regular verbs. This was the opposite effect than seen with the SLI and age-matched groups. It is possible that these younger participants' accuracy was increased by *any* additional experience with the verb because this added to their overall lexical knowledge about each specific verb which, in turn, benefitted their productions. Other than this unique MLU group result, we saw that the accuracy all of the groups was associated with increased lexical frequency, which was in agreement with previously discussed lexical frequency studies (Marchman, Wulfeck, & Weismer, 1999; van der Lely & Ullman, 2001).

What about the relationship between telicity and lexical frequency? One possibility is that, as expected, the reason why telicity bootstraps past-tense production is because telic verbs are often heard in the past tense. As such, frequency measures may fully capture the effects of completed events. At the same time, we must consider the possibility that this is an artifact of how we measured telicity. Recall that we did not closely replicate other studies examining telic verbs and past tense production. The continuous measurement of lexical frequency allows it to capture a continuum of lexical influence, while telicity categories are subject to the terms set for each category. As previously discussed, we defined our categories in a different manner than other previous telicity studies, and there are other ways this could have been done, as well. When measured in this way, telicity outcomes were subject to the constraints we put on each category, so it is possible that our divisions were not significant or caused our telicity ratings to appear insignificant. One final possibility that was briefly explored above is that our verbs were not selected, nor portrayed in the scenarios, based on telicity characteristics. For the other telicity studies, the experimenters set up scenarios that showed exaggerated continuous events or exaggerated short, completed events that allowed them to highlight the telicity properties of the target verbs and, in turn, target telicity as a facilitative past tense effect. A prospective study that considers verbs with high and low frequency inflected forms and verbs selected for the purpose of examining completed vs. ongoing events could tease these two factors apart.

Phonological Factors

We expected and found that higher phonotactic probability was influential for our participant groups. What was surprising, however, was that both positional and biphone probability were similar in their account of accuracy, and that the difference seemed to reside in whether the stem or inflected form phonotactic information was considered. Here we saw that increased familiarity and experience increased the likelihood of past tense, just like with lexical frequency.

For the phonological composition model, we saw, as predicted, that the SLI group was less likely to accurately produce past tense when the stem ended in a mid consonant. This was expected, based on earlier research that suggested both that consonant combinations that include mid consonants are harder for many typical children and that more complex articulatory combinations are even more problematic for children with SLI (Bortolini & Leonard, 2000; Kirk & Demuth, 2005; Marshall & van der Lely, 2007; Smit, Hand, Freilinger, Bernthal, & Bird, 1990). The lack of reliable results for the other participant groups may have been due to several large standard deviations within the typical groups, suggesting a variety of phonological abilities was present for these typically-developing children.

Finally, we considered each of these phonological models to decide on the best overall representation of accuracy accounted for by phonological factors. From the phonotactics-only model discussed previously, we know that phonotactic probability, specifically measured here as inflected form biphone probability, accounts for a large amount of past tense accuracy. Similarly, we know that the both place and manner also accounted significantly for the past tense accuracy of the participant groups. Ultimately, we concluded that place and manner do a better job of predicting past tense use. Biphone probability information tells us about combinations of sounds throughout the entire word, while suggesting how familiar a child might be with a particular sound combination. What biphone probability does not tell us is anything about combinations of sounds in any specific position of the word. Because English regular verbs are inflected at the end of the stem, it makes sense that the phonological information specifically in this position, the end of the stem, would be important in any account of past tense prediction.

Another possible explanation is that place and manner are not especially closely related to phonotactics. Place and manner are very clear-cut phonetic distinctions and, at least in this study, pertained only to the very final phoneme of the verb stem. Meanwhile, phonotactic measures can be measured to account for the entire word or part of the word and, as a manner of their calculation, are related to the frequencies of sounds that may not even be in the word. It is possible that a different manner of computing phonotactics, for instance, only considering frequency information for the coda of the final syllable of the word instead of the entire-word approach we took, may have also changed the relationship between the categorical and continuous phonological factors.

