# 14 Syntactic Structure, Grammatical Accuracy, and Content in Second-Language Writing: An Analysis of Skill Learning and On-line Processing

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## Abstract

This chapter examines second-language sentence production both as a skill and as an on-line process by measuring relationships among linguistic and content characteristics of language samples both between and within participants. Written language samples were obtained from high school students enrolled in an intermediate-level English as a Second Language (ESL) class with embedded science instruction. Across participants, the skills of producing sentences with correct English grammar and accurate science content were positively associated with the skills of producing complex syntactic structures and more elaborate science content. Within participants, the on-line production of correct grammar was compromised when complex science content was expressed. The pattern of results obtained highlight the importance of analyzing bilingual language acquisition data in terms of both skill learning and on-line performance.

## Introduction

The primary purpose of this chapter is to examine second-language sentence production both as a skill and as an online process. This is accomplished by measuring relationships among linguistic and content characteristics of written language samples both between and within participants. In particular, we wanted to find out the strengths and directions of the correlations among syntactic complexity, grammatical accuracy, content complexity, and content accuracy, and the implications of these associations for the cognitive processes underlying sentence production in bilinguals.

Written language production is a complex skill. It involves the recruitment and coordination of several component subskills. A competent speaker of a language must retrieve linguistic structures, grammatical rules, vocabulary, and other features of language to produce novel sentences. For late learners of a second language, proficiency in these skills and their coordination takes time to develop, and the learner must be able to retain these skills across periods of time in which they are not using the language.

The long-term learning of a skill and the quality of performance during learning have long been distinguished in the skill learning literature (e.g., Estes, 1955; Tolman, 1932). The primary basis for this distinction is that manipulations that reduce error during learning tend to increase error in a delayed retention test, and vice-versa. The factors leading to optimum performance during learning and those leading to optimum long-term retention are not the same. Achievement of long-term learning and transfer in second language learning is likely based on the same factors that lead to good skill retention and transfer more generally. If so, then language learning in an immersion context is ideally suited to long-term retention because of the unpredictably spaced repetitions of various syntactic structures and vocabulary, the variation of semantic context for syntactic structures, and the variation of syntactic context for vocabulary. Speaking in conversation and writing for communicative purposes also requires retrieving vocabulary and linguistic structures from memory. As with other skills, under these learning conditions, although retention and transfer should be high, errors in second language performance are to be expected until a high level of proficiency is reached.

Based on the distinction between performance during learning and long-term retention, some predictions can be made about the relationships among various characteristics of second language production. First, long-term learning and retention of second language skills ought to be a function of practice. Immersion in a language environment exposes the learner to many components of language simultaneously, thereby giving the learner practice with the various language sub-skills. This simultaneous practice implies that the learning of language components should be positively correlated across time and across individuals. Evidence of positive associations among various aspects of language is found in the literature. For example, vocabulary size is correlated with grammar skills (Harrington, 1992) and with the syntactic complexity of utterances (Kemper, Kynette, Rash, O'Brien, & Sprott, 1989).

The second set of predictions can be made about performance during learning, or online processing, which will depend heavily on both the level of learning that has been achieved and on the cognitive resources available for each component of language processing. In capacity models of attention (e.g., Kahneman, 1973; Wickens, 1984), there exists a limited pool of cognitive processing resources that can be focused on one task or allocated across multiple tasks. The more attention that is required to perform one task, the less cognitive resources will be left to allocate to other tasks. Therefore, if a person tries to perform two tasks that require high levels of attention, one or the other will suffer. The deficit in performance under such conditions of divided attention can be manifested either as an increase in

the time necessary to carry out the task or as a decrease in the quality or accuracy of performance. Under certain circumstances, some pairs of tasks can be performed simultaneously with little or no detectable decrement in performance relative to performing the tasks individually. The first circumstance, and least controversial, is that one or both of the tasks can become more automatic with practice. As each task is better learned, it requires less attention and leaves more resources available to allocate to the other task. The second circumstance is when the two tasks rely on separate pools of attentional resources. Under a multiple-resource theory of attention (Wickens, 1984), the pool of cognitive resources is subdivided into pools that are used for different modalities of processing. Two tasks that draw upon the same partition will interfere with each other, but two tasks that draw upon separate partitions will not suffer when performed simultaneously.

In healthy adult native speakers of a language, production of correct grammar and complex syntactic structures is thought to require little attention, because these skills are so well learned that they have become automatic (Bock, 1982; Levelt, 1989). In a not-yet-fluent second language, all aspects of second language production ought to require more attention than they do in the person's own native language and more attention than they do for native speakers of the language being learned. Under conditions of divided attention, healthy adult native speakers of a language do not appear to suffer cognitive consequences in terms of grammatical accuracy. For example, in one study in which the primary language task was describing a picture, having to perform a secondary tone-discrimination task did not compromise any aspect of language production relative to describing the picture alone (Murray, Holland, & Beeson, 1998). In the same study, mildly aphasic individuals, for whom language presumably requires more attention, exhibited profound decrements in language production performance when attention was divided. Specifically, dividing attention decreased the rate of sentence production, decreased the syntactic complexity (in terms of embedded clauses) of the utterances, increased the proportion of sentences with grammatical errors, increased the number of word-finding errors, and decreased the number of correct information units produced. Thus, it appears that all of these language performance deficits are potential consequences of attentional overload to examine in second language production. However, there is little published research on the attentional demands of producing sentences in a developing second-language.

