Acquisition of Irregular Past Tense by Children With Specific Language Impairment

Mabel L. Rice
University of Kansas
Lawrence

Kenneth Wexler
Massachusetts Institute
of Technology
Cambridge

Janet Marquis
University of Kansas
Lawrence

Scott Hershberger
California State at
Long Beach

In this paper we add to what is known about the tense-marking limitations of children with specific language impairment (SLI) by exploring the acquisition of regular and irregular past tense, encompassing the age range of 2;6 to 8;9 (years;months) and comparing the performance of 21 children with SLI to that of 23 control children of the same age and 20 younger control children of equivalent mean length of utterance (MLU) at the outset. The analysis differentiated between the morphophonological component of past tense marking and the morphosyntactic component (finiteness). In the morphosyntactic component, the performance of the SLI group trails that of the two control groups over 3.5 years, whereas in the morphophonological component, the SLI group's performance is equivalent to that of the younger controls. Models of growth curves for regular past tense and irregular finiteness marking show the same pattern, with linear and quadratic components and the child's MLU at the outset as the only predictor. For morphophonological growth the picture changes, with an interaction of linear trend and MLU and the child's receptive vocabulary emerging as a predictor. The findings support a morphosyntactic model, such as the extended optional infinitive (EOI) model, with regard to the limitations in finiteness marking and for affected children.

KEY WORDS: specific language impairment, past tense, child language impairment, language acquisition, irregular past tense

It is now well known that English-speaking young children with specific language impairment (SLI) are likely to encounter difficulty with the acquisition of past tense morphology in English. For example, instead of saying "Patsy walked," affected children are likely to say "Patsy walk," thereby omitting the past tense morpheme in a grammatical context where it is required. This fact is of theoretical interest because it is compatible with different explanations for the grammatical limitations that are characteristic of children with SLI, and different explanations propose different sources for the underlying problem.

In this paper we further explore the tense-marking abilities of children with SLI and younger unaffected comparison children by examining their acquisition of irregular past tense morphology. The comparison of regular versus irregular past tense morphology has played a central role in theoretical accounts of grammatical acquisition in young children since the phenomenon of over-regularization (i.e., forms such as "goed") was first reported. Thus, the available normative literature is rich with observations, generalizations, and arguments that focus almost exclusively on the ways that children learn the morphophonological

1092-4388/00/4305-1126

rules evident in the exceptional irregular forms. At the same time, empirical evidence about irregular verb acquisition by children with SLI is relatively sparse. The few studies that do exist enter into the debate about how over-regularizations and, by extension, the "add *-ed*" rule are learned and subsequently unlearned.

This study picks up the question from a different perspective. We are interested in how children come to know that a past tense marker is obligatory in the surface form of an English clause. In the model that we follow, the morphophonological rules that govern the phonetic structure of a particular morpheme are considered to be part of the grammar that "spells out" the surface forms. Knowledge of the obligatory nature of tense marking is thought to be part of a different grammatical domain, one that interacts with the configurational representations of syntax and the associated principles that govern word order. What this study contributes is an analysis that attempts to differentiate between the morphophonological rules for spell-out and the morphosyntactic knowledge of obligatory tense marking. Because we look at longitudinal evidence encompassing the ages from 2;6 to 8;9, we are able to add new information about the growth curves of irregular past tense for children with SLI and younger unaffected children and to investigate whether the predictors for regular and irregular past tense are the same. We evaluate the outcomes in terms of competing explanations of the tendency of children with SLI to drop regular *-ed* past tense forms more frequently than younger language-equivalent children.

A Brief Summary of Key Findings About Past Tense Acquisition by Children With SLI

With regard to regular past tense, two generally accepted facts have emerged from the current literature: (a) Young English-speaking children with SLI are likely to show a prolonged period of acquisition for regular past tense. (b) The way the children deviate from the adult form is to produce a bare stem of a lexical verb (e.g., *walk* where *walked* is expected). Replicated evidence across different labs shows that this difference exceeds that expected by a simple delayed emergence of language in that affected children typically perform at levels below those of younger language-equivalent control children (Bishop, 1994; Leonard, Bortolini, Caselli, McGregor, & Sabbadini, 1992; Marchman, Wulfeck, & Ellis Weismer, 1999; Montgomery & Leonard, 1998; Oetting & Horohov, 1997; Rice & Wexler, 1996; Rice, Wexler, & Cleave, 1995; Rice, Wexler, & Hershberger, 1998).

Although the number of studies of irregular past tense use by children with SLI is small, some repeated findings are beginning to emerge. One is that, in contrast with regular past tense, for irregular past tense the percentage correct for children with SLI is comparable to that of younger language-matched control children (Leonard et al., 1992; Leonard, Eyer, Bedore, & Grela, 1997; Oetting & Horohov, 1997). Second, as in the case of regular past tense, examination of error patterns shows that children with SLI are more likely to use bare stem forms for irregular past tense than are younger control children (Leonard et al., 1992; Marchman et al., 1999 [for age-control comparisons]; Oetting & Horohov, 1997). Third, there are reports in the literature that overgeneralized irregular past tense forms (such as "catched") appear in the responses of children with SLI. Oetting and Horohov (1997) report an over-regularization rate of 34% for the SLI group, 61% for younger controls, and 81% for age-matched controls.

The limitations of the existing literature are both empirical and conceptual. With regard to empirical limitations, only two of the previous studies compared performance on regular and irregular past tense verbs for children with SLI and younger language-matched controls as well as age-matched controls (Leonard et al., 1992; Oetting & Horohov, 1997). Thus, there is a need for further evidence contrasting the two forms of past tense within groups of affected and control children. Further, the available group evidence is cross-sectional, for SLI children ages 3;7 to 6. Longitudinal growth curves are needed to evaluate the developmental trajectories of the two verb types. The study reported here addresses both of these empirical limitations.

An unresolved conceptual issue is how to bring together in one explanation three empirical observations regarding the performance of children with SLI relative to younger language-matched controls: Children with SLI are more likely to drop regular past tense, to use bare-stem forms as errors for irregular past tense, and to perform at comparable levels of percentage correct on irregular past tense verbs. In search of conceptual clarifications we consider the distinctions between morphosyntactic and morphophonological models and how such distinctions can be used in measures of children's acquisition of regular and irregular past tense.

Acquisition of English Past Tense in Unaffected Children

Morphosyntactic Model

The optional infinitive account of children's acquisition of tense argues that young English-speaking children are slow to learn the obligatory properties of tense marking, but they know other syntactic properties. This is a morphosyntactic model of past tense, which incorporates the following distinctions drawn from contemporary linguistic models of adult language and children's language acquisition (cf. Crain & Lillo-Martin, 1998; Haegeman, 1994). Under this model, each matrix (main) clause has a site licensed for tense and subject-verb agreement marking. Forms carrying tense and agreement marking are regarded as finite forms. Past tense marking on the lexical verb appears in various morphological forms, which can be either regular (e.g., *walk/walked*) or irregular (e.g., *dig/dug*). It can also appear as a past tense form of a copula or auxiliary verb form.

Regardless of the surface form, certain principles apply. First, finiteness is an obligatory property of a full clause. In English this can be seen in third-person singular present tense *-s*, past tense, *BE* copula, and *BE* and *DO* auxiliary contexts, where omission of the forms in obligatory contexts is not permitted. Second, because there is only one licensed site per clause, it is not possible to have both options in the same matrix clause, as is shown in 1a and 1b.

1a. *Patsy was saw John.

1b. *Patsy made him went home.

Third, tense and agreement marking are closely related to word order. For example, in English finite forms cannot move from the licensed site in order to express negation or to form a question, as shown in 2a and 2b.

2a. *Patsy saw not John./Patsy did not see John.

2b. *Saw Patsy John?/Did Patsy see John?

These rules apply whether the verb form follows the regular or irregular paradigm for past tense marking. There is now a large literature examining how the principles governing finiteness marking (i.e., tense/agreement marking) are evident in different languages and ongoing investigation of how those principles operate in children's grammar across languages (cf. Schütze, 1997; Wexler, 1998).

The crucial point here is that within a morphosyntactic framework, knowledge of the obligatory property of finiteness and its related properties (such as site licensing, one site per main clause, and word order) is distinguished from knowledge of the phonetic structure for a given lexical verb form to express past tense. This is not to say that phonetic structure is unimportant, because of course it is vital, but to emphasize that the rules for the interface of phonology and morphology are distinct from those that govern the interface between morphology (i.e., finite forms) and syntax—a distinction that potentially is very relevant to understanding the nature of children's language impairments.

Morphophonological Models

Much of the literature on children's acquisition of past tense has focused on the morphophonological learning involved. A central dispute has been whether a *Dual Mechanism* or a *Single Mechanism* is involved in learning regular versus irregular forms of past tense. The *Dual Mechanism* account argues that there is a computational function that is operative for regular past tense affixation, which is supplemented by a rote ("look-up") function that operates for irregular past tense forms that are not computed but are retrieved from the lexical store. Thus, growth in accuracy of regular versus irregular past tense is attributable to different mechanisms of learning and storage (see Marcus et al., 1992; Pinker, 1994).

In contrast, a *Single Mechanism* account, such as that offered by connectionist theorists, posits that a single learning mechanism can handle both regular and irregular forms of past tense morphology. The variations in accuracy are dependent upon surface-level features, such as the frequency of input and shared phonological features (Plunkett & Marchman, 1991, 1993).

Explanations of Tense Deficits of Children With SLI

Explanations of the tense deficits of children with SLI can be categorized as predominately morphosyntactic versus morphophonological in perspective.

Morphosyntax: Extended Optional Infinitive (EOI) Account

This morphosyntactic account regards regular past tense *-ed* as part of a cluster of affected morphemes (i.e., third person singular *-s*, *BE*, *DO*). In a cross-sectional study, Rice et al. (1995) established that a set of tense-marking morphemes differentiates affected 5-year-old children from unaffected same-age controls as well as 3-year-old language-matched controls, whereas morphophonologically similar control morphemes, such as plural *-s*, do not show a decreased accuracy in the affected group. These findings were replicated in a second sample of children (Rice & Wexler, 1996). In a longitudinal study, Rice et al. (1998) discovered that the individual items in the set of tense-marking morphemes show similar growth curves in the period from 3 to 8 years old. Furthermore, the same predictor model was obtained for each morpheme, showing that maternal education, child nonverbal intelligence, and child receptive vocabulary scores do not predict growth for any of the morphemes. Evidence from non-English languages indicates that the phenomenon is probably not limited to bare stems and omission of auxiliaries and copulas. In languages that have inflected infinitival forms, children with SLI use inflected infinitives in contexts where finite forms would be expected (for German, see Rice, Noll, & Grimm, 1997; French: Jakubowicz, Nash, & van der Velde, 1999 and Paradis & Crago, 1999; Italian: Bottari, Cipriani, &

Chilosi, 1996; Swedish: Hansson, Nettelbladt, & Leonard, 2000). As expected, grammaticality judgment tasks also show that English-speaking children with SLI are more likely than younger controls to accept dropped tense marking as "OK," and this tendency persists throughout the 6- to 8-year-old period (Rice, Wexler, & Redmond, 1999). Because the omission pattern is accepted in judgments as well as in the production data, it does not seem to be attributable to production constraints alone (cf. Bishop, 1994). The EOI has been interpreted as an extended period of an "immature" child grammar.