Summary and Implications

In our final overall model, we found that the best model for predicting past tense accuracy included a combination of lexical frequency and stem-final place and manner information. With this model, we can return to our research questions. We found that there were, in fact, significant differences between the models that included continuous variables and those that contained categorical variables. Although one might have expected that any continuous measure would do better at capturing variance than a categorical measure, this was not the case. In the end, the information from the categorical variables provided the best unique information from phonology, while the continuous lexical measure outweighed the telicity information. Therefore, we recognize that the contributions of categorical and continuous variables can vary due to the information they are representing and that both had important effects in this study.

Although there were not as many significant effects for participant group as we predicted, particularly in the areas of lexical aspect and phonological composition, there were some group effects. Most notably, these included that the MLU-matched TD group's accuracy increased with stem lexical frequency residuals unlike the other two groups and that past tense production by the SLI group was uniquely affected by stems that ended in alveopalatals consonants.

When we consider the clinical implications of this study, we have gained important information about lexical and phonological factors that are and are not facilitative for past tense production. Therefore, as we seek to design assessment and intervention tasks that consider these factors and promote learning, we can carefully select appropriate verb stimuli. For example, an appropriate assessment task would include verbs that have a range of facilitative and non-facilitative components. This is because assessment would seek to portray the child's abilities with particularly facilitative verbs, as well as if and where his/her performance breaks down as more difficult, non-facilitative verb targets are presented. For instance the following verbs might make good assessment targets: *cry, play, walk, work, clean, color, rest, exercise, say,* and *break.* These verbs were chosen because they represent a variety of combinations of facilitative and non-facilitative factors. *Cry* and *play* have high inflected form lexical frequencies and non-alveopalatal and continuant stem endings. *Walk* and *work* have high inflected form lexical frequencies and back place stem endings. *Clean* and *color* have high inflected form lexical frequencies and continuant stem endings. *Rest* and *exercise* have low lexical frequencies and obstruent and alveopalatals stem endings. *Say* and *break* are irregular verbs with high inflected form lexical frequencies.

For intervention, we can suggest that learning is facilitated by using targets that are highly facilitative for accurate past tense inflection. As the child's accuracy increases at these easier levels, then less-facilitative verb components could be introduced to promote learning of more difficult forms. For instance, a clinician may wish to start intervention with the following verbs, *cry, play, stretch, close, clean,* followed by introducing other verbs, such as *rake, rest, exercise, say, bite, break,* and *do* just prior to dismissal. Note that verbs *cry, play, stretch, close, clean,* are regular verbs with at least one phonological composition facilitative characteristic, such as a vowel stem ending or continuant stem ending, and they all have high inflected form lexical frequencies. *Rake, rest, exercise, say, bite, break,* and *do* would be more challenging verb targets, as this list includes some irregular verbs, regular verbs with low inflected form lexical frequencies, and stems with obstruent and/or alveopalatals final consonants.

REFERENCES

Bortolini, U., & Leonard, L. B. (2000). Phonology and children with specific language impairment: Status of structural constraints in two languages. *Journal of Communication Disorders, 33,* 131-149.

Dunn, L. M., Dunn, L. M., & Service, A. G. (1997). *PPVT-III: Peabody Picture Vocabulary Test.* American Guidance Service.

Gillam, R. B., & Pearson, N. A. (2004). *Test of Narrative Language.* Austin, TX: PRO-ED. Inc.

Jokel, R., Rochon, E., & Anderson, N. (2010). Errorless learning of computer-generated words in a patient with semantic dementia. *Neuropsychological Rehabilitation, 20,* 16-41.

Johnson, B. W., & Fey, M. E. (2006). Interaction of lexical and grammatical aspect in toddlers' language. *Journal of Child Language, 33,* 419-435.

Johnson, B. W., & Morris, S. R. (2007). Clinical implications of the effects of lexical aspect and phonology on children's production of the regular past tense. *Child Language Teaching and Therapy, 23,* 287-306.

Kirk, C., & Demuth, K. 2005. Asymmetries in the acquisition of word-initial and word-final consonant clusters. Journal of Child Language, 32 (4), 709-734.