A related approach is to think about the potential consequences of attentional overload as a function of working memory. Both comprehension and production of language require maintenance of information in working memory. The importance of working memory for language comprehension has been demonstrated in studies in which individual differences in working memory capacity are associated with measures of sentence comprehension. Individuals with lower working memory span showed lesser comprehension of sentences with complex embedded clause structures (King & Just, 1991). Although the causal relationship has not been definitively established, it appears that working memory limitations of the lower-span individuals reduce their comprehension. Working memory also appears to be important for language production. Among older native speakers, working memory

capacity as measured by digit span is positively correlated with the mean number of clauses per utterance in speaking and writing, even controlling for the age of participants (Kemper et al., 1989). That is, participants with greater short-term memory capacity produced more syntactically complex utterances with more subordinate/embedded clauses.

Working memory has been linked with some aspects of second language processing, although it has not been studied as much as with first language processing. In studies of adult learners of English as a Second Language, a measure of working memory based on reading span was positively correlated with both the grammar and reading portions of the Test of English as a Foreign Language (TOEFL) and with other tests of vocabulary and grammar (Harrington, 1992). These studies of how individual differences in working memory are associated with specific language skills and characteristics may help us to make predictions about second-language sentence production. We know that the capacity of verbal working memory in a person's not-yet-fluent second language is lower than that of a native speaker of the language and increases with proficiency (e.g., Chincotta, Hyönä, & Underwood, 1997). Therefore, if verbal working memory capacity is a limiting factor in the quality of first-language processing, then second-language processing ought to exhibit the same performance deficits as that of native speakers who have low working memory capacity. A further implication would be that these features will improve with increased proficiency, because of the increase in working memory capacity. Generally, a second-language learner's reduced working memory capacity will make them more susceptible to attentional overload.

A third set of predictions can be derived from the models that have been developed to explain the complex series of cognitive steps necessary for on-line language production in healthy adult native speakers. These models are in agreement that the idea or message to be expressed is conceptualized before the syntax of an utterance is planned (Bock, 1982; Garrett, 1975; Grabowski, 1996; Kellog, 1996; Levelt, 1989). The temporal sequence of these processes suggests that characteristics of the idea or message will influence characteristics of the syntax. Once the idea or propositional structure is formulated, an *appropriate* syntactic frame must be selected. Thus, the idea or propositional structure constrains the possible syntactic structures for the sentence, and one of these structures is planned and produced. In the present study, students' complex ideas were hypothesized to constrain their choices of syntactic structures to those containing embedded clauses or prepositional phrases.

Some of the models include assumptions about the level of attention required for each stage of sentence production. Those researchers who address attention or working memory in their models are in agreement that attention is required for conceptualization of the idea or message (Bock, 1982; Grabowski, 1996; Kellog, 1996; Levelt, 1989). However, there is some disagreement about the role of attention in syntactic processing. In their models of speech production, Bock and Levelt claim that at least for healthy adult native speakers, syntactic processes are automatic. In contrast, in their models of writing, Grabowski and Kellogg claim that attention is required for translating the message into a syntactic frame. Again, these

models are meant to explain the production performance of adult native speakers, who have a high level of expertise in sentence production in their language. In relatively novice second-language learners, the level of attention required for the various production steps may be greater. Clearly, conceptualization of the message, which requires attention in monolinguals, will require attention in second-language learners, but probably not more attention than in monolinguals, because it is thought to be a non-linguistic set of processes. However, planning of the syntactic frame of the sentence and application of morphosyntactic markings may require more processing resources for second-language learners, because of their relative inexperience or lack of expertise. The attentional resources that second-language learners need to produce correct grammar may not always be available to them when the idea they intend to express is complex. Therefore, in the present study, a trade-off would be expected between idea complexity and correct grammar at the sentence level.

## The Present Study

Written language can provide a rich database for studying complex structures, because writing tends to have longer sentences and sentences with more complex syntactic structure than spoken language (e.g., Kemper et al., 1989). Writing is also the modality in which late second-language learners initiate the use of new syntactic structures (Weissberg, 2000). In the present study, writing samples were obtained from late learners of English, in order to explore the relationships among features of sentence production. The participants were high school students of English as a Second Language (ESL). The content of the writing samples was constrained by the curriculum of their ESL class, which was based on science content. Students were to write sentences about what they had learned in their science lessons. Evaluations of the program and examinations of changes over time using the microdevelopmental approach appear elsewhere (Gelman, Meck, Romo, Meck, Francis, & Fritz, 1995; Gelman, Romo, & Francis, in press). The analyses here focused on linguistic characteristics of sentence production, specifically correct grammar, use of embedded clauses, use of prepositional phrases, and also included the total number of sentences produced. In addition to the relationships among these language variables, we were interested in how linguistic characteristics of the sentences would be related to the content expressed. Constraining the topic to science made it possible to evaluate both the accuracy of the content in each statement and the complexity of the ideas expressed.