Under the EOI account, the regular/irregular verb distinction is different from that of finite/nonfinite. This generates an interpretive framework that brings together in one account the separate facts about regular and irregular verb acquisition, summarized in Table 1. The EOI model predicts lower performance for the SLI group relative to the MLU control group on regular past tense use in obligatory contexts, comparable performance of the SLI and MLU control groups on percentage correct use of irregular past tense forms, and a greater likelihood for the SLI group than the MLU group of bare-stem responses for irregular as well as regular past forms. The second prediction is because the percentage-correct use conflates two dimensions: that of morphophonological learning and the morphosyntactic requirement to mark finiteness. The morphophonological learning of affected children is expected to parallel that of children at a similar language level. The framework adds a crucial new prediction: On a measure of finiteness of irregular past tense, differences in performance level between regular and irregular past tense should disappear for the SLI group and the control groups as well, because the likelihood of attempting to mark tense is tied to an underlying grammatical representation that holds across surface forms, and children can draw upon incomplete morphophonological learning to mark irregular past tense although it may not match the adult past tense forms. At the same time, if children do not regard past tense marking as obligatory, they will not try to mark it on regular or irregular past tense forms. Furthermore, because the morphophonological learning is different from finiteness, growth curves are likely to differ for the two dimensions.

Table 1. Predictions of two models of past tense.

Variables	Extended Optional Infinitives	Low Phonetic Substance
Predicted Group Differences		
Regular past % correct	SLI < MLU < CA	SLI < MLU < CA
Irregular past % correct[a]	SLI = MLU < CA	SLI = MLU < CA
Irregular past bare stem errors	SLI > MLU > CA	SLI = MLU
Finiteness % correct[b]	SLI < MLU < CA	—
Predicted Variable Relationships		
Irregular finiteness = regular past, all groups		—
Growth of finiteness ≠ growth of irregular past, all groups		—

[a]Number correct divided by total attempted (i.e., correct + over-regularization + bare stems).
[b]Number correct + overgeneralizations divided by total attempted (i.e., correct + over-regularizations + bare stems).

Morphophonological Models of SLI

Low Phonetic Substance (LPS)

An alternative explanation for the tendency of young children with SLI to drop regular past tense *-ed* focuses on the phonological properties of the affix. See predictions in Table 1. This is well exemplified in a study by Montgomery and Leonard (1998), who studied 21 8-year-old children with SLI and 21 children in each of two control groups: one group of children matched for chronological age and another matched for receptive syntax. The experimental tasks were a word-recognition reaction-time task and an off-line task of grammaticality judgments. Third person singular *-s* and past tense *-ed* were regarded as low phonetic substance morphemes versus progressive *-ing* as a high phonetic substance morpheme. Lexical verbs were presented in stem versus inflected conditions. Children with SLI did not differentiate between inflected versus noninflected *-ed/-s* but they did so for progressive *-ing*, whereas the control children did differentiate. On the grammaticality judgment tasks, the SLI group performed lower than the chronological age group on missing *-s/-ed*. Note that the results are compatible with the predictions of the EOI account, but the models differ in interpretation. The LPS model attributes the tendency to drop *-ed* to the low phonetic substance of the regular affix, because "Children with SLI are generally less efficient to process spoken language relative to normally developing peers" (p. 1441).

Irregular past tense forms do not show the low phonetic substance of the regular forms. In English (Leonard et al., 1997), and more recently Swedish (Hansson et al., 2000), the interpretation is that the internal vowel changes of irregular past tense phonology present an advantage to the spoken language processor. That is, it would be easier for a child to detect the difference between, for example, *ride/rode* than *play/played*. For this reason, irregular past tense forms should not be more difficult for children with SLI than expected for their language level (i.e., SLI group = MLU controls, cf. Hansson et al.).

Note that the predictions of group performance on accuracy of regular and irregular past tense are the same for the EOI and the LPS accounts, although the interpretations are different. The differences between the two models become more evident with regard to the interpretation of the observed bare-stem errors for irregular past tense, expected levels of finiteness marking (i.e., crediting overgeneralizations as attempts to mark tense), and an expected comparability of finiteness of irregular past tense forms and regular past tense percentage correct. With regard to the likelihood of bare stem errors for irregular past tense, Hansson et al. (2000) and Leonard (1998) predict that the SLI group will be equivalent to the MLU controls on irregular past tense accuracy. We can extrapolate from that prediction to the expectation that the SLI group will also show the same error patterns as the younger controls. Thus the prediction is that the SLI group will be similar to the MLU controls on the bare-stem variable. The LPS model is silent regarding the bigger picture of interrelationships among regular- and irregular-past forms, and bare stems and overgeneralizations, because the explanation for regular past tense *-ed* omission posits a breakdown in processing that is not operative for irregular past tense forms. To the extent that the rate of irregular finiteness marking is comparable to that of the percentage correct on regular past tense *-ed* (in spite of surface differences in phonology), as predicted by the EOI, and a unified account is preferable to two separate explanations, there is support for the claim that a problem with finiteness is at the root of the bare-stem phenomenon for regular past tense.

Other Morphophonological Models of SLI

Two recent studies are important because they provide valuable empirical evidence of immediate relevance to this study. They are explicit investigations of the Connectionist and Dual Mechanism accounts of past tense morphophonology, to determine if the performance of children with SLI follows the predictions of those particular models. The study reported here is not focused on differentiating between these two models, but because some of the empirical phenomena are the same as those of this study, the investigations are highly pertinent. Marchman et al. (1999) studied 31 children with SLI and 31 control children in the age range of 6 to 12 years (mean = 8;4) and their performance on an experimental probe task consisting of regular and irregular past tense forms. They report that bare stems were more likely for the SLI group than the control children for both regular and irregular forms of verbs. The frequency of suffixations (over-regularizations) was not statistically different for the two groups, although the raw numbers showed more over-regularizations for the SLI group. The authors conclude that the zero marking (bare-stem errors), regardless of verb type, seen in children with SLI is accounted for by alveolar stop consonant stem-final phonology (although their data show zero marking across all phonological contexts). Over-regularizations, they conclude, are determined by low-frequency past tense forms, interference from regular phonological patterns, and an absence of a final alveolar stop consonant. They also attribute the tendency of the SLI group to generate bare stems of verbs as an over-regularization from a subclass of irregular verbs that show zero marking (e.g., *put*, *cut*). In apparent contrast to the LPS account, the authors conclude that children with SLI are "over-sensitive to the presence of specific phonological features in stems. Such an over-sensitivity may interfere with efficient lexical processing and hence the organization of general patterns that obtain across individual grammatically inflected forms" (p. 13).

Oetting and Horohov (1997) investigated the Dual Mechanism model in a study of 11 6-year-olds with SLI and 11 children in each of two control groups, one matched for chronological age and the other matched for MLU. They also used an experimental probe task to evaluate regular and irregular past tense performance. They report that in the probe data, the over-regularization rate for the SLI group was lower than that of either control groups, in contrast to the similar rates reported by Marchman et al. (1999). The difference in outcomes could be because Oetting and Horohov adjusted the rates to control for group differences in the number of correct uses, an adjustment that was not part of the Marchman et al. calculation. Oetting and Horohov added further evidence of a bare-stem tendency in their report that the SLI group had higher rates of bare stems for both verb types than did the control groups.

Purpose of Investigation

As is evident from the literature summarized above, there are several important gaps in the available information about children's acquisition of past tense markers. Virtually all of the available studies of children with SLI approach the question from a morphophonological perspective: How do children learn the phonological properties of past tense? There is need of an investigation motivated by a morphosyntactic view of finiteness marking. The few studies of irregular past tense provide interesting but early and incomplete findings that are not easily integrated into explanations for children's omission of regular past tense. The available literature lacks a long-term investigation during the acquisition period in which children with SLI are observed longitudinally and compared to longitudinal observations of control children. Therefore, there are no reports of growth-curve modeling to examine whether the predictors and growth curves are similar across groups and across past tense forms. This study adds to what is known about past tense acquisition by investigating children's acquisition of irregular and regular past tense, longitudinally from age 3 to 8. The performance of children with SLI is compared with that of two control groups: an age-matched group and a younger MLU-equivalent group. Differences and similarities are evaluated for the two categories of past tense verb, and the efficacy of explanatory models is evaluated.

Method

Participants

The participants in this study are the same as the children studied in Rice et al. (1998). A total of 64 children participated: 21 initially identified before kindergarten as SLI, 23 children as age-matched controls (henceforth referred to as 5N because each was nonaffected and about 5 years old), and 20 children as a language-control group, selected for equivalent levels of MLU[1] (referred to here as 3N because they were nonaffected and their mean age was about 3 years). See Table 2 for a descriptive summary of the participants by group.

The children in the SLI group were identified as SLI and receiving intervention from certified speech-language pathologists in the year before kindergarten enrollment (ages 4;5–5;0). Each child showed receptive language performance one or more standard deviations below the mean on the Peabody Picture Vocabulary Test–Revised (PPVT-R; Dunn & Dunn, 1981) and a MLU one standard deviation or more below the age norms of Leadholm and Miller (1993). The children's performance on the Test of Language Development–Primary (TOLD-P:2; Newcomer & Hammill, 1988) was one standard deviation or more below the mean on the five-subtest language quotient, where the mean is 100 and one standard deviation is 15. Two children were admitted whose score was slightly above this criterion on the TOLD-P:2, one with a standard score of 88 and another with a standard score of 93, because they met all other criteria. The children were screened for speech competency, with performance on a speech probe demonstrating that they produced final *-t*, *-d*, *-s*, and *-z*. Some of the children showed speech delay patterns of mispronunciations of /s/, /sh/, /ch/, /r/, and /l/ that are mild developmental speech errors sometimes seen in younger unaffected children and in young children with SLI (Shriberg, Tomblin, & McSweeney, 1999). The children met the following exclusionary criteria: intellectual functioning above clinical levels of intellectual impairment, with an age deviation of 85 or above on the Columbia Mental Maturity Scale (CMMS; Burgemeister, Blum, & Lorge, 1972), and passing score on hearing screening at 25 dB (30 dB in noise environments) at 1, 2, and 4 Hz.

At the outset of the study, there were 14 boys and 7 girls in the SLI group: 17 Caucasian, 3 Hispanic, and 1 Native American. The group means (and standard deviations) were as follows: age, 56 months (3.3); PPVT standard score, 72 (7); PPVT raw score, 29 (9.4); MLU, 3.49 (.67); TOLD-P:2 five-subtest language quotient, 76 (7); CMMS, 94 (7). Mother's education was assessed on

[1]Although there is some controversy in the literature regarding MLU as a matching criterion, in our studies we find highly replicable outcomes with MLU-matched control groups and stable patterns of MLU comparability across time (Rice, Rice, & Redmond, 2000). For the growth curve analyses reported in the Results here and in the earlier study of Rice et al. (1998, p. 1424), the same outcomes obtained for MLU morphemes (used here) and MLU words, suggesting that the MLU-morphemes measure is not affected by group differences on the tense morphemes.