Korkman, M., Kirk, U., Kemp, S., & Corporation, P. (1998). *NEPSY: A Developmental Neuropsychological Assessment.* Psychological Corporation.

van der Lely, H. K. J., & Ullman, M. (2001). Past tense morphology in specifically language impaired children and normally developing children. *Language and Cognitive Processes, 16,* 177-217.

Leonard, L. B., et al. (2007). Lexical aspect and the use of verb morphology by children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 50,* 759-777.

Leonard, L. B., Davis, J., & Deevy, P. (2007). Phonotactic probability and past tense use by children with specific language impairment and their typically developing peers. *Clinical Linguistics & Phonetics, 21,* 747-758.

Li, P. and Y., Shirai (2000). The Acquisition of Lexical and Grammatical Aspect. Berlin, Mouton de Gruyter.

MacWhinney, B. (2000). *The CHILDES project: Tools for analyzing talk. Third Edition.* Mahwah, NJ: Lawrence Erlbaum Associates.

Marchman, V. A., Wulfeck, B., & Weismer, S. E. (1999). Morphological productivity in children with normal language and SLI: A study of the English past tense. *Journal of Speech, Language and Hearing Research, 42,* 206-219.

Marshall, C. R., & van der Lely, H. K. J. (2007). Derivational morphology in children with Grammatical-Specific Language Impairment. *Clinical Linguistics and Phonetics, 42,* 71-91.

Marshall, C. R., & van der Lely, H. K. (2006). A challenge to current models of past tense inflection: The impact of phonotactics. *Cognition, 2*, 302-320.

Owen, A. J. (in press). Factors affecting accuracy of past tense production in children with Specific Language Impairment: The Influence of verb type, clause order, and sentence type. *Journal of Speech, Language, and Hearing Research.*

Rice, M. L., & Wexler, K. (1996). Toward tense as a clinical marker of Specific Language Impairment in English-speaking children. *Journal of Speech and Hearing Research, 39,* 1239-1257.

da Silva, L., & Sunderland, A. (2010). Effects of immediate feedback and errorless learning on recognition memory processing in young and older adults. *Neuropsychological Rehabilitation, 20,* 42-58.

Smit, A. B., Hand, L., Freilinger, J. J., Bernthal, J. E., & Bird, A. (1990). The Iowa Articulation Norms Project and its Nebraska replication. *Journal of Speech and Hearing Research, 55,* 779-798.

Storkel, H.L. (2004). Methods for minimizing the confounding effects of word length in the analysis of phonotactic probability and neighborhood density. *Journal of Speech, Language, and Hearing Research, 47,* 1454-1468.

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, & Computers, 36,* 481-487.

Werner, E., & Kresheck, J. (1983). *Structured Photographic Expressive Language Test-II*. DeKalb, IL: Janelle Publications.

APPENDIX A

TELICITY FACTOR Z-SCORES AND FINAL CLASSIFICATIONS

Verb	Condition	Target	Dynamic	Clear Endpoint	Punctual	Final Telicity Classification
answer	subord	a	-0.37	1.07	0.40	neutral
	subord	b	-0.37	1.07	0.40	neutral
	subord	c	-0.37	1.07	0.40	neutral
bake	adjun		0.18	0.05	-1.08	neutral
	coord		0.07	-0.57	-1.03	atelic
bark	adjun		0.07	-0.06	-0.59	neutral
	coord		0.29	-0.47	-0.81	neutral
	subord		0.62	-0.47	-0.37	neutral
believe	subord	a	-1.14	-0.47	-1.03	atelic
	subord	b	-1.47	-0.47	-1.36	atelic
	subord	c	-1.58	-0.26	-1.14	atelic
bend	adjun		0.18	0.87	0.51	telic
	coord		0.51	0.66	0.40	telic
	subord		0.29	0.87	0.18	neutral
bite	adjun		-0.04	0.97	0.73	telic
	coord		0.62	1.28	1.06	telic
	subord		0.40	1.07	0.84	telic
bounce	adjun		0.51	-0.16	-0.92	neutral
	coord		0.51	0.05	-0.48	neutral
	subord		0.73	-0.36	-0.92	neutral
break	adjun		0.07	0.97	0.51	telic
	coord		0.29	0.76	0.95	telic
	subord		0.51	1.17	0.84	telic
carry	adjun		0.07	0.05	-1.03	neutral
	coord		0.62	0.15	-0.37	neutral
	subord		0.62	-0.57	-0.81	neutral
clap	adjun		0.40	-0.36	-0.48	neutral
	coord		0.84	-0.36	-0.59	neutral
clean	adjun		0.62	-0.67	-0.81	neutral
	coord		0.51	-0.16	-1.03	neutral
climb	adjun		0.73	-0.36	-0.92	neutral
	coord		0.95	0.25	-0.81	neutral
close	adjun		-0.15	1.28	1.06	telic
	coord		0.51	1.28	0.95	telic
	subord		0.29	1.07	1.06	telic
color	adjun		-0.04	-0.88	-1.14	atelic