These aspects of sentence production could be studied both as characteristics of students and as characteristics of sentences. Each of the language and content variables was measured for each sentence and summarized to characterize the sentence production of each student. The summary measures obtained for each student were used to examine the sentence characteristics as skills. The individual measures for each sentence were used to examine how sentence characteristics go together or trade off in on-line processing. We expected that the difficult aspects of

second-language sentence production, such as the use of correct grammar and complex syntax, would be well acquired by the same students. However, it is not clear whether those features would appear in the same sentences. Those aspects of sentence production that require attention and draw upon the same resource pool should tend not to appear in the same sentences. In contrast, aspects of sentence production that draw upon separate resources or do not require attention should be independent or positively associated at the sentence level.

Another prediction was that focusing on communication of complex information would compromise linguistic characteristics of sentences produced. Anecdotally, many second-language speakers (and even many first language speakers) report that their pronunciation and grammar are not as accurate when discussing complicated topics as they are in everyday conversation. In contrast to potential trade-offs among different language components during on-line processing, some aspects of sentence production may have a positive relationship. For example, certain syntactic structures appear to lend themselves well to particular types of semantic content, such as how adverbial clauses (adjuncts and participials) can be used to convey cause, conditions, purpose, manner, time, location, and comparison. Therefore, we also looked at how semantic content was related to the language variables at both the student and sentence level.

## Method

### Participants

The study participants were 9th- and 10th-grade students (aged 14-17) at a large public high school in the San Fernando Valley of the Los Angeles metropolitan area. These students were in the second level of a 4-level ESL program. Their class was an experimental section that included a science curriculum covering a range of related topics in physical and biological science. A detailed description of the program and curriculum are given elsewhere (Gelman et al., 1995; Meck & Gelman, 1993).

A total of 30 students were enrolled for at least part of the term. Of the 30 students, 8 either started the semester late, moved before the semester was over, or did not attend regularly. The notebooks of the remaining 22 students who were present throughout the semester were considered for analysis. Two of these students were excluded (as explained in the next section), leaving 20 participants (11 male, 9 female) for the analyses of skill learning and on-line processing. The native languages of the participants were Spanish (11), Korean (6), Farsi (1), Hebrew (1), and Tagalog (1).

### Data Collection Procedure

The ESL teacher taught 10 science themes over the course of a 20-week semester. At the end of each science unit, the class was asked to generate as a group

a list of 10 to 20 science terms relevant to the theme under study. After the class agreed upon the list, students were given approximately 15 minutes to independently construct concept maps in their notebooks. In this exercise, students drew lines to link terms that they thought to be related to each other. Subsequently, they were given approximately 15 minutes more to independently write up to 10 sentences to describe the relationships among the terms they had linked in their concept maps. Thus, the maps were used as a mechanism both to constrain the content and to get students to think deeply about the set of terms. Both of these activities were graded on a credit/no credit basis.

## Characteristics of the Database

A sentence was defined as a numbered word sequence that contained at least one verb. If two complete sentences were combined, they were separated. The database had to be carefully checked to eliminate cases in which students copied sentences from other students' notebooks or from the sentences that other students were asked to write on the chalkboard to explain to the class. There were several such cases, but in each, it was clear from examination of differential sentence quality which student copied and which student composed the sentences.

The 10-sentence exercise was performed for 10 units, and the 2nd through 9th units were analyzed. The original database, after excluding the students with low attendance contained 1271 sentences. Of these sentences, 37 sentences, all produced by the same student, were judged to be inappropriate, in that they stated simply which terms in the map could be connected, without describing the relationship. Two independent coders evaluated whether or not each of the remaining 1234 sentences was comprehensible enough to allow for coding of its content and structure. Classifications matched in 98% of the cases (Cohen's $\kappa$ = .89). Consensus was reached on all discrepancies, resulting in 81 sentences being deemed as incomprehensible. One student accounted for 38 of the incomprehensible sentences. This student and the student who produced 37 inappropriate sentences were excluded from analysis because they were outliers and because they each produced less than 25 codeable sentences. The remaining 20 students produced a total of 1160 sentences, of which 42 (3.6%) were incomprehensible. Thus, the body of codeable data contained 1118 sentences, with a mean of 55.9 sentences (*SD* = 14.2) produced by each student.

## Variables

### Grammatical Errors

For each sentence, two coders, both native speakers of English, each wrote independently a "correct model" version of each sentence (i.e., how the sentence could have been written to be grammatically correct in English). In correcting the

sentences, coders used a minimal change approach, making as few changes as were necessary to make the sentence grammatically correct. For each participant the percentage of sentences containing at least one grammatical error was computed. Averaging across participants, the mean percentage of sentences containing grammatical errors was 70.1% ($SD$ = 11.9%).