Table 2. Participant descriptions at the outset of the study: Group means (and standard deviations).

Group	Number	Age[a]	PPVT-R[b]	PPVT-R[c]	MLU[d]	TOLD-P:2[e]	CMMS[f]	Mother's education[g]
SLI	21 (14 boys)	56 (3.3)	72 (7)	29 (9.4)	3.49 (.67)	76 (7)	94 (7)	2.5
5N	23 (11 boys)	59 (4.1)	108 (8)	62 (8.8)	4.18 (.58)	112 (9)	107 (10)	4.1
3N	20 (10 boys)	36 (3.9)	101 (9)	24 (8.3)	3.66 (.58)	107 (9)	110 (9)	4.5

[a]Age in months.
[b]PPVT-R standard score.
[c]PPVT-R raw score.
[d]Mean length of utterance in morphemes.
[e]Five subtest language quotient; at Round 3 for 3N group.
[f]At Round 3 for 3N group.
[g]Scale of 1 = some high school and 5 = some graduate school.

a scale where 1 = some high school and 6 = completed a graduate degree. The group mean was 2.5, with a distribution across the entire range; 16 were high school graduates or above.[2]

Children in the 5N and 3N groups were drawn from preschool centers in the same residential areas as the children in the SLI group. These children were regarded as "normally developing" by their classroom teachers, passed the hearing screening, and had scores on the PPVT-R and the TOLD-P:2 in the normal to high-normal range. The children in the 3N group had MLU values that were within ±1 *SD* of the mean expected for age. In order to ensure equivalent levels across the two groups, each subject in the MLU group was within .10 morphemes of at least 1 child in the SLI group. The CMMS was administered to the children in the 5N group at the outset of the study. Children in the 3N group were too young to receive the CMMS at the time of the initial measures. At age 4 years, they were tested on the CMMS, which is used here as an estimate of their intellectual functioning at age 3 years.

In the first year, 23 5N children were recruited: 11 boys and 12 girls; 21 Caucasian, 2 African-American. The group means (and standard deviations) are as follows: age, 59 months (4.11); PPVT standard score, 108 (8); MLU, 4.18 (.58); TOLD-P:2, 112 (09); CMMS, 107 (10). The mean level of mother's education was 4.1. All were high school graduates or above.

In the first year, 20 3N children were recruited: 10 boys and 10 girls; 19 Caucasian, 1 Native American. The group means (and standard deviations) are as follows: age, 36 months (3.9); PPVT standard score, 101 (9); PPVT raw score, 24 (8.3); MLU, 3.66 (.58); Test of Early Language Development (TELD; Hresko, Reid, & Hammill, 1981), 130 (8) [note that in subsequent rounds, this group's TOLD-P:2 scores are 107 (9) at Round 3 and 112 (10) at Round 5, leading us to believe that the TELD at Round 1 is an overestimate]); CMMS, 110 (9). The mean level of mother's education was 4.5. All were high school graduates or above.

As reported in Rice et al. (1998), at Round 7 when the children in the SLI group were 8 years old their group performance continued to show low language levels relative to age expectations. Their PPVT-R standard score mean (and standard deviation) was 85 (11); MLU, 4.85 (.84); TOLD-P:2 five-subtest language quotient, 79 (8); CMMS, 99 (12). Only one child in the group had scores for both the PPVT-R and the TOLD-P:2 tests above 85, and this child did not perform well on the measures of tense marking. Overall, the poor language performance of the children persisted from preschool through age 8. This outcome is consistent with a recent report by Johnson et al. (1999), which notes persistent language impairment from preschool through age 19, with 73% of the children maintaining their status as language impaired throughout this period. Likewise, the outcomes of the 3N and 5N groups are very similar to their initial test performance (see Rice et al., 1998, for group means).

Another important observation is that under the selection criteria of at least one standard deviation below the mean on the PPVT-R for the SLI group and a match on MLU for the control group, the outcome is a control group matched not only for MLU but also for PPVT-R raw scores. At the outset, the two groups did not differ statistically on this measure. Furthermore, over the 7 times of measurement the two groups show parallel gains in PPVT-R raw scores, with similar group measures and variances (Rice, Rice, & Redmond, 2000). As we have noted in previous reports with this sample, we recognize the lexical deficits of the SLI group. We consider the lexical and MLU deficits to be part of a delayed onset of language (cf. Rice & Wexler, 1996). The observed morphosyntactic deficits are of interest because they exceed the MLU and lexical expectations.

Procedures

The children were tested at 6-month intervals, once in the fall semester and again in the spring semester, for a total of seven rounds of data collection, encompassing the ages from 2;6 to 8;9. The SLI group age range was 4;5 to 8;9 years. The mean ages in months per group per round are as follows: SLI: 57, 65, 72, 79, 85, 92, 97; 3N: 36, 43, 49, 57, 62, 69, 74; 5N: 59, 65, 72, 79, 85, 91, 96. Data collection was carried out in the children's schools (a total of 63 different centers, overall).

Measures

Past tense performance was measured on an elicitation probe. The elicitation probe consisted of pairs of pictures, showing a child engaged in an activity in one picture and the child having completed the activity in the second picture. The examiner showed the first practice set of pictures and said, "Here the boy is raking [referring to the first picture]. Now he is done [referring to the second picture]. Tell me what he did to the leaves." Children were encouraged to use a complete sentence, with an overt subject, in order to ensure an obligatory

---

[2]This sample of affected children yields a group mean for mother's education that is lower than that of the control groups and a lower group mean level of nonverbal intelligence (although each child is within normal range, and the mean is near the instrument's age mean). This outcome is consistent with a large-scale epidemiological study (Tomblin, 1996) which found that a sample of randomly selected affected children is more likely to include mothers who did not complete as many levels of higher education as a randomly selected group of unaffected children. Given the academic risk levels associated with the condition of SLI and the likelihood that it runs in families, these findings are not surprising. As shown in the Results section, neither variable is significantly correlated with the tense variables for the SLI group or for the 3N group.

context for tense marking. Two practice items were given, to establish the task expectations. Nineteen experimental items were then administered, without feedback as to accuracy of the child's response and without any adult model of the target form. Eleven regular past tense items were intermingled with eight irregular past forms. Lexical verb items were selected for familiarity, ease of naming, and visual depiction.[3] Pilot testing established that young children could easily generate the target names of the selected activities. The regular forms were *brush, clean, color, climb, jump, kick, paint, pick, plant, play, wash*; irregulars were *catch, dig, fall, make, ride, swim, throw, write*. Items were selected to represent the *-t, -d,* and *-ed* allophonic variants of regular past and internal vowel changes for irregular past, with the exception of one irregular item that involved a final consonant change (i.e., *make/made*). All but one of the regular items (i.e., "planted") would have been as frequent as Oetting and Horohov's (1997) criteria for "frequent" verbs, as defined by frequency counts of Hall, Nagy, and Linn (1984) compiled from spontaneous language samples of children between the ages of 4;6 and 5;0. All but *dug* of the irregular items would have been as frequent as the regular "frequent" items of Oetting and Horohov. In addition, of relevance to the study of Marchman et al. (1998), the items for both regular and irregular forms were mostly ones in which the final consonant of the stem form was not an alveolar stop consonant (i.e., only 2 regular items and 2 irregular items involved alveolar stop consonants; i.e., final *-t* and *-d*). Another difference from the items of Marchman et al. is that items with zero change from present to past tense, such as *cut/cut*, were not included in the irregular past tense items.

Reliability

Reliability of measurement was reported in detail in Rice et al. (1998). Essentially, the relevant reliability calculations are as follows: For spontaneous transcription and coding, research assistants were trained to 90% agreement with trained coders; subsequently, interrater agreement, assessed over rounds, was at 90% or better for utterance boundaries, morpheme transcription, morpheme coding, and morpheme counting. For the experimental coding, all examiners were trained to criterion levels of 90% agreement or better with trained examiners before participating in data collection. Interexaminer agreement for past tense coding was 99%, collapsed across regular and irregular past forms.

[3]The possible number of items is constrained by the ability of the youngest children to participate in such a task. At the first time of measurement, the 3N group's age mean was 36 months, which is relatively young for such a task (cf. Oetting & Horohov's youngest group, whose average age was 48 months). Although more items might enhance our understanding of item generalization, there is the risk that a longer task will lead to a breakdown in participation by the youngest children and/or require two separate testing sessions.

Results

Experimental Probe Growth Curves

Figures 1–7 display the growth curves for performance on the experimental probes. The figures display three groups and three dependent variables over time. Figures 1–3 show group differences on a given variable (cf. Table 1, predicted group differences); Figure 4 shows a sample of actual individual growth curves; Figures 5–7 show relationships among the three variables within groups (cf. Table 1, predicted variable relationships). The dependent variables are (a) regular past percentage correct (# correct divided by total # of regular past probe items attempted, i.e., obligatory contexts); (b) irregular past percentage correct (# correct divided by total # of irregular past items attempted)[4]; and (c) finiteness percentage for irregular past verbs, calculated as number correct + number of over-regularizations divided by total number of irregular past items attempted. Under this calculation, a child was credited for forms such as *falled*, as showing knowledge of the need to mark finiteness, even though the chosen phonological pattern was not the adult form.[5] As far as we know, this is the first time such a measurement has been reported. The import of the adjusted index of finiteness is that it credits a child for knowing that past tense must be marked, but relaxes the requirement of morphophonological accuracy to accept children's generalization errors. See Table 3 for group means and standard deviations for each variable at each time of measurement, for each group.

There are several things to note from the figures. With regard to group differences, Figure 1 shows the regular past tense percentage correct. (See Figure 5 of Rice et al., 1998, where the same data are graphed so as to display age differences between the SLI and 3N groups). As reported by Rice et al. (1998), performance on this variable yields statistically significant differences ($p < .01$) between the SLI group and the 5N group

[4]Following Brown (1973) and Marcus et al. (1992) we use the conventional calculation of percent correct in obligatory contexts, where the numerator is the number correct and the denominator is the total number of obligatory contexts in which the form appeared, for both regular and irregular verbs. Because each child did not necessarily respond to each item on the probe task, the number of obligatory contexts is the number of items attempted. The variation in total number of responses across children is very small; for most of the data points almost all children attempted all items.

[5]Errors of present tense for past tense, such as "falls" for "fell," are rare events in the data. Although such forms are marked for tense, they are removed from the analyses as instances of "other tense" and do not enter either the numerator or denominator for the percentage calculations.

Figure 1. Regular past probe percentage correct per group.