	coord		0.51	-0.67	-1.36	neutral
cough	adjun		-0.26	0.46	0.51	neutral
	coord		-0.04	0.46	0.40	neutral
	subord		-0.04	0.35	0.51	neutral
count	adjun		-0.15	0.56	-0.48	neutral
	coord		0.62	-0.36	-0.92	neutral
crawl	adjun		0.40	0.46	-0.48	neutral
	coord		0.84	0.15	-1.03	neutral
	subord		0.62	0.66	-0.59	neutral
cry	adjun		-0.37	-0.57	-1.14	atelic
	coord		-0.04	-0.36	-1.03	neutral
	subord		0.40	1.17	-1.03	neutral
dance	adjun		0.51	-0.26	-1.14	neutral
	coord		0.62	-0.77	-1.25	neutral
	subord		0.84	-0.57	-1.14	neutral
discover	subord	a	-0.37	0.66	0.31	neutral
	subord	b	-0.70	0.66	0.31	neutral
	subord	c	-0.59	0.66	0.07	neutral
draw	adjun		0.18	-0.77	-1.36	atelic
	coord		0.73	-0.77	-1.14	neutral
	subord		0.51	-0.77	-1.14	neutral
drink	adjun		-0.15	0.05	-0.59	neutral
	coord		0.29	0.25	-0.26	neutral
	subord		0.29	0.97	-0.37	neutral
eat	adjun		-0.26	0.66	-0.70	neutral
	coord		0.51	0.66	-0.48	telic
	subord		0.18	0.97	-0.26	neutral
exercise	adjun		0.95	-0.77	-1.14	neutral
	coord		0.84	-0.77	-1.14	neutral
fall	adjun		-0.92	0.76	0.62	neutral
	coord		-0.37	1.07	0.73	telic
	subord		-0.15	0.76	0.62	telic
figure	subord	a	-0.26	0.87	-0.48	neutral
	subord	b	-0.59	0.87	-0.15	neutral
	subord	c	-0.59	0.93	-0.04	neutral
fish	adjun		-0.15	-0.77	-1.03	atelic
	coord		-0.04	-0.67	-1.03	atelic
float	adjun		-0.81	0.66	-1.14	neutral
	coord		-0.48	-0.77	-1.47	atelic
fly	adjun		0.73	0.25	-1.03	neutral
	coord		-0.37	1.07	-0.59	neutral
	subord		0.73	0.97	-1.03	neutral
giggle	adjun		-0.37	-0.67	-0.92	atelic