Further classification of the grammatical errors revealed that the 4 most prevalent error types were subject-verb agreement, determiner errors, auxiliary verb errors, and preposition errors (see Gelman, Romo, & Francis, in press). These four error types were examined for their potential as variables in a student-level and in a sentence-level associative analysis. In order to be a good candidate for a sentence-level analysis, the error would have to occur in at least 20% of the sentences. Determiner errors, preposition errors, and auxiliary verb errors did not occur in enough sentences to provide a good sentence-level analysis. The error type that had the potential to occur across the largest proportion of sentences was subject-verb agreement errors. That is, on average, 94% of sentences produced by any student required subject-verb agreement marking, and only 12% of these sentences required multiple instances of subject-verb agreement marking. On average, a student made subject-verb agreement errors in 38.4% ($SD$ = 13.1%) of their sentences, allowing for a powerful analysis of the associations between subject-verb agreement errors and other language and content variables in the study.

## Syntactic Structure Variables

The sentence structure analysis focused on two syntactic structures: embedded clauses and prepositional phrases. Embedded clauses are a widely accepted indicator of sentence complexity. Prepositional phrases were also examined as a secondary indicator of more sophisticated sentence structure. These structures allow one to increase the number of propositions expressed in a sentence through the recursive property of language. Previous findings in the literature support the interpretation of prepositional phrase usage as a measure of complexity. For example, the lag time taken prior to producing a memorized sentence is increased both when it contains a prepositional phrase and when it contains an embedded clause, relative to a more simple structure, even when the length of the sentences in words and syllables is held constant (Ferreira, 1991).

Two coders, both with formal training in linguistics, coded the clauses and prepositional phrases of each sentence and checked each other's work to ensure accuracy. The average proportions of sentences containing embedded clauses and prepositional phrases are shown in Table 1. Across participants, the mean proportion of sentences with embedded clauses was 22.7% ($SD$ = 13.2%). On average, students produced prepositional phrases in 48.2% of their sentences ($SD$ = 16.7%). Several sentences contained more than one prepositional phrase. The validity of both embedded clause usage and prepositional phrase usage as indicators of proficiency in creating sentence structures is supported by the significant increase in the percentage of sentences with each of these structures over the duration of the course (Gelman et al., in press).

Table 1. *Descriptive Statistics on Linguistic and Content Variables.*

| Variable | Mean | SD |
|---|---|---|
| Total number of comprehensible sentences | 55.9 | 14.2 |
| Grammatical accuracy measures | | |
| % of sentences containing grammatical errors | 70.1 | 11.9 |
| % of sentences containing subject-verb agreement errors | 38.4 | 13.1 |
| Grammatical complexity measures | | |
| % of sentences containing embedded clauses | 22.7 | 13.2 |
| % of sentences containing prepositional phrases | 41.9 | 14.3 |
| Idea complexity measure | | |
| % of sentences expressing a complex idea | 29.4 | 13.9 |
| Content accuracy measure | | |
| Average concept accuracy score | 3.0 | 0.4 |

## Number of Sentences Produced

Because the students were given a limited amount of time (approximately 15 minutes) to complete the sentence assignment, the total number of sentences produced is a measure of the speed of processing. The main reason to include this variable was to find out whether students who produced more sentences had done so at the expense of grammatical accuracy or syntactic complexity.

## Complexity of Ideas Expressed

Based on content, sentences were classified as expressing simple or complex ideas. Sentences classified as expressing *simple ideas* included those that described properties, category membership, sources, mechanics, or functions of entities. Sentences classified as expressing *complex ideas* included those that explained conditions and circumstances for how and why entities, substances, or processes were related to one another. Thus, *description* of science terms was considered to be simple and *explanation* of science terms was considered to be complex. Table 2 shows several examples of simple and complex ideas that students produced. Two independent raters coded the complexity of each sentence. Agreement on classifications into the two categories was 95% (Cohen's κ = .88). Consensus was reached on all discrepancies. As shown in Table 1, the average proportion of sentences that expressed complex ideas was 29.4% (*SD* = 13.9). It is important to note that this classification was based on the content rather than the structure of the

sentence. Although, as will be explained later, idea complexity was associated with syntactic complexity, complex clause structures were not necessary for the expression of complex ideas, as shown by the examples in Table 2.

Table 2. *Examples of Simple and Complex Ideas*

| Idea Complexity Category | Examples of Student Sentences[a] |
| --- | --- |
| Simple Ideas | Water and dirt don't have the same temperature. |
| | Atmosphere is made up of different elements and compounds. |
| | The heat comes from the sunlight. |
| | Our body needs a lot of carbohydrates. |
| | We inhale oxygen. |
| | Water absorbs energy from sunlight. |
| Complex Ideas | The balloon has gas when it has air. |
| | Plants need water, carbon dioxide, and sunlight for photosynthesis. |
| | When we add heat energy to the water, it causes the water to change temperature. |
| | An egg can't float in hot water. |

[a]Spelling, punctuation, and grammatical errors have been corrected.