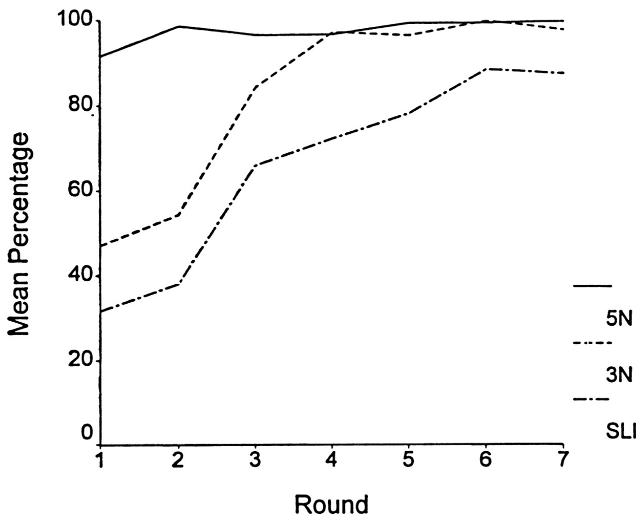
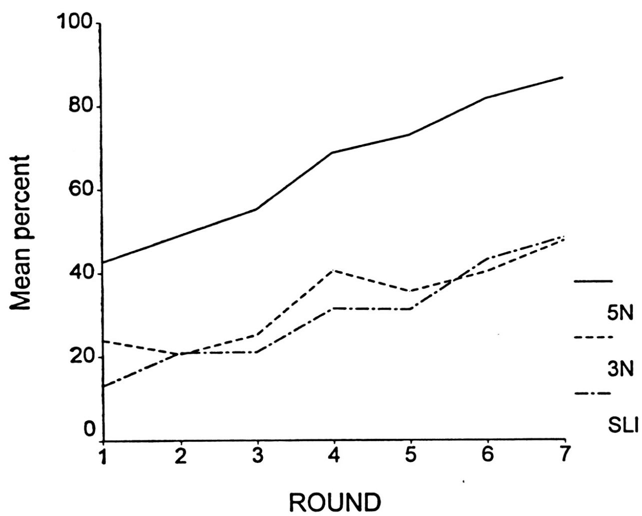


Figure 2. Irregular past probe percentage correct per group.

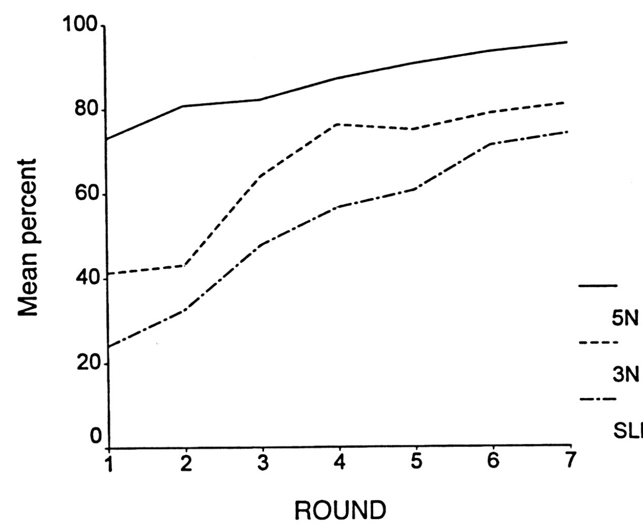


at each time of measurement and significant differences ($p < .05$) between the SLI group and the 3N group when the SLI group's age is 6 to 8.5 years (i.e., Rounds 3–7). (Pairwise comparisons of group performance within rounds are reported here for each variable because overall ANOVAs of group × round yield significant differences for both group and round for all three variables, and the group comparisons are of primary interest. See Rice et al., 1998, for detailed reports of effect sizes. For the round effect, and possible interactions of group × round, the growth curve analyses reported below are the preferred data analytic strategy to investigate models of growth.) Descriptively, for regular past tense, the 5N group is near ceiling throughout the time of measurement; the SLI group trails the younger group throughout—a difference that reaches statistical significance when the SLI group is age 6;0 (see Rice et al., 1998, for further data documentation).

Figure 2 shows the irregular past tense percentage correct. As expected, the SLI group performs at a level similar to that of their younger language controls throughout the study. This level is below that of the age-control children, who are steadily improving their accuracy on the probe irregular verbs during this age period. As we will discuss later, this is a somewhat misleading description because the groups differ in the ways in which they are incorrect, but if we focus on morphophonological accuracy (i.e., a child must say "fell," not "falled" or "fall"), we can see steady growth for all three groups, although it is slower for the SLI and younger language controls during the time sampled. For the SLI/5N comparisons, the values of t and p for each round are as follows: 4.72, .000; 3.4, .001; 4.73, .000; 5.26, .000; 5.23, .000; 4.14, .000; 4.63, .000. For the SLI/3N comparisons, the values are as follows: 1.68, .10; –.5, .95; .55, .58; 1.25, .22; .53, .59; –.30, .76; –.09, .93.

The picture shifts greatly when we consider group differences on the percentage finiteness variable (see Figure 3). The pattern here follows that of the percentage correct on regular past tense forms, not the pattern of the irregular past tense accuracy (i.e., the SLI group differs from the age controls and the younger language controls at each round). For the comparison with the age controls, the following values were obtained for t and p for Rounds 1 to 7, respectively: 6.83, .000; 6.09, .000; 5.87, .000; 5.11, .000; 5.25, .000; 4.87, .000; 3.64, .001. For the comparison with the younger language controls, the values are as follows: 2.91, .005; 1.87, .06; 3.91, .000; 4.14, .000; 3.87, .000; 3.95, .000; 3.00, .004. This is striking because the likelihood of some attempt to mark tense is what the two measures share, without

Figure 3. Irregular past probe percentage finiteness per group.



concern for the morphophonological learning evidenced in over-regularizations.

Following conventional practices, the figures display growth curves for group averages at each time of measurement. One could wonder if the group means obscure two contrasting individual profiles—one that involves a sharp jump in accuracy (for example, a child could go abruptly from 50% correct to ceiling levels of performance) versus another pattern of prolonged low performance such that children stay at chance levels, around 50%, throughout. Either of these scenarios may be anticipated if the notion of "optional" is equivalent to "chance" and "nonoptional" is equivalent to "adult-like." Note that this is not the definition of *optional* in the OI/EOI account, where actual levels of optionality are regarded as empirical issues in need of discovery and are thought to be influenced by the child's native language, age/acquisition level, and degree of affectedness. The empirical issue here is whether the group averages are in fact obscuring the two other possible scenarios of individual growth curves. Inspection of the individual data shows that the two alternative possibilities are not characteristic outcomes. Instead, individual children's growth tends to cluster around the group trajectories (although there is variance across actual individual curves, as expected). This can be seen in Figure 4, which shows the individual growth curves of 14 representative children in the SLI group for regular past tense (which, in turn, is representative of the same point for the irregular past and finiteness variables), displayed around the group mean growth curve (the black line). Furthermore, the standard deviations shown in Table 3 show expected patterns, such that at times of change there are larger variances within groups per measure, and as groups reach high levels of performance the variability across individuals is reduced. The general conclusion is that the group means do not mask distinctly different growth profiles of subgroups of children.

Figure 4. Individual growth curves (gray lines) and group mean (black line) for SLI group for regular past percentage correct.

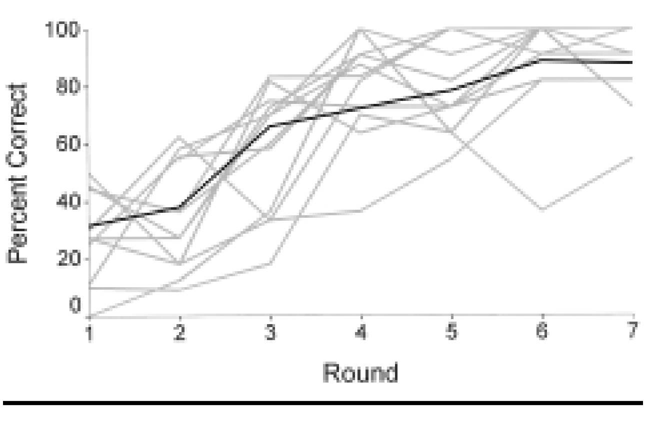


Table 3. Group means (and standard deviations) per group per time of measurement for percentage correct for regular past tense, percentage correct irregular past tense, and percentage adjusted finiteness-marking.

Group	Round	Correct Regular	Correct Irregular	Finite Irregular
SLI	1	32 (24)	13 (14)	27 (27)
	2	38 (22)	21 (18)	39 (26)
	3	66 (28)	21 (18)	56 (27)
	4	72 (34)	31 (22)	66 (28)
	5	78 (19)	31 (24)	72 (25)
	6	89 (18)	43 (30)	82 (17)
	7	88 (19)	48 (26)	86 (20)
3N	1	47 (34)	24 (20)	53 (37)
	2	54 (38)	21 (26)	54 (35)
	3	84 (23)	25 (24)	82 (24)
	4	97 (06)	40 (23)	91 (15)
	5	97 (07)	35 (30)	93 (13)
	6	100 (00)	40 (32)	97 (07)
	7	98 (04)	48 (33)	98 (05)
5N	1	92 (18)	43 (26)	85 (19)
	2	99 (03)	49 (30)	95 (09)
	3	97 (08)	55 (27)	95 (08)
	4	99 (06)	69 (25)	96 (07)
	5	100 (02)	73 (23)	99 (03)
	6	100 (02)	82 (26)	99 (03)
	7	100 (00)	86 (18)	100 (00)

To return to the comparisons across measures, it is easier to see the close alignment of the percentage correct for regular past tense and the percentage of finiteness marking if the variables are graphed within groups. These are displayed in Figures 5–7 (cf. Table 3). In these figures it becomes obvious that the two variables are at virtually the same levels of performance at each time of measurement for each group, and these levels of performance are consistently higher than that of the irregular past percentage-correct measure (i.e., the index that requires full morphophonological learning of the tested forms).[6]

Another important thing to note from the figures is the shape of the growth curves for each measure, especially for the SLI group and the language-control (3N) group, who show change throughout the period. It can be seen that the growth in percentage-correct irregular past tense seems to be steady over time (i.e., linear),

[6] An analysis of the children's spontaneous utterances at each round was carried out to examine the same lexical verbs that were used in the experimental probe for the irregular past tense items. The findings yielded the same patterns over rounds as obtained for the probe measures. For the 3N group, the mean percentage finite irregular past tense exceeded the mean percentage correct irregular past, a difference that was evident for the SLI group as well. Also, the SLI group's level of growth curve performance was below that of the 3N group at each time of measurement.

whereas the growth in percentage-correct regular past tense and percentage finiteness both show a period of accelerated change (i.e., nonlinear components in the growth curve).

Following Rice et al. (1998), we carried out growth-curve modeling with the 3N and the SLI groups to answer these questions: (a) Do children grow linearly in their use of grammatical tense? (b) Do children grow nonlinearly in their use of grammatical tense? (c) Are there individual differences in the rate and type of growth? (d) Are there group differences in the rate and type of growth? and (e) Are there individual and group differences in growth after covarying out individual differences at the outset because of nonverbal intelligence (CMMS), comprehension vocabulary (PPVT-R raw scores), mother's education, or MLU? The lack of variation in the longitudinal performance of the 5N group ruled out growth modeling in this control group.

The method of analysis followed hierarchical linear modeling (HLM) procedures (Bryk & Raudenbush, 1992; Bryk, Raudenbush, & Congdon, 1994), using a mixed-model analysis, where predictor covariates are considered as fixed variables and the children's growth over time (both linear and nonlinear) are random effects. As random effects, a different linear and nonlinear regression coefficient is obtained for each child. It is these regression coefficients that provide information concerning the rate of change of each child. The dependent measures were percentage correct on regular past tense, percentage correct on irregular past tense, and percentage finite irregular past tense.