	coord		-0.04	-0.57	-1.03	atelic
growl	adjun		-0.04	-0.36	-0.59	neutral
	coord		0.18	-0.57	-0.81	atelic
guess	subord	a	-0.59	0.46	-0.04	neutral
	subord	b	-0.59	0.46	0.29	neutral
	subord	c	-0.70	0.46	0.07	neutral
	subord	d	-0.70	0.25	0.18	neutral
	subord	e	-0.81	0.25	0.29	neutral
	subord	f	-0.81	0.25	0.29	neutral
hide	adjun		-0.81	0.15	-0.15	neutral
	coord		0.62	-0.16	-1.25	neutral
	subord		-0.26	-0.36	-0.37	neutral
hop	adjun		0.62	-0.16	-0.48	neutral
	coord		1.06	-0.26	-0.26	neutral
	subord		0.73	-0.36	-0.37	neutral
hug	adjun		-0.59	0.35	-0.07	neutral
	coord		0.40	0.35	-0.81	neutral
	subord		0.07	0.46	0.07	neutral
hum	adjun		-0.37	-0.77	-1.03	atelic
	coord		0.18	-0.88	-1.14	atelic
imagine	subord	a	-0.70	-0.57	-1.14	atelic
	subord	b	-0.70	-0.57	-0.92	atelic
	subord	c	-1.03	-0.57	-0.92	atelic
jump	adjun		0.84	-0.16	-0.48	neutral
	coord		0.84	-0.16	-0.70	neutral
	subord		0.84	1.07	0.40	telic
kiss	adjun		-0.15	0.76	0.51	telic
	coord		0.73	0.76	0.29	telic
	subord		0.18	0.87	0.51	telic
know	subord	a	-1.58	-0.57	-1.25	atelic
	subord	b	-1.58	-0.57	-1.25	atelic
	subord	c	-1.58	-0.57	-1.25	atelic
	subord	d	-1.58	1.07	-1.36	neutral
	subord	e	-1.58	-0.47	-1.03	atelic
	subord	f	-1.58	-0.47	-1.03	atelic
listen	adjun		-1.14	-0.67	-1.47	atelic
	coord		-0.04	-0.98	-1.58	atelic
paddle	adjun		0.95	-0.67	-1.25	neutral
	coord		1.06	-0.57	-1.25	neutral
paint	adjun		0.18	0.15	-0.81	neutral
	coord		0.62	-0.77	-1.25	neutral
plant	adjun		0.29	-0.36	-0.92	neutral
	coord		0.62	0.15	-0.59	neutral

play	adjun		0.29	-0.67	-1.36	atelic
	coord		0.40	-0.67	-1.25	atelic
	subord		0.84	-0.47	-1.03	neutral
point	adjun		-0.59	0.35	0.51	neutral
	coord		0.18	0.25	0.29	neutral
rake	adjun		0.29	-0.77	-1.36	atelic
	coord		0.84	-0.36	-1.36	neutral
read	adjun		-0.15	-0.77	-1.36	atelic
	coord		0.18	-0.16	-1.03	atelic
	subord		-0.26	-0.57	-1.14	atelic
remember	subord	a	-0.92	-0.16	-0.81	atelic
	subord	b	-1.14	-0.06	-0.48	atelic
	subord	c	-1.03	-0.06	-0.48	atelic
rest	adjun		-1.58	-1.08	-1.47	atelic
	coord		-1.25	-0.88	-1.25	atelic
ring	adjun		-0.26	-0.36	-0.81	neutral
	coord		0.51	0.25	-0.15	neutral
	subord		0.18	-0.67	-0.48	neutral
roll	adjun		0.40	-0.77	-0.92	atelic
	coord		0.73	-0.67	-1.03	neutral
run	adjun		0.84	0.97	-0.70	neutral
	coord		0.84	0.87	-0.70	neutral
	subord		0.95	0.87	-0.59	neutral
sail	adjun		-0.92	-0.88	-1.47	atelic
	coord		0.18	-0.77	-1.25	atelic
say	subord	a	-0.04	0.66	-0.04	neutral
	subord	b	-0.04	0.76	0.07	neutral
	subord	c	-0.04	0.66	-0.07	neutral
scare	adjun		0.07	0.15	0.40	neutral
	coord		0.40	0.87	0.40	neutral
	subord		0.18	0.35	0.29	neutral
scratch	adjun		0.07	-0.47	-0.70	neutral
	coord		0.62	-0.26	-0.92	neutral
sing	adjun		0.07	-0.36	-1.03	neutral
	coord		0.51	-0.57	-1.25	neutral
	subord		0.40	-0.47	-1.03	neutral
sit	adjun		-0.81	0.76	0.18	neutral
	coord		-0.04	0.46	-0.26	neutral
	subord		-0.48	0.05	-0.07	neutral
sleep	adjun		-1.25	-0.67	-1.36	atelic
	coord		-1.14	-0.57	-1.36	atelic
	subord		-1.36	-0.67	-1.25	atelic
slip	adjun		-0.70	0.56	0.81	neutral