**Content Accuracy**

Content accuracy was coded on a 5-point anchored scale from 0 (no correct science content) to 4 (completely correct science content). Scale anchor points were 0 = no display of understanding; 1 = mostly unclear and inaccurate; 2 = about half correct and half incorrect; 3 = mostly clear and accurate; 4 = clearly accurate display of understanding. For each student, an average accuracy score was computed by dividing the total score by the total number of sentences. On average, students' sentences were scored as "mostly clear and accurate", a score of approximately 3 ($M = 3.03$, $SD = .44$).

**Relationships Among the Linguistic and Content Variables**

Relationships among the linguistic and content variables were examined at two levels of analysis, one that emphasized skill levels, and one that emphasized on-line processing. The skill analysis was performed at the student level. This student-level analysis would reveal the features that go together to characterize individual students' ideas and language skills. For example, this analysis will show whether students who express more complex ideas tend to use more prepositional phrases or make less grammatical errors. The on-line processing analysis was performed at the level of the individual sentence. This sentence-by-sentence analysis would reveal the characteristics that co-occur in individual sentences. For example, this analysis will show whether complex ideas are expressed using complex sentence structures and whether complex structures are more likely to contain grammatical errors. Thus, it can reveal cognitive trade-offs among different aspects of written language production.

**Skill Learning: Student-Level Associations**

Seven variables were used in the skill-level analysis. The linguistic variables for the student-level analysis were the proportion of sentences containing at least one grammatical error, the proportion of sentences containing at least one subject-verb agreement error, the proportion of sentences containing at least one embedded clause, and the proportion of sentences containing at least one prepositional phrase. The total number of sentences produced was also included as a variable. The content variables were the proportion of sentences that expressed complex ideas and the average content accuracy score.

Table 3 shows the correlations among the seven variables at the student level. The proportion of sentences containing grammatical errors was not significantly associated with any of the content or syntactic structure variables, although this variable appears to be negatively associated with all of the content and sentence structure variables. The small sample size limits the strength of the conclusions to be drawn, but the negative direction of these non-significant correlations suggests that students who express more complex or accurate ideas or who use more embedded clauses and prepositional phrases are not compromised on producing grammatically correct sentences. That is, there were no trade-offs among the skills of producing grammatically correct sentences, using complex sentence structures, and learning about science.

An analysis focusing specifically on subject-verb agreement errors more definitively demonstrated the relationship between grammatical errors and complexity. The rate of subject-verb agreement errors was significantly negatively correlated with the proportion of complex ideas, science content accuracy, and the use of both embedded clauses and prepositional phrases. Thus, competence in producing correct verb morphology was associated with competence in producing more complex syntactic structure and more complex content.

Table 3. *Correlations Among the Main Content and Language Variables Across Students (N = 20).*

| | Content accuracy | Embedded clause | Prep. phrase | Grammar error-any | S-V Agr. error | Total sentences |
|---|---|---|---|---|---|---|
| % of sentences expressing a complex idea | .739** | .955** | .433$^M$ | −.327 | −.521* | .001 |
| Average content accuracy | | .756** | .346 | −.306 | −.562** | .278 |
| % of sentences containing an embedded clause | | | .347 | −.341 | −.501* | .087 |
| % of sentences containing a prepositional phrase | | | | −.280 | −.523* | .198 |
| % of sentences containing any grammatical error | | | | | N/A [a] | −.547* |
| % of sentences with a subject-verb agreement error | | | | | | −.248 |
| Total number of sentences produced | | | | | | |

\* $p < .05$; \*\* $p < .01$; \*\*\* $p < .001$; $^M p < .10$
Note: All *p*-values are based on a two-tailed test against the hypothesis that $\rho = 0$.
[a] This correlation of .612 is not meaningful, because all sentences with subject-verb agreement errors by definition contain grammatical errors.

    Students who wrote about more complex ideas also wrote more accurate ideas, which shows that those with more complex ideas had fewer misconceptions about the material, as explained by Gelman et al. (in press). Students who wrote more complex and/or accurate ideas also used complex sentence structures that contained

more embedded clauses and more prepositional phrases. That is, students who knew more science had more linguistic tools to express their knowledge.

The correlations of the total number of sentences produced by each participant with the linguistic and content variables were examined to determine whether the students who produced more sentences did so at the expense of accuracy and/or complexity. Only one variable, the overall proportion of sentences with grammatical errors, was significantly associated with the total number of sentences produced, such that students who produced more sentences had more accurate grammar. Thus, it appears that the students who were more competent at producing correct grammar were able to produce more sentences in the time allotted, suggesting that those students had developed a greater degree of automaticity in sentence production. Importantly, none of the syntactic or idea complexity variables turned out to be negatively associated with the total number of sentences produced. Therefore, it is clear that there was no trade-off between students' productivity and the complexity of their sentence structures or content. In addition, students who worked faster did not sacrifice the accuracy of the scientific content expressed.

From the student-level analysis alone, it does not appear that there are any cognitive trade-offs among the skills underlying the various language and content variables. The following sentence-level analysis will examine whether trade-offs occur in on-line production of sentences.