Inspection of the zero order correlations among the variables is a valuable step before formal modeling. The correlations are reported in Table 4, where it can be seen that among the set of variables, overall, the interrelatedness is low.[7] Within the predictor set, the index of nonverbal IQ (CMMS) correlates with MLU (r = .29) and mother's education (r = .54). MLU yields the only significant correlation with an outcome variable, and this is the finiteness measure only (r = .41). Although high degrees of multicollinearity might have been expected on some theoretical accounts, high levels of intercorrelation are not evident.

Four nested models were evaluated: Model 1 examined whether the four covariates (mother's education and child's CMMS, PPVT-R, and MLU) were significantly related to the dependent measure. Model 2 added to Model 1 a linear growth term in order to determine whether, on average, children (regardless of group membership) changed linearly across time. Model 3 added to Model 2 a nonlinear (quadratic) growth term. Model 4 added to Model 3 two interaction terms. One term represented the interaction between group membership and linear growth; the second, the interaction between group membership and nonlinear growth. The significance of either term would indicate that the groups grew differently.

Table 4. Zero order correlations among predictor variables and outcome variables at Time 1, collapsed across SLI and 3N groups.

	CMMS	MLU	M's ed	Reg Past[e]	Irreg Past[f]	Finite[g]
PPVT-R[a]	–.132	.25	–.04	.10	.04	.16
CMMS[b]		.29*	.54**	.24	.05	.28
MLU[c]			–.02	.29	.13	.41**
M's ed.[d]				.04	.08	.14

[a]Peabody Picture Vocabulary Test–Revised raw score.
[b]Columbia Mental Maturity Scale.
[c]Mean length of utterance.
[d]Mother's education.
[e]Percentage correct on regular past tense.
[f]Percentage correct on irregular past tense.
[g]Percentage finiteness on irregular past tense.

*.05
**.01

The findings are reported here for the overall model, consisting of the full equation for the combined four models (see Appendix). We list the coefficients, standard errors, and p values for each significant covariate or growth term. The outcomes for regular past tense are essentially the same as for the Composite Tense model reported in Rice et al. (1998). For the covariates (Model 1), only MLU was a significant predictor (.112 [.047], $p < .05$); linear growth (Model 2) was significant (.081 [.008], $p < .001$), as was the quadratic growth term (Model 3), (–.018 [.005], $p < .001$). There were small but significant interactions of group with the linear term (Model 4), (–.121 [.056], $p < .06$), and group with the quadratic term (Model 4), (.014 [.006], $p < .05$), suggesting that the shape of the curve differs for the two groups.

In contrast, growth-curve modeling outcomes were different for the measure in which morphophonological accuracy was necessary (i.e., percentage correct of the irregular forms [e.g., for *fall*, only *fell* was credited as correct]). For the covariates (Model 1), MLU was again significant (.101 [.043], $p < .05$), and two additional covariates were significant: receptive vocabulary (.008 [.003], $p < .05$) and nonverbal intelligence (–.008 [.003], $p < .05$). Linear growth (Model 2) was significant (.042 [.008], $p < .001$), but there were no significant quadratic growth term (Model 3) nor interactions. These findings indicate that, unlike the model of regular past, a child's initial receptive vocabulary and nonverbal intelligence

[7]The same general pattern of findings holds for PPVT standard scores as well, with some minor variations. Standard score correlates with the group variable by definition, whereas raw score does not. Within the predictor variables, and relationships with the outcome variables, similar patterns are evident for PPVT-R raw and standard scores.

were associated with irregular past tense percentage correct; and the obtained mean growth curve was a steady, linear upward progression of equal change over the time units and lacked the quadratic curve of the finiteness measures.

On the other hand, the finiteness measure of irregular past tense yielded a model highly similar to that of the regular past tense percentage correct. For the covariates, only MLU was a significant predictor (.131 [.044], $p < .01$); linear growth was significant (.077 [.008], $p < .001$), as was the quadratic growth term (–.01 [.003], $p < .01$). There were no significant group interactions. Overall, the growth-curve modeling verifies that for the SLI group and the 3N group, as depicted in Figures 5 and 6, the acquisition curves for regular past tense *-ed* and the morphophonologically different finiteness measure of past tense show the same linear and quadratic components, and the relationship to the set of covariates is the same (i.e., MLU is a significant predictor, but mother's education and child's nonverbal intelligence and receptive vocabulary are not predictive).

In order to examine more directly the predictive relationship of the covariates to the observed growth trajectories, a series of analyses were carried out to determine the best model to predict the outcomes for each of the three dependent variables. These analyses included, in addition to the terms of the modeling reported above, additional interaction terms, to determine if nonverbal IQ (CMMS), receptive vocabulary (PPVT), MLU, or mother's education affect the linear component of growth. The analyses were carried out using the PROC MIXED of SAS (SAS 8.0, 1999). The findings, summarized in Table 5, are highly congruent with the first analyses. For the regular past tense percentage correct, the best fitting model shows the following significant terms: Group, indicating expected group differences at the intercept (–.16 [.04], $p < .001$), Linear (.29 [.04], $p < .001$), Quadratic (–.02 [.003], $p < .001$), MLU (.14 [.05], $p < .01$), and a Linear by MLU interaction, indicating that MLU predicts linear growth in this variable (–.023 [.01], $p < .05$). In the best model, there was no interaction of the quadratic term and the covariates. The interaction of group with linear growth found in the first analysis did not replicate in this analysis, suggesting that the linear growth is similar across the two groups.

Figure 5. Three measures of past tense: SLI group.

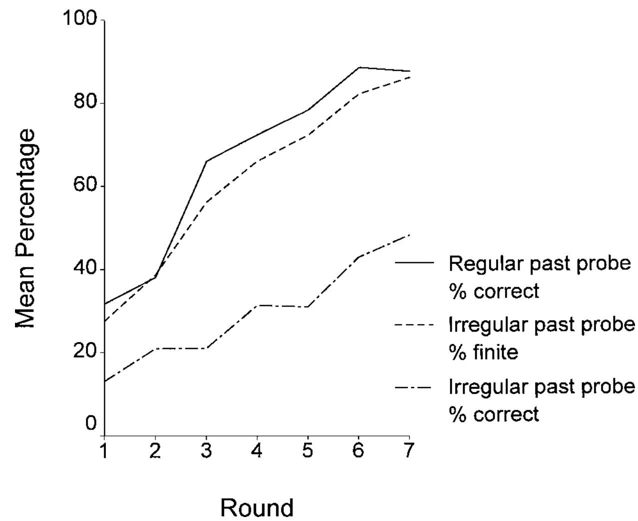
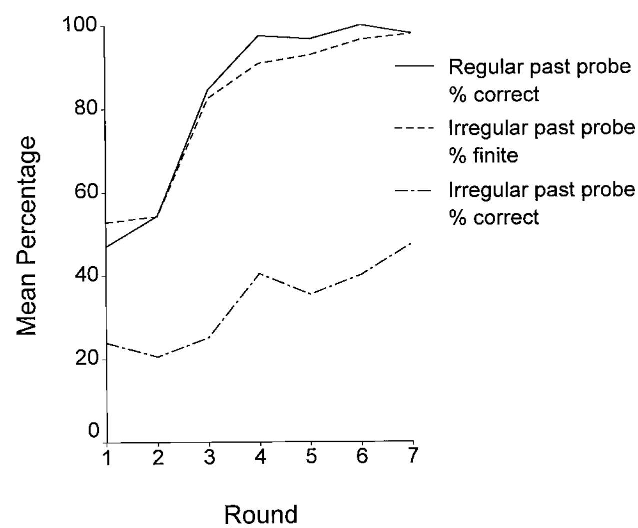


Figure 6. Three measures of past tense: 3N group.



For irregular past percentage correct, as in the first analyses, the predictive models differ from the regular

Table 5. Summary of best-fitting models to predict growth, per outcome variable.

	Group / Intercept	Linear	Quadratic	MLU	PPVT	Linear × MLU		Linear × PPVT
Regular past % correct	√	√	√	√		√		
Irregular past % correct		√		*	*	√	or	√
Finiteness % correct	√	√	√	√		√		

*Neither MLU or PPVT has an effect on the intercept, but the term must be included in the model with interaction terms.

Figure 7. Three measures of past tense: 5N group.

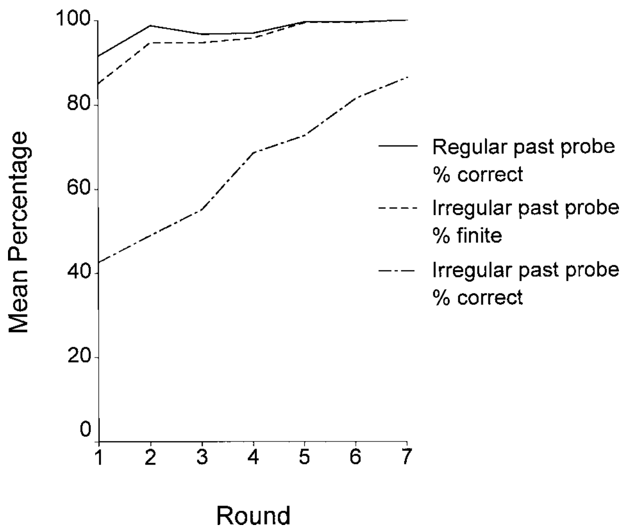
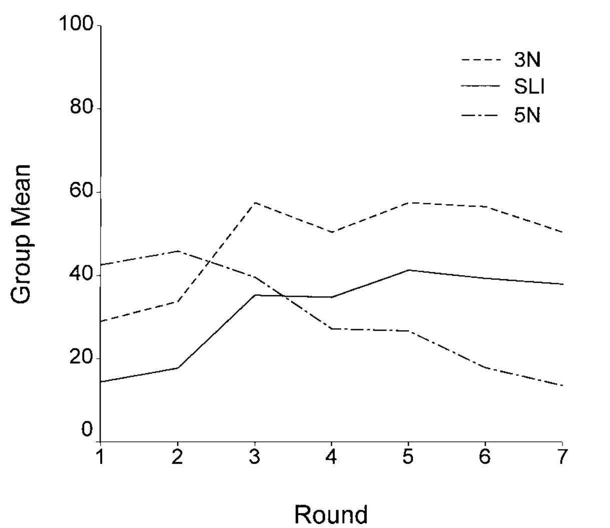


Figure 8. Estimated percentage correct gain due to overgeneralization: Irregular past tense probe.