	coord		-0.37	0.87	0.62	telic
smile	adjun		-0.92	-0.47	-0.04	neutral
	coord		-0.26	-0.26	-0.59	neutral
	subord		-0.37	-0.06	-0.04	neutral
sneeze	adjun		-0.48	0.87	0.84	telic
	coord		-0.04	1.17	0.84	telic
	subord		-0.04	0.66	0.73	telic
snore	adjun		-0.81	-0.57	-1.03	atelic
	coord		-1.03	-0.47	-1.03	atelic
squish	adjun		0.29	-0.88	-1.25	atelic
	coord		0.51	0.76	0.29	telic
	subord		0.18	0.05	-0.15	neutral
stamp	adjun		0.07	-0.06	-0.15	neutral
	coord		0.73	0.66	0.29	telic
stand	adjun		-0.59	0.15	-0.37	neutral
	coord		0.18	0.15	0.07	neutral
	subord		-0.48	-0.57	-0.37	neutral
stir	adjun		0.29	0.05	-0.04	neutral
	coord		0.95	-0.26	-1.03	neutral
stretch	adjun		-0.26	0.05	-0.70	neutral
	coord		0.40	0.15	-0.26	neutral
	subord		0.29	-0.06	-0.70	neutral
swim	adjun		0.95	-0.57	-1.14	neutral
	coord		0.73	-0.67	-1.25	neutral
	subord		0.84	-0.67	-1.14	neutral
think	subord	a	-0.70	-0.98	-1.03	atelic
	subord	b	-1.14	-0.78	-0.70	atelic
	subord	c	-1.14	-0.67	-0.70	atelic
throw	adjun		0.18	1.07	0.84	telic
	coord		0.73	1.07	0.51	telic
	subord		0.62	0.97	0.73	telic
trip	adjun		-0.59	0.66	0.73	neutral
	coord		-0.59	0.97	0.73	neutral
turn	adjun		0.07	-0.47	-0.81	neutral
	coord		0.62	-0.77	-1.03	neutral
walk	adjun		0.18	0.25	-1.14	neutral
	coord		0.62	-0.67	-1.36	neutral
wave	adjun		-0.15	-0.47	-0.70	neutral
	coord		0.84	-0.26	-0.81	neutral
whisper	adjun		-0.37	-1.08	-1.36	atelic
	coord		0.40	0.05	-0.70	neutral
whistle	adjun		-0.15	-0.13	-0.48	neutral
	coord		0.51	-0.36	-1.14	neutral

wiggle	adjun	0.40	-0.67	-1.03	atelic
	coord	0.73	-0.77	-1.03	neutral
work	adjun	0.51	-0.77	-1.47	neutral
	coord	0.51	-0.88	-1.25	neutral
yawn	adjun	-0.92	0.34	-0.37	neutral
	coord	-0.04	0.35	-0.04	neutral
yell	adjun	0.29	-0.06	-0.48	neutral
	coord	0.62	0.35	-0.37	neutral