## On-Line Performance: Sentence Level Associations

In language production, several different cognitive processes must be executed simultaneously. As explained in the introduction, the attentional requirements of processing a newly learned second language are greater than those of processing one's native language. To the extent that the different components of language production and thought tap the same cognitive resources, trade-offs among the content and language features within sentences were to be expected. Such trade-offs imply that the mental effort used to produce one feature compromises the production of another feature and that the features exhibiting the trade-off require attention. The linguistic variables examined at the sentence level were whether the sentence contained a grammatical error, whether the sentence contained a subject-verb agreement error, whether the sentence contained an embedded clause, and whether the sentence contained a prepositional phrase. The content variables examined at the sentence level were the idea complexity classification, and the content accuracy score for the sentence.

To examine sentence-level associations, it is not sufficient to merely sort all sentences bivariately and calculate a single measure of association for the entire set of sentences. When the marginal distributions of the variables vary across participants, such a measure will not necessarily show the same degree or even direction of association (Wickens, 1993). In this data set, it is clear that the marginal distributions (i.e, proportions of sentences with embedded clauses, grammatical errors, etc.) vary across students. Therefore, a statistical analysis that takes between-subject variability into account was employed. For each student, a contingency table

was constructed for the bivariate classification of each sentence on each pair of variables. Kendall's tau-b ($\tau_b$), a measure of ordinal association was calculated for each participant for each pair of variables. As suggested by Wickens (1993), the association measures obtained for each participant were subjected to a single sample *t* test against the hypothesis that the population mean sentence-level association is zero. The values of the observed mean $\tau_b$ across participants for each pair of variables are shown in Table 4. It should be noted that measures of ordinal association are not on the same scale as the correlation coefficients obtained from continuously-distributed variables, such as those in the subject-level analysis. Therefore, the values should not be compared to those of Table 3.

Table 4. *Mean Within-Student Sentence-Level Associations Among Content and Linguistic Variables: Values of Kendall's tau-b.*

|  | Content accuracy | Embedded clause | Prep. phrase | Grammar error-any | Subj-verb agr. error |
|---|---|---|---|---|---|
| Idea complexity classification | .122*** | .787*** | .135** | .134*** | .082* |
| Content accuracy |  | .148*** | .021 | −.039 | −.060 |
| Sentence contains embedded clause |  |  | −.017 | .111** | .042 |
| Sentence contains prepositional phrase |  |  |  | .062$^M$ | −.110* |
| Sentence contains any grammatical error |  |  |  |  |  |
| Sentence has subject-verb agreement error |  |  |  |  |  |

\* *p* < .05; \*\* *p* < .01; \*\*\**p* < .001, $^M$*p* < .10
Note:  All *p*-values are based on a two-tailed single-sample *t* test against the hypothesis that the mean association in the population is zero.

At the sentence level, the rate of grammatical errors was positively associated with content complexity and the use of embedded clauses. That is, sentences that expressed complex ideas were more likely to contain grammatical errors (*M* = 79.5%) than were those that expressed simple ideas (*M* = 65.7%). Likewise, sentences with embedded clauses (*M* = 78.2%) were more likely to contain grammatical errors (*M* = 78.2%) than were sentences with simple structures (*M* =

66.8%). For sentences with prepositional phrases, the pattern was similar, in that sentences with prepositional phrases had more grammatical errors ($M = 73.2\%$) than sentences without prepositional phrases ($M = 68.0\%$), but the association was only marginally significant. These patterns clearly indicate a trade-off in sentence processing resources between the syntactic complexity and grammatical accuracy of the output.

Looking specifically at subject-verb agreement errors, a similar pattern emerged. Sentences with complex ideas were more likely to contain subject-verb agreement errors ($M = 42.9\%$) than were sentences with simple ideas ($M = 35.3\%$). The association between embedded clause usage and subject verb agreement errors was not significant. The direction of the association between prepositional phrase usage and subject-verb agreement errors was unexpected—sentences with prepositional phrases were *less* likely to contain subject-verb agreement errors ($M = 32.6\%$) than were sentences without prepositional phrases ($M = 43.5\%$). At the sentence level, the usage of embedded clauses and the usage of prepositional phrases were not associated, meaning that these structures did not necessarily appear in the same sentences. Having an embedded clause in a sentence did not increase or decrease the probability of having a prepositional phrase in the sentence.

Content complexity was positively associated with both syntactic variables. Of the complex ideas, on average, 72.0% were expressed using sentences with embedded clauses. In contrast, less than 1% of sentences with simple ideas contained embedded clauses. A similar, but less dramatic pattern was observed in the usage of prepositional phrases; on average, 54.4% of the complex ideas were expressed using sentences with prepositional phrases, as compared to a lower rate of 39.2% for simple ideas.

Content accuracy and grammatical accuracy were not associated, suggesting that they draw upon different resource pools. That is, the accuracy of the idea was not associated with the accuracy of the grammar used to express it. The accuracy of ideas was significantly associated with their complexity; the complex ideas were rated as more accurate than the simple ideas. More accurate ideas were also more likely to contain embedded clauses than were less accurate ideas.