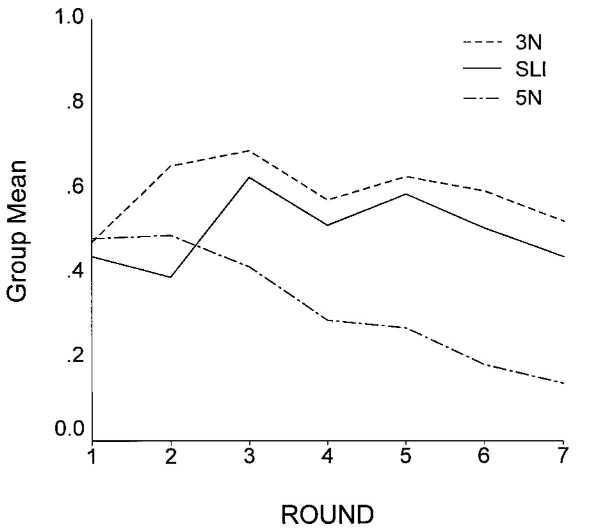
past percentage correct. Two models emerged from these analyses, showing that either MLU or PPVT, but not both in the same model, was a significant predictor. The MLU model shows a small probability only for the linear by MLU interaction (.025 [.013], $p < .06$). The PPVT model includes the following terms with small probabilities: Linear (.05 [.01], $p < .001$) and Linear by PPVT (.001 [.0008], p .08). If both MLU and PPVT are entered into the model, neither emerges as a significant predictor. Again, there was no interaction of the quadratic term with either MLU or PPVT. Inspection of modeled growth curves for the MLU model shows a pattern of increasing dispersion for children with different initial values of MLU, such that children with higher initial levels gain at a greater rate. The modeled curves for PPVT show minimal variance around the slope, and the rate of growth for children at higher initial levels is somewhat smaller than those with lower initial levels, suggesting some sort of a "catch-up" effect.

Finally, for the finiteness index of irregular verb outcome, the best-fitting model of growth is the same as for the regular past tense percentage correct: the expected Group term (–.19 [.04], $p < .001$), Linear (.24 [.04], $p < .001$), MLU (.17 [.05], $p < .001$), and Linear by MLU interaction (–.02 [.01], $p < .05$). Overall, the best-fitting models support the interpretation that MLU is the only variable that predicts the linear slope of growth for the regular past tense percentage correct (with no interaction with the quadratic slope), and it also is the only predictor of linear growth for finiteness percentage correct for irregular past tense verbs. In contrast, PPVT emerges as a possible predictor for the irregular past percentage correct.

In order to evaluate the predictions regarding children's use of bare stems, and the appearance of overgeneralizations of *-ed* on irregular verb forms, further analyses examined the children's error responses. As reported in other studies, the group data for all three groups showed bare stems instead of regular past tense forms, and the group data for all three groups showed bare stems and over-regularizations for irregular past tense forms. The adjustments in performance on the irregular items attributable to over-regularizations can be calculated as the percentage of finiteness-marked forms minus the percentage of correct forms, which is reported in Figure 8 for the three groups at each time of measurement. Several outcomes are evident in the figure. First, the 3N group is most likely to benefit from over-regularizations, gaining 30–55% over the times of measurement and showing a relatively level line from Time 3 (when they were about 4 years old) through Time 7 (when they were about 6 years old). The SLI group also adopted an "add *-ed*" strategy, especially between Rounds 2 and 3, and they persisted with it in subsequent rounds. At the same time, the 5N group (5–8 years old) showed a decline in over-regularization over the time of measurement as they arrived at ceiling performance on the irregular past tense items.

Another way to view the over-regularization outcomes is to calculate the proportion of irregular past tense responses that were over-regularizations (cf. Marcus et al., 1992). This is graphed in Figure 9, calculated as the number of over-regularizations divided by the number of finite responses (i.e., over-regularizations + correct irregulars). It can be seen that the over-regularization rate is highest for the 3N group and lowest, and declining over time, for the 5N group. ANOVAs at each round showed significant group effects, with 5N < SLI at each

Figure 9. Proportion of over-regularizations: Irregular past tense probe.



round and no difference between the 3N and SLI group for all but Round 2, where the SLI group's performance was significantly lower ($t = 2.29$, $p < .05$). It is interesting to note that Figures 8 and 9 both show that the over-regularizations for the SLI group jump between Times 2 and 3, which is when there is a corresponding gain in the percentage correct in regular verb forms, a relationship predicted by Marcus et al.

The extent to which bare stems appeared for irregular past tense forms was calculated as the proportion of incorrect responses that were bare stems. In these data, the errors were almost all either bare stems or over-regularizations, so the proportion of bare stems is an indirect measure of over-regularizations. As suggested by Figures 8 and 9, the over-regularizations increased over time for the SLI and 3N groups, meaning the bare-stem proportions decreased. For the SLI group, the proportion of errors on irregular past tense items that were bare stems is as follows for each of the 7 times of measurement, beginning at Time 1: 83, 77, 55, 44, 37, 25, 25. For the 3N group, the values are as follows: 59, 49, 22, 15, 11, 05, 03; for 5N, 25, 13, 17, 14, 07, 04, 00. Inspection of Figures 5–7 shows that the likelihood of bare stems for regular versus irregular past tense forms is very similar, as indicated by the small difference between the two top lines on the figures, for both groups of children. Overall, it is obvious that SLI and 3N children are learning two features of irregular verbs during this period: the need to mark the verbs as past tense (i.e., to drop the bare-stem responses) and the means of phonologically representing the past tense morphemes (i.e., the irregular form paradigms). Furthermore, the bare-stem phenomenon appears regardless of morphophonological differences (i.e., an affix vs. a vowel-internal stem change).

Summary and Discussion

This investigation contributes new empirical documentation of the growth trajectories of regular and irregular past tense verb acquisition for children with SLI, ages 5–8 years, and compares their performance to two control groups: one of younger language-matched children and the other of age-matched children. As documented earlier, throughout this period the SLI group falls below the younger control group in their acquisition of regular past tense *-ed*. In this first report of longitudinal records of the SLI group's performance on irregular past tense forms percentage correct, we find their growth on this variable to be parallel to that of the younger children throughout the period observed. These two outcomes are consistent with the two interpretive models evaluated: that of the EOI account and that of the LPS account. When the pattern of error responses is examined, the outcomes over time are consistent with reports of other investigators (i.e., the SLI group was more likely than controls to produce bare-stem forms of the irregular past tense as well as the regular past tense [and the likelihood was similar across form class]); and the group was similar to the language-matched controls in their use of over-regularized *-ed* affixes for irregular past verb stems.

Perhaps of most import, a new, theoretically motivated index of irregular past tense acquisition, that of finiteness percentage correct, revealed growth curve outcomes that, despite differences in surface phonology, paralleled those of regular past tense *-ed* for each of the groups. Furthermore, growth-curve modeling showed that the regular/finiteness percentage-correct variables followed similar trajectories (linear + quadratic) and were both predicted by initial MLU, in contrast to the irregular percentage-correct variable, which showed linear, and not quadratic, growth and was predicted by PPVT or MLU.

On an interpretive level, this investigation emphasized the difference between the morphosyntactic elements of past tense marking and the morphophonological elements. The morphosyntactic component is evident in children's understanding of the obligatory properties of finiteness (i.e., knowing that past tense contexts require the use of a past tense form). The morphophonological element is evident in children's understanding of the phonological structure of regular and irregular past tense morphology. Much of the available theoretical literature examining the acquisition of regular and irregular past tense has focused on the phenomenon of over-regularization and the phonological learning necessary for the patterns of irregular past tense morphology, a perspective that focuses on the surface differences between the two forms of past tense morphology. In contrast, a morphosyntactic perspective notes that the syntactic principles related to finiteness (e.g., obligatory marking, site licensing, one site per matrix clause, and word order) apply regardless of variations in surface phonology.

Two interpretations of the SLI group's limitations were evaluated. The morphosyntactic model, the EOI account, posits that the children's limitations reflect an underlying immature grammar that allows for optional tense marking in obligatory contexts, a morphosyntactic optionality that is distinct from the surface phonological components to be learned. As summarized in Table 1, this model generates a set of interrelated predictions that unify observations on regular and irregular past tense performance by affected children relative to controls, on percentage-correct indices, on the form of errors (i.e., bare stems and overgeneralizations), and on the relationship among variables. The most interesting predictions of group differences bear on the comparison of the SLI and younger MLU-equivalent control group. The SLI group is predicted to perform below the younger controls on percentage-correct regular past tense, to be equivalent to the controls on percentage-correct irregular past tense (where full morphophonological accuracy is required), and to be below the controls on a finiteness measure (where the morphophonological accuracy is relaxed to include any attempts to mark past tense, such as "catched"). The model also predicts a greater occurrence of bare-stem errors within the affected group for irregular as well as past tense verbs, because such forms do not mark tense. Finally, the model predicts that growth in regular past tense percentage correct and irregular finiteness percentage will run in tandem for each group, because both measures are tapping into the same underlying representations of obligatory tense marking, irrespective of differences in surface phonology. This brings a corollary expectation, of a different pattern of growth for finiteness versus irregular past percentage correct, for all groups.

In contrast, the LPS account of the morphological limitations of children with SLI posits two discrete predictions for performance on past tense forms as a function of the phonological properties of the two form classes: The regular past tense percentage correct is expected to be lower for children with SLI than for MLU-equivalent controls as a consequence of the unstressed, low-salience surface properties of the regular affix *-ed*; the two groups should be equivalent on percentage correct on irregular past tense forms because the phonetic substance of the irregular verb forms, with the stem-internal vowel changes, should not pose the same processing difficulty as the regular affix. The two groups would also be equivalent for bare-stem errors on irregular past tense as well, assuming their error strategies would not differ from those of language-matched controls. The model is silent on the ways in which a finiteness index, which gives credit for over-regularizations of irregular past tense forms, would align with the percentage correct of regular past tense, or the likelihood that the growth of finiteness will parallel that of regular past tense percentage correct, or the probability that the growth of finiteness will not show the same growth pattern as the irregular past tense percentage correct.

A key contribution of this study is the calculation of the percentage of finiteness-marked irregular verb forms, a new measure that relaxes the morphophonological requirements for irregular past tense accuracy, and generates meaningful predictions with other indices of past tense acquisition (cf. Table 1). This measure yielded a clear pattern in the evidence, showing that for all three groups of children the level of performance on regular past tense forms and on the finiteness measure was virtually the same throughout the time period sampled. This provided strong support for the notion that the morphosyntactic component of finiteness marking should be differentiated from the phonological properties of past tense morphology. Further, the lower performance of the SLI group, as compared with the younger MLU group, throughout the time sampled, clearly demonstrates that the underlying dimension of finiteness remains relatively difficult for English-speaking children with SLI, regardless of the surface properties of the morphology.

Converging methods of calculating growth-curve models for the SLI and 3N groups provided strong corroboration that the dimensions of finiteness and surface phonology are not identical over time, and furthermore they show different relationships with four predictor variables that index a child's receptive vocabulary (PPVT-R), MLU, nonverbal intelligence (CMMS), and mother's education. Three outcomes are especially noteworthy. One is that the two groups' growth curves were very similar, but at different levels of accuracy; the measures of regular past tense and finiteness for the SLI group are below those of the younger language-matched control group. The second, and major, finding is that the shape of the curves for regular past tense/finiteness differs from that of irregular past tense (where the expected surface phonology is necessary for credit as "correct"). For the finiteness dimension, linear and quadratic components of growth are present, whereas for the irregular past tense/phonological dimension, a linear component alone describes the shape of development. A third outcome is that for the finiteness dimension, the child's initial MLU is the only significant predictor of linear growth in the model, but for the phonological dimension a child's initial receptive vocabulary emerged as an alternative predictor. The relationship between these two possible predictors is such that if they are both entered into a growth model, their effects cancel each other out, but if each is entered singly, either MLU or PPVT emerges as a predictor. Essentially, with growth in MLU over time comes growth in percentage correct of regular past tense, finiteness, and percentage correct of irregular past tense for both groups of children. Note that these results hold when MLU is measured in words instead of morphemes, so we do not think that the relationship is an artifact of the past tense morphology contributing to the gains in MLU. Only the irregular past tense percentage correct, where morphophonological accuracy is required, shows an influence of receptive vocabulary on linear growth.

