Toward Understanding Syntactic Processing and Phonological Awareness in Specific Language Impairment

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BRIEF. Grammar and sounds were studied in six-year olds to determine the difference between children with and without Specific Language Impairment.

ABSTRACT. Children with Specific Language Impairment (SLI) have difficulty with grammar in sentences (syntax), and sounds that make up words (phonology). This study looked at the difference in the two skills among six-year old children with and without SLI to determine if there is a link between syntactic processing and phonological awareness. Grammar detection in the brain was measured by electroencephalography (EEG), which records electricity on the scalp, showing if a child knows when a sentence is correct or not. Three parts of the Comprehensive Test of Phonological Proficiency (CTOPP) were used to test sound perception. Preliminary results confirm that six-year olds without SLI are able to understand correct syntax, and can distinguish between sounds.

INTRODUCTION.

Specific Language Impairment (SLI) is a disorder in which children have less-developed language skills. Children with SLI have more trouble learning syntax (grammar) and phonology (sounds) than children with typical language development (TLD). Understanding the role of syntactic processing and phonological awareness is important in order to find a possible SLI rehabilitation treatment. The three goals of this study are to (1) look at differences in syntactic processing between children with and without SLI, (2) look at differences in phonological awareness between children with and without SLI, and (3) look for a relationship between syntactic processing and phonological awareness.

Someone's ability to process syntax, how words come together to make sentences, is measured by electroencephalography (EEG), which detects electrical signals on the scalp. Syntactic processing can be studied in EEG data by observing the P600 component, a peak in the signal around 600 milliseconds after the verb; subjects with a better understanding of grammar will have a more defined P600 than subjects with poor grammar understanding. Because previous studies show that there is a difference in the P600 between children with and without SLI [1], it's hypothesized that children with SLI will have a less-defined P600, indicating decreased language development.

Someone's awareness of phonology, the way sounds make up words, is measured behaviorally. The Comprehensive Test of Phonological Proficiency (CTOPP) is used to study children's understanding of sounds [2]. Children who have greater sound understanding tend to score higher than those with poor sound understanding. Previous research shows that children with SLI are less able to detect variations in speech sounds [3]. This suggests that children with SLI do not process sounds as well as children with TLD, which should manifest as lower scores on the CTOPP. It's hypothesized that children with SLI will score lower on the CTOPP, confirming their deficit in processing sounds.

It's hypothesized that there is a positive relationship between a child's ability to process syntax and his or her phonological awareness, and a deficit in one correlates with a deficit in the other. Previous studies show that there is indeed a relationship between phonology and syntax in children with SLI [4], and it's common to have difficulties in both syntactic and phonological processes.

MATERIALS AND METHODS.

Participants.

A total of forty six-year-old participants, n=15 with SLI and n=25 with TLD, will be recruited for the study. Thus far, the study has eleven participants with TLD, 8 female and 3 male. The Preliminary results shown below are based on these participants. The children all had English as a primary language, minimal musical training, and normal hearing. Presence or absence of an SLI diagnosis was confirmed using the SPELT-3 test [5]. The subjects participated in two tasks: (1) EEG measurement of brain responses to syntactic violations in sentences, and (2) a standardized behavioral test to measure phonological awareness.

Syntactical Processing.

For the syntactical component of this study, 120 sentences were used. To counterbalance the stimuli across lists and conditions, 2 lists of 120 sentences were created. Within each list, 30 of each type of sentence (correct or incorrect, tense or subject-verb agreement) were used. All sentences had corresponding violation sentences. For example, the sentence "Every year, the man buys a present for his mother," has an equivalent sentence with incorrect subject-verb agreement: "Every year, the man *buy a present for his mother." Corresponding sentences were balanced across conditions, lists, and participants so that each participant only heard the sentence once, in one condition. Sentences were recorded