## Discussion

### Sentence Production Skill Analysis

The analysis of summary measures of language skill across students indicated that the different components of language learning tend to be learned well by the same students. Specifically, the production of more complex sentence structure, in terms of either embedded clauses or prepositional phrases, was positively associated with correct usage of subject-verb agreement marking. Perhaps it is not surprising that the students who have a better mastery of verb morphology would produce more sentences with complex clause structures, because sentences with embedded clauses contain multiple verbs. The analysis of the relationship between syntactic

complexity and overall grammatical accuracy was less conclusive, but suggests the same pattern, that students who produced more complex sentence structures produced fewer grammatical errors. This pattern of association suggests that these language subskills develop together in early stages of second-language learning.

Across students, there was considerable variability in the total number of sentences produced in the time frame allowed, which prompted us to examine the relationship between the quantity of sentences and their quality. One possibility was that the students who produced more sentences would have done so at the expense of complexity or accuracy, or that the students who wrote more complex ideas or used more complex syntactic structures would not have time to write as many sentences. Considering all of the language and content complexity and accuracy variables, there was no indication of such a trade-off between sentence quantity and sentence quality across participants. If anything, the students who produced more sentences produced better quality sentences, in that they made fewer grammatical errors. The number of sentences produced was not reliably associated with any of the content or language complexity variables (although the directions of the associations were positive), which suggests that the students wrote sentences at a level of complexity commensurate with their language skills.

The content variables, idea complexity and content accuracy, were highly correlated with each other, perhaps as indicators of a greater understanding of the scientific material. These variables were also correlated with the use of complex syntactic structures. Furthermore, the proportion of sentences with complex ideas increased over the duration of the course (Gelman et al., in press). One explanation is that the complexity of students' ideas increased, because the students' capacity to remember the complex ideas may have increased. The influence of memory on complexity could have taken place either during learning, where over time they became better able to store complex ideas in long-term memory, or during output, where they had to maintain the idea in working memory to be able to produce it. This suggests that one needs greater working memory capacity to produce complex ideas and to hold a complex idea in mind while producing a sentence to express it.

**Online Processing Analysis**

At the sentence level, the majority of sentences with complex ideas were expressed using complex clause structures, whereas very few of the sentences with simple ideas had complex clause structures. Similarly, sentences with complex ideas were more likely to contain prepositional phrases than were those with simple ideas. In fact, a secondary analysis revealed that *all* of the sentences with complex ideas contained at least one embedded clause or prepositional phrase. This finding suggests that students generated sentence structures that were useful, or perhaps necessary, to explain their complex ideas. Scientific explanation typically includes purposes, causes, necessary and sufficient conditions, time and location circumstances, consequences, and comparison. Any of these components of explanation can be expressed using an adverbial clause or adverbial prepositional phrase. Another way to express causality is through causal verbs, such as "cause" or

"make", many of which can take an embedded noun clause as a complement. For increased precision in scientific explanation, it also helps to specify the identity of entities involved or give additional information about the entities involved. These types of information can be given using adjectival clauses (relative clauses) and adjectival prepositional phrases. With few exceptions, the students did not express their ideas with complex clause structures unless they were expressing a complex idea. This extreme positive association at the sentence level made the corresponding positive student-level correlation inevitable.

Grammatical errors were more likely to occur in sentences with complex ideas. This trade-off in performance suggests that both production of correct grammar and production of complex ideas require attention and draw upon the same pool of cognitive resources. Grammatical errors were also more likely to occur in sentences with complex syntactic structure, indicating that production of correct grammar and production of complex syntax both draw attentional resources from the same pool.

That sentences with complex ideas would suffer subject-verb agreement errors is not surprising given that the verb appears to be particularly sensitive to processing demands of the sentence. For example, Ferreira (1991) showed that in producing memorized sentences with complex objects, participants paused just before the main verb. In reading comprehension, King and Just (1991) found that reading times for the main verb in sentences with relative clauses were affected more than reading times for other words in the sentences by the syntactic complexity of that relative clause (subject-relative or object-relative). However, in our study, subject-verb agreement errors were reliably positively associated only with idea complexity, and not with the measures of syntactic complexity.

Because grammatical accuracy is compromised both in sentences with complex ideas and sentences with embedded clauses or prepositional phrases, and because of the high association between idea complexity and use of embedded clauses, it is not immediately obvious which type of complexity draws the cognitive resources away from grammatical accuracy. To answer this question, an additional analysis examined the proportion of sentences with grammatical errors as a function of both idea complexity and syntactic structure for sentences. As shown in Table 5, the answer is not simple, because all complex ideas were expressed using either an embedded clause or a prepositional phrase, and only 6 of the simple ideas were expressed using embedded clauses, leaving two cells of the table insufficient for analysis.