Considered collectively, the findings show strong support for the EOI interpretation of the relatively low performance on regular past tense verbs by English-speaking children with SLI as primarily attributable to their immature understanding of the obligatory properties of tense marking. At the same time, there is support for the predictions shared by the EOI and LPS account relative to the expected performance of the SLI group and the younger language-matched group, such that when morphophonological learning is required (i.e., on the irregular past tense percentage correct), the two groups would be expected to be at similar levels because, presumably, the morphophonological learning for irregular past tense forms is similar in both groups. The difference between the two accounts is that the EOI interpretation does not attribute dropped *-ed* to children's incomplete knowledge of the phonological structures of the regular past tense affix and related problems in paradigm-building (cf. Leonard et al., 1997). Indeed, the affected children knew enough about the regular *-ed* phonological form to allow them to generate the form for irregular as well as regular past tense verb forms, during the same period when they were using *-ed* inconsistently for marking regular past.

It is important to clarify the EOI position with regard to the gradual change evident in the growth curves over the period studied (i.e., children typically improved their performance over the 6-month intervals studied and were not likely to jump instantaneously from limited use to full adult-like use). This pattern of growth is now demonstrated for multiple morphological indices of tense marking (cf. Rice et al., 1998) and for grammaticality judgments of tense omission as well (cf. Rice et al., 1999). The acquisition of the obligatory properties of tense marking, and the related reduction of optional use (keeping in mind that *optional* is not synonymous with *chance*), is not characterized by instantaneous acquisition mechanisms. In fact it is protracted over a relatively long period in English-speaking children, especially those with SLI. As discussed in Rice and Wexler (1998), we favor a maturational interpretation of children's acquisition of tense, where the increased likelihood of obligatory tense marking is part of an underlying grammatical system that changes with growth. Maturational mechanisms are not necessarily instantaneous change mechanisms, nor are learning accounts necessarily linear in nature. The shape of the growth curves does not differentiate nativist versus learning accounts of language acquisition (cf. Elman et al., 1996). At the same time, it is essential for models of acquisition to have an empirically accurate representation of the growth curves, and the findings here show clearly that the syntactic dimension of finiteness and the phonological dimension of morphology are not drawing upon the same mechanisms. Further, the finiteness dimension is especially difficult for young children with SLI.

Although the study was not designed to clarify how children arrive at full morphophonological competency (i.e., how they learn the irregular past tense forms), the outcomes are relevant to current formulations. As expected in the Dual Mechanism account, growth in the irregular past tense percentage correct, and only this measure, was predicted by receptive vocabulary. This suggests that lexical learning is strongly linked with the morphophonological learning required for irregular past tense, but not for the regular past tense or overgeneralized forms (included in the finiteness percentage correct). Additional support comes from inspection of Figures 8 and 9, suggesting that, as predicted by Marcus et al. (1992), increased over-regularizations of *-ed* seems to coincide with a gain in the percentage correct in regular verb forms.

A few empirical matters are worthy of note. One is that caution is in order in comparing the percentage correct in obligatory contexts for irregular past tense in this study and the levels reported in other studies. The most comparable available evidence is that reported by Oetting and Horohov (1997, p. 69), who report on the following mean proportion correct for their 10-item experimental probe: SLI group, 33.6%; MLU, 24.5%; CA-matched group, 61.8%. Their children's ages are similar to those of the children in this study at Round 4, where the obtained means, as reported in Table 2, are also similar: SLI, 31; 3N (MLU), 40; 5N (CA), 69. In contrast, Leonard et al. (1992) report for irregular past tense probe performance a mean for the SLI group of 65, for children of about the same age as Round 1 of this study (cf. mean of 13% reported in Table 2). The higher values of Leonard et al. (1992) may be attributable to the way the percentages were calculated. Leonard (personal communication) reports that in these percentages the children's over-regularizations were removed from the numerator as well as the denominator for calculation of the percentage correct of irregular past tense forms. An example from an individual affected child's data in this study shows how this could lead to a different value. A child had 7 scorable attempts out of the 8 irregular past tense items, 1 of which was correct, 2 were bare stems, and 4 were overgeneralizations. The percentage correct calculated in the way reported here is 1/7 (14%); it would be 1/3 (33%) if the overgeneralizations were removed from the numerator and denominator. The percentage finiteness, as reported here, is 5/7 (71%). From the example it can be seen that the effect of removing overgeneralizations from the percentage correct would be to raise the accuracy estimate, and, further, it is apparent that the percentage finiteness is not the same as would be obtained by removing overgeneralizations from the numerator and denominator.

Another way in which the levels of performance could be affected is in procedural differences across studies. In the measures reported here, and in Oetting and Horohov (1997) and in Marchman et al. (1999), regular and irregular forms of past tense are intermingled on the probe, whereas in Leonard et al. (1992) a wider selection of morphemes was sampled in a picture-elicitation procedure that included other spontaneous utterances as well. The possible effect of these procedural variations remains to be explored.

Possible frequency of input effects, and associated item effects, have played a central role in debates about the morphophonological acquisition of irregular past tense forms as compared to the regular *-ed* affix. Although those dimensions are not of primary interest in this investigation, some relevant observations can be offered. On an interpretive level, the EOI account and, presumably, the LPS account as well would expect that whatever frequency effects and item effects that may exist would be similar for the SLI and younger control groups. Comparisons with previous studies are complicated by differences in items, item classifications, and data analytic procedures. Oetting and Horohov (1997) found a frequency effect, but no group × frequency interaction. However, the contrast in frequency was more extreme for their item groupings than for the items of this study, where almost all the items would be regarded as "frequent" by their classification. Visual inspection of the item levels of performance for the data reported here does not reveal any differences between groups in patterns of item difficulty; instead there is strong similarity. Frequency effects are not evident at the level of a uniform advantage for items found to be more frequent in caretaker input by Hall et al. (1984). For example, *wrote* is 10 times more frequent than *rode*, yet the two items are very similar in accuracy, suggesting that a similarity in phonological neighborhoods overrode frequency effects for these items. In Marchman et al. (1999), the one interesting way in which group differences (keeping in mind that group differences compared SLI with their age-matched controls) interacted with item characteristics was in the greater likelihood that the SLI group would produce bare-stem responses for verbs that ended in /t/ or /d/—a finding that caused the authors to suggest that bare stems are produced more frequently in children with SLI because of the phonological properties of the verb stem. Given that only 2 of the regular and 2 of the irregular stem forms of this study ended with /t/ or /d/, that does not seem like a plausible account of the performance of the children investigated here. The identification of the contributions of the finiteness dimension to irregular past tense marking, as described in this study, will certainly add complexities to the attempts to isolate the ways in which input frequency or item effects interact with possible group differences, but should nevertheless be considered in future studies.

The outcomes of this study suggest that, although there is a relatively extensive literature available on the acquisition of past tense by children with and without specific language impairment, the domain of regular and irregular past tense continues to hold new information for furthering our understanding of the morphological limitations of affected children. This investigation provided a relatively long growth trajectory, documenting performance on a relatively circumscribed experimental probe task. Valuable next steps would be to explore the early period of acquisition, at younger ages than the children of this study, to determine predictors of onset and early growth in the morphosyntactic and morphophonological aspects of tense marking in English, as well as in the middle childhood period where acquisition is ongoing for affected children. Ultimately, an integrated model of morphophonological and morphosyntactic acquisition of tense marking is the objective, which would allow for greater precision in the development of experimental measures and explanations of possible sources of limitation in affected children.

Acknowledgments

This investigation was supported by National Institute on Deafness and Other Communication Disorders Award R01 DC01803 to Mabel L. Rice and Kenneth Wexler. We wish to express our appreciation to the participants in the study and their parents and teachers, who graciously contributed their time and efforts to our ongoing investigations. The work required the assistance of a number of lab participants. We especially thank Karla Rice for her oversight of data collection and multiple valuable suggestions; Hiromi Morikawa for her management of the database and calculations of the outcomes and Mary Howe for her early contributions in this position; Sean Redmond for his assistance with data collection and insightful comments; Patsy Woods for preparation of the manuscript and other valuable assistance; and the following lab assistants: Patricia Cleave, Chien Wang, Su Dong Chen, Laura Smith, Carol Schekall, Candice Odle, Fiona Carswell, and Sara Tweed. Preliminary reports of this investigation were presented at the Symposium on Research in Child Language Disorders, June 1999, and at the Boston University Conference on Language Development, November 1999.

References

Bishop, D. V. M. (1994). Grammatical errors in specific language impairment: Competence or performance limitations? *Applied Psycholinguistics, 15,* 507–550.

Bottari, P., Cipriani, P., & Chilosi, A. M. (1996). Root infinitives in Italian specific language impaired children. In A. Stringfellow, C. Cahana-Amitay, E. Hughes, & A. Zukowski (Eds.), *Proceedings of the 20th Annual Boston University Conference on Language Development* (pp. 75–86). Somerville, MA: Cascadilla Press.

Brown, R. (1973). *A first language: The early stages.* Cambridge, MA: Harvard University Press.

Bryk, A. S., & Raudenbush, S. W. (1992). *Hierarchical linear models.* Newbury Park, CA: Sage Publications, Inc.

Bryk, A. S., Raudenbush, S. W., & Congdon, R. T. (1994). *Hierarchical linear models manual.* Newbury Park, CA: Sage.

Burgemesiter, B. B., Blum, L. H., & Lorge, I. (1972). *Columbia Mental Maturity Scale.* San Antonio, TX: Psychological Corporation.

Clahsen, H., & Dalalakis, J. (1999). Tense and agreement in Greek SLI: A case study. In *Essex Research Reports in Linguistics,* 1–26.

Crain, S., & Lillo-Martin, D. (1998). *An introduction to linguistic theory and language acquisition.* Oxford, U.K.: Blackwell.

Dunn, L., & Dunn, L. (1981). *Peabody Picture Vocabulary Test–Revised.* Circle Pines, MN: American Guidance Service.

Elman, J. L, Bates, E.A., Johnson, M.H., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1996). *Rethinking innateness: A connectionist perspective on development.* Cambridge, MA: MIT Press.

Haegeman, L. (1994). *Introduction to government and binding theory.* Cambridge, MA: Blackwell.

Hall, W., Nagy, W., & Linn, R. (1984). *Spoken words: Effects of situation and social group on oral word usage and frequency.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Hansson, K., Nettelbladt, U., & Leonard, L. B. (2000). Specific language impairment in Swedish: The status of verb morphology and word order. *Journal of Speech, Language, and Hearing Research, 43,* 848–864.