APPENDIX B

LEXICAL FREQUENCY INFORMATION

Verb	Log stem lexical frequency	Log inflected form lexical frequency	Log total lexical frequency
answer	-0.44	-0.52	-0.62
bake	-0.92	-0.33	-0.85
bark	-1.09	-0.95	-1.16
believe	-0.11	-1.05	-0.39
bend	-0.73	-0.07	-0.80
bite	0.21	1.51	0.76
bounce	-0.95	-0.62	-0.96
break	0.35	0.91	0.41
carry	-0.16	-0.21	-0.14
clap	-0.89	-0.95	-1.11
clean	0.25	0.15	0.14
climb	-0.24	0.26	-0.22
close	0.37	0.68	0.30
color	0.55	0.00	0.47
cough	-0.72	-1.05	-0.87
count	0.09	-0.66	-0.07
crawl	-1.05	-0.76	-1.01
cry	-0.03	0.26	0.31
dance	-0.19	-0.46	-0.11
discover	-1.64	-0.76	-1.71
do	2.21	2.41	2.44
draw	0.32	0.11	0.23
drink	0.55	0.04	0.46
eat	1.20	0.84	1.21
exercise	-1.03	-1.63	-1.18
fall	0.50	1.11	0.64
figure	-0.42	-0.02	-0.53
fish	0.45	-1.34	0.29
float	-1.42	-0.95	-1.29
fly	-0.02	0.02	0.00
giggle	-1.88	-1.63	-1.79
go	1.85	1.59	2.11
growl	-1.60	-1.63	-1.59
guess	0.50	-0.58	0.31
hide	-0.24	-0.28	-0.08
hop	-0.43	-0.62	-0.59
hug	-0.57	-0.66	-0.77
hum	-0.08	0.73	-0.35
imagine	-0.67	-1.63	-1.00
jump	0.08	0.32	0.17
kiss	0.06	-0.08	-0.06

know	1.86	0.73	1.78
listen	0.37	-0.62	0.25
paddle	-1.21	-1.63	-1.52
paint	0.05	-0.06	-0.06
plant	-0.47	-0.39	-0.48
play	1.21	0.64	1.21
point	-0.36	-0.33	-0.41
rake	-1.29	-1.63	-1.57
read	0.70	1.42	0.58
remember	0.86	0.00	0.69
rest	0.13	-1.63	-0.10
ring	0.03	-0.17	-0.05
roll	-0.03	-0.11	-0.10
run	0.32	0.82	0.52
sail	-1.34	-1.17	-1.48
say	1.36	1.77	1.61
scare	-0.69	0.52	-0.37
scratch	-0.68	-0.46	-0.78
sing	0.34	-0.03	0.27
sit	1.04	0.53	1.03
sleep	0.45	0.08	0.48
slip	-0.93	-0.23	-0.89
smile	-0.78	-0.81	-0.65
sneeze	-1.25	-0.58	-1.30
snore	-1.97	-0.95	-1.79
squish	-2.41	-0.55	-1.50
stamp	-1.45	-0.41	-1.45
stand	0.34	0.18	0.36
stir	-0.77	-1.17	-1.00
stretch	-1.15	0.40	-0.62
swim	-0.35	-0.46	-0.11
think	1.64	1.46	1.61
throw	0.47	0.48	0.39
trip	-0.40	-0.62	-0.62
turn	0.92	0.73	0.86
walk	0.39	0.40	0.40
want	1.73	1.13	1.69
wave	-1.09	-0.81	-0.95
whisper	-1.21	-1.17	-1.21
whistle	-0.76	-0.81	-0.98
wiggle	-1.60	-0.35	-1.38
work	0.70	0.15	0.70
yawn	-1.31	-1.34	-1.28
yell	-0.96	-0.33	-0.85

APPENDIX C

HOEFFDING'S D OUTPUT

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1.Regularity (Regular)	1.00	-0.01	-0.01	-0.01	0.00	0.01	0.03	0.04	0.03	-0.01	-0.02	0.00
2. Stem positional probability	–	1.00	0.10	0.32	0.10	0.00	0.00	0.00	0.00	-0.01	-0.01	0.00
3. Stem biphone probability	–	–	1.00	0.05	0.26	0.00	0.01	0.01	0.00	-0.01	-0.01	0.00
4. Inflected positional probability	–	–	–	1.00	0.12	-0.01	0.01	0.01	0.00	-0.01	-0.01	0.00
5. Inflected biphone probability	–	–	–	–	1.00	0.01	0.02	0.02	0.01	-0.01	-0.01	-0.01
6. Number of consonants in cluster at the end of stem	–	–	–	–	–	1.00	0.02	0.03	0.02	-0.01	-0.02	0.00
7. Stem lexical frequency	–	–	–	–	–	–	1.00	0.69	0.22	-0.01	-0.01	0.02
8. Total lexical frequency	–	–	–	–	–	–	–	1.00	0.29	-0.01	-0.01	0.04
9. Inflected lexical frequency	–	–	–	–	–	–	–	–	1.00	-0.01	-0.01	0.27
10. Telicity (Neutral)	–	–	–	–	–	–	–	–	–	1.00	-0.01	-0.01
11. Telicity (Telic)	–	–	–	–	–	–	–	–	–	–	1.00	0.00
12. Ratio of inflected to stem	–	–	–	–	–	–	–	–	–	–	–	1.00