Of the sentences expressing simple ideas, the error rates for sentences with one prepositional phrase (64%) were no higher than for those with no prepositional phrase (65%), suggesting that sentences with prepositional phrases were no more taxing than those without. Of the sentences expressing complex ideas, the grammatical error rate for sentences containing an embedded clause with no prepositional phrase (72%) was no higher than for sentences containing a prepositional phrase but no embedded clause (75%). This suggests that the embedded clauses were not more taxing on attentional resources than prepositional phrases. (The error rate for complex idea sentences containing both embedded clauses and prepositional phrases is higher, but these are longer sentences with more

opportunities for errors.)  Taken together, these two findings suggest that syntactic complexity in and of itself does not compete with grammatical accuracy for attention. In contrast, considering only sentences that contained prepositional phrases, complex ideas were more likely to have a grammatical error (75%) than were simple ideas (64%). This pattern suggests that idea complexity, rather than clause complexity, competes with grammar for cognitive resources.

Table 5. *Proportion of Sentences Containing Grammatical Errors as a Function of Idea Complexity and Syntactic Structure.*

| Syntactic structure | Simple ideas | Complex ideas |
|---|---|---|
| No prepositional phrase and no embedded clause | 65% | ---[b] |
| One prepositional phrase but no embedded clause | 64% | 75% |
| One embedded clause but no prepositional phrase | ---[a] | 72% |

[a]  Only 6 such sentences were produced.
[b]  No such sentences were produced.

## A Comparison Between Skill Learning and On-Line Performance

The pattern of associations among the language and content variables was different in the student-level analysis than in the sentence-level analysis, which shows that relationships among the sentence production skills were different from relationships among features of sentences in on-line production. The dissociations between these two levels of analysis are particularly informative. The strongest dissociations were observed among the correlations of grammatical accuracy with the complexity variables. At the student level, students who wrote more complex sentences in terms of content or clause structure made fewer grammatical errors. However, at the sentence level, the sentences with more complex content or clause structure were more likely to contain grammatical errors. Thus, the direction of the relationship was different for the two levels of analysis, meaning that complex sentences tended to have grammatical errors, but that didn't mean that students who attempted more complex sentences made more errors overall. Despite the fact that these students attempted more complex sentences, it seems that these students were less likely to make errors than students who wrote less complex sentences.

Features that indicate syntactic complexity, embedded clauses and prepositional phrases, are positive indicators of more sophisticated language production skills. Therefore, the skills ought to be correlated across second-language learners as they

were in this study. The substantial increase in the use of such structures over the course of language acquisition indicates that sentences containing such structures are more difficult to produce. If one of the structures is to be produced, the attentional resources for producing another complex structure may not remain available. Given these attentional demands, if one of the structures is present in a sentence, it would be reasonable to expect that the other would not be present. In fact, in the present study, there was little if any indication that the uses of these two syntactic structures were associated either positively or negatively at the sentence level. Other indicators of complexity, say different types of embedded clauses, might in fact be expected to have a negative or disjunctive relationship at the sentence level in the early stages of second language acquisition because of the increased processing demands of producing two rather than only one of the structures. In the sample analyzed here, instances of sentences with multiple embedded clauses were infrequent and therefore could not be analyzed in this way.

This study was our initial attempt at implementing a new approach to the study of second language acquisition, and as such, it is limited in scope. We did not have access to comparable data for native English speakers. Therefore, we do not know whether these patterns are characteristic of English-speaking students in regular science classes. Perhaps a more interesting comparison would have been sentences produced by the same students in their native languages, but such data were not collected. Thus, although some of the findings run contrary to what the literature suggests for adult native speakers, we do not have primary data for native speakers. A second limitation of this study is that the only second language examined was English. Our sample did include students with different native languages, and the two larger language groups, Spanish and Korean, both showed the same patterns of association among the critical variables, despite the fact that they differed in their propensity to make some types of errors. It remains to be seen whether the patterns of association among the content and linguistic variables generalize to other second languages. We speculate that similar patterns may exist among science content sophistication, clause structures, and correct grammar across different second languages, although the specific error types involved may differ.

## Conclusions

As a complex behavior, language production requires the successful simultaneous performance of several cognitive sub-tasks. In second-language sentence production, some of the components that do not appear to require attention in adult native speakers may require attention until sufficient experience with the language is logged. In learning to perform multiple attention-demanding tasks simultaneously, it is not uncommon to observe degraded performance relative to performing each task in isolation. So long as the essential components of second language production require attention, language production will be reduced in complexity relative to the native language and contain syntactic imperfections. As automaticity develops in the various component subskills of language production,

trade-offs among sentence features in on-line production ought to be diminished, increasing speed and complexity and decreasing errors. In particular, as the production of correct syntactic morphology, such as subject-verb agreement becomes more automatic, sentence production should become more fluent (i.e., faster), and more resources should be available for translating complex ideas into written or spoken language.

When studying characteristics of complex behavior, such as language, it is useful to examine relationships among critical characteristics both as indicators of students' language skill development and at the level of the individual sentence. Studying characteristics of second-language sentence production both at the level of the student and at the level of the sentence provided different kinds of information. Some seemingly conflicting sets of relationships emerged, but they can be understood by considering the different properties of skill acquisition and on-line performance. This distinction may also help us to interpret how attentional demands of bilingual sentence processing change with acquisition or vary according to proficiency.

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