Hresko, W. P., Reid, D. K., & Hammill, D. D. (1981). *Test of Early Language Development.* Austin, TX: Pro-Ed.

Jakubowicz, C., Nash, L., & van der Velde, M. (1999). Inflection and past tense morphology in French specific language impairment. In A. Greenhill, H. Littlefield, & C. Tano (Eds). *Proceedings of the 23rd Annual Boston University Conference on Language Development* (pp. 289–300). Somerville, MA: Cascadilla Press.

Johnson, C. J., Beitchman, J. H., Young, A., Escobar, M., Atkinson, L., Wilson, B., Brownlie, E. B., Douglas, L., Taback, N., Lam, I., & Wang, M. (1999). Fourteen-year follow-up of children with and without speech/language impairments: Speech/language stability and outcomes. *Journal of Speech, Language and Hearing Research, 42,* 744–760.

Leadholm, B., & Miller, J. (1993). *Language sample analysis: The Wisconsin guide.* Milwaukee,WI: Wisconsin Department of Public Instruction.

Leonard, L. B. (1998). *Children with specific language impairment.* Cambridge, MA: MIT Press.

Leonard, L. B., Bortolini, U., Caselli, M. C., McGregor, K. K., & Sabbadini, L. (1992). Morphological deficits in children with specific language impairment: The status of features in the underlying grammar. *Language Acquisition, 2,* 15–179.

Leonard, L. B., Eyer, J. A., Bedore, L. M., & Grela, B. G. (1997). Three accounts of the grammatical morpheme difficulties of English-speaking children with specific language impairment. *Journal of Speech, Language, and Hearing Research, 40,* 741–753.

Marchman, V. A., Wulfeck, B., & Ellis Weismer, S. (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.

Marcus, G. F., Ullman, M., Pinker, S., Hollander, M., Rosen, T. J., & Xu, F. (1992). Overregularization in language acquisition. *Monographs of the Society for Research in Child Development, 57* (Serial No. 228).

Montgomery, J. W., & Leonard. L. B. (1998). Real-time inflectional processing by children with specific language impairment: Effects of phonetic substance. *Journal of Speech, Language, and Hearing Research, 41,* 1432–1443.

Newcomer, P. L., & Hammill, D. D. (1988). *Test of Language Development 2–Primary.* Austin, TX: Pro-Ed.

Oetting, J. B., & Horohov, J. E. (1997). Past-tense marking by children with and without specific language impairment. *Journal of Speech, Language, and Hearing Research, 40,* 62–74.

Paradis, J., & Crago, M. (1999, November). *Is French SLI EOI?* Paper presented at the 24th Annual Boston University Conference on Language Development. Boston.

Pinker, S. (1994). *The language instinct.* New York: William Morrow Co.

Plunkett, K., & Marchman, V. (1991). U-shaped learning and frequency effects in a multi-layered perception: Implications for child language acquisition. *Cognition, 38,* 43–102.

Plunkett, K., & Marchman, V. (1993). From rote learning to system building: Acquiring verb morphology in children and connectionist nets. *Cognition, 48,* 21–69.

Rice, M. L., Noll, K. R., & Grimm, H. (1977). An extended optional infinitive stage in German-speaking children with specific language impairment. *Language Acquisition, 6,* 225–295.

Rice, K. J., Rice, M. L., & Redmond, S. M. (2000, June). *MLU outcomes for children with and without SLI: Support for MLU as a matching criterion.* Poster presented at the Symposium on Research in Child Language Disorders, Madison, WI.

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

Rice, M. L., Wexler, K., & Cleave, P. L. (1995). Specific language impairment as a period of extended optional infinitive. *Journal of Speech and Hearing Research, 38,* 850–863.

Rice, M. L., Wexler, K., & Hershberger, S. (1998). Tense over time: The longitudinal course of tense acquisition in children with specific language impairment. *Journal of Speech and Hearing Research, 41*, 1412–1431.

Rice, M. L., Wexler, K., & Redmond, S. M. (1999). Grammaticality judgments of an extended optional infinitive grammar: Evidence from English-speaking children with specific language impairment. *Journal of Speech and Hearing Research, 42,* 943–961.

SAS 8.0 [Computer software]. Cary, NC: SAS Institute.

Schütze, C. (1997). *INFL in child and adult language: Agreement, case and licensing.* Unpublished doctoral dissertation, Massachusetts Institute of Technology, Cambridge, MA.

Shriberg, L., Tomblin, J. B., & McSweeny, J. (1999). Prevalence of speech delay in 6-year-old children and co-morbidity with language impairment. *Journal of Speech, Language, and Hearing Research, 42,* 1461–1481.

Tomblin, J. B. (1996, June). *The big picture of SLI: Epidemiology of SLI.* Paper presented at the Symposium on Research in Child Language Disorders, Madison, WI.

Wexler, K. (1998). Very early parameter setting and the unique checking constraint: A new explanation of the optional infinitive stage. *Lingua, 106,* 23–79.

Wexler, K., Schütze, C. T., & Rice, M. L. (1999) . Subject case in normal and SLI children: Evidence for the AGR/TENSE deletion model. *Language Acquisition, 7,* 317–344.

Received September 30, 1999

Accepted July 5, 1000

Contact author: Mabel L. Rice, PhD, Child Language Doctoral Program University of Kansas, 1082 Dole, Lawrence, KS 66045. Email: mabel@ukans.edu

Appendix. Mathematical Representation of the Model.

The mathematical form of the mixed model may be viewed as a model composed of several separate models for different levels of data. For longitudinal data, Level 1 represents the within-person observation occasions. The mathematical model for these data is:

$$Y_{ij} = \pi_{i0} + \pi_{i1}\,(time_{ij}) + \pi_{i2}\,(time_{ij})^2 + e_{ij}$$

where Y_{ij} is the dependent variable for person *i* at observation *j* and $time_{ij}$ indicates the measurement occasion. The coefficient representing the mean value of the outcome variable at a specified occasion is the intercept coefficient, π_{i0}. The coefficient representing the mean rate of change over time is the linear slope coefficient, π_{i1}. The coefficient representing the mean change in the rate of change (acceleration or deceleration) is the quadratic slope coefficient, π_{i2}. The random variability in the outcome variable is represented by the e_{ij} term.

The second level (Level 2) model represents the between-person effects by considering the coefficients of the Level-1 model as person-level outcomes that may themselves be modeled. Thus, the coefficient for the intercept in our HLM models is represented as:

$$\pi_{i0} = \beta_0 + \beta_1\,(group_i) + \beta_2\,(mlu_i) + \beta_3\,(ppvtr_i) + \beta_4\,(cmms_i) + \beta_5\,(mother\ educ_i) + u_{i0}$$

The coefficient β_0 represents the mean population value of the intercept, which is the mean population value of the outcome variable across all persons at a specified occasion. The individual differences from the mean population value are represented by the u_{i0} term, which represents random variation in the parameter due to differences between persons. Each additional β coefficient for a specified covariate represents a change in the mean level for child *i* due to the child's values on the covariate.

Similarly for our HLM model, the Level-2 model for the Level-1 parameter representing the linear change over time is

$$\pi_{i1} = \beta_6 + \beta_7\,(group_i) + u_{i1}$$

where β_6 represents the population mean rate of change over time, β_7 represents the effect of child *i*'s group on the rate of change, and the u_{i1} is the random component of the slope term, which represents individual deviations from the population mean rate. And finally, the last coefficient in our full HLM Level-1 model (the quadratic term) is represented as

$$\pi_{i2} = \beta_8 + \beta_9\,(group_i) + u_{i2}$$

where β_8 represents the population mean change in the rate of change over time (quadratic slope), β_9 represents the effect of child *i*'s group on the quadratic slope, and the u_{i2} is the random component of the quadratic term, which represents individual deviations from the population mean quadratic value.

A single equation representing the multilevel model for longitudinal data may be obtained by substituting the Level 2 models into the Level 1 model. Below we show the complete model for the HLM analyses after rearranging terms.

$$\begin{aligned} Y_{ij} = {} & \beta_0 + \beta_1\,(group_i) + \beta_2\,(mlu_i) + \beta_3\,(ppvtr_i) \\ & + \beta_4\,(cmms_i) + \beta_5\,(mother\ educ_i) + \beta_6\,(time_{ij}) \\ & + \beta_7\,(time_{ij})\,(group_i) + \beta_8\,(time_{ij})^2 \\ & + \beta_9\,(time_{ij})^2\,(group_i) + u_{i0} + u_{i1}\,(time_{ij}) \\ & + u_{i2}\,(time_{ij})^2 + e_{ij} \end{aligned}$$

The mathematical models obtained for the "best models" analysis in this study are variations of the general model obtained using these concepts of Level-1 and Level-2 variables. Our approach to building these models was a forward selection method as discussed by Bryk & Raudenbush (1992). Starting with a linear time model, we used restricted maximum likelihood estimation (REML) to evaluate fixed effects for higher order time effects (quadratic and cubic) using REML F-tests. The random components were then evaluated using REML deviances. Differences in deviance statistics are approximately chi-square distributed and are evaluated as chi-square difference tests, with degrees of freedom equal to the difference in the number of parameters between nested models. A similar forward selection procedure was used for adding the covariates to the model. Each covariate was examined separately for its effect on the intercept and slope. Covariates that were not significant were examined further only if previous results or theory indicated that they might have a significant effect in conjunction with the already determined significant covariates. The "best models" retain only effects that have very low probabilities as indicated by the default F-statistics in the SAS PROC MIXED program. Models with interactions always retain the individual components of the interaction, regardless of significance of the component itself. The mathematical models are given below.

The best models for the irregular past tense and the finiteness measure for irregular past tense are:

Full mathematical model:

$$Y_{ij} = \beta_0 + \beta_1 (group_i) + \beta_2 (mlu_i) + \beta_3 (time_{ij}) + \beta_4 (mlu_i)(time_{ij}) + u_{i0} + u_{i1} (time_{ij}) + e_{ij}$$

The Level 1 equation:

$$Y_{ij} = \pi_{i0} + \pi_{i1} (time_{ij}) + e_{ij}$$

The Level 2 equations:

$$\pi_{i0} = \beta_0 + \beta_1 (group_i) + \beta_2 (mlu_i) + u_{i0}$$
$$\pi_{j1} = \beta_{p1} = \beta_3 + \beta_4 (mlu_i) + u_{i1}$$

The best model for the percent correct irregular past tense with* mlu *as the covariate is:

Full mathematical model:

$$Y_{ij} = \beta_0 + \beta_1 (mlu_i) + \beta_2 (time_{ij}) + \beta_3 (mlu_i)(time_{ij}) + u_{i0} + u_{i1} (time_{ij}) + e_{ij}$$

The Level 1 equation:

$$Y_{ij} = \pi_{i0} + \pi_{i1} (time_{ij}) + e_{ij}$$

The Level 2 equations:

$$\pi_{i0} = \beta_0 + \beta_1 (mlu_i) + u_{i0}$$

$$\pi_{i1} = \beta_2 + \beta_3 (mlu_i) + u_{i1}$$

In this last model *ppvtr* may be substituted for *mlu*.