APPENDIX D

REJECTED COMBINED PHONOLOGICAL REGRESSION MODEL

	Variance	SD		
Random Factors				
Stem	0.41	0.64		
Participant	1.75	1.32		
	Coefficient	SE	z-value	p-value
Fixed Factors				
Intercept	2.75	0.63	4.35	< 0.01*
Participant Group (reference category = Age)				
MLU Group	-0.76	0.75	-1.01	0.31
SLI Group	-1.72	0.69	-2.49	0.01*
Regularity (reference category = Irregular)				
Regular	0.83	0.73	1.15	0.25
Place of Production (reference category = Back)				
Front	-0.16	0.84	-0.19	0.85
Mid	-0.52	0.69	-0.75	0.45
Vowel	0.93	0.70	1.34	0.18
Phonotactic Probability				
Inflected Biphone	0.20	0.32	0.64	0.52
Manner of Production (reference category = Continuant)				
Obstruent	0.69	0.55	1.27	0.21
Participant Group*Regularity (reference category = Age, Irregular)				
MLU*Regular	-0.78	0.74	-1.06	0.29
SLI*Regular	-0.26	0.69	-0.38	0.70
Participant Group*Place (reference category = Age, Back)				
MLU*Front	0.35	0.85	0.41	0.68
SLI*Front	0.54	0.80	0.67	0.50
MLU*Mid	0.05	0.66	0.07	0.94
SLI*Mid	-0.93	0.62	-1.49	0.14
MLU*Vowel	-0.69	0.69	-1.00	0.32
SLI*Vowel	-0.22	0.65	-0.35	0.73
Participant Group*Manner (reference category = Age, Continuant)				
MLU*Obstruent	-1.17	0.54	-2.15	0.03*

SLI*Obstruent	-1.01	0.51	-1.98	0.05*
Participant Group*Phonotactic Probability (reference category = Age)				
MLU*Inflected Biphone	-0.46	0.30	-1.52	0.13
SLI*Inflected Biphone	-0.21	0.29	-0.70	0.48
Regularity*Place (reference category = Irregular, Back)				
Regular*Front	0.56	0.99	0.57	0.57
Regular*Mid	0.20	0.84	0.24	0.81
Regular*Vowel	-0.90	1.13	-0.80	0.43
Regularity* Manner (reference category = Irregular, Continuant)				
Regular*Obstruent	-1.53	0.63	-2.42	0.02*
Regularity*Phonotactic Probability (reference category = Irregular)				
Regular*Inflected Biphone	-0.30	0.34	-0.89	0.38
Participant Group*Regularity*Place (reference category = Age, Irregular, Back)				
MLU*Regular*Front	-0.62	1.00	-0.62	0.38
SLI*Regular*Front	-1.65	0.95	-1.74	0.08
MLU*Regular*Mid	-0.32	0.82	-0.40	0.69
SLI*Regular*Mid	0.16	0.78	0.20	0.84
MLU*Regular*Vowel	0.25	1.13	0.22	0.83
SLI*Regular*Vowel	0.35	1.10	0.32	0.75
Participant Group*Regular*Manner (reference category = Age, Irregular, Continuant)				
MLU*Regular*Obstruent	1.60	0.63	2.57	0.01*
SLI*Regular*Obstruent	1.39	0.59	2.36	0.02*
Participant Group*Regularity*Phonotactic Probability (reference category = Age, Irregular)				
MLU*Regular*Inflected Biphone	0.71	0.33	2.15	0.03*
SLI*Regular*Inflected Biphone	0.51	0.32	1.62	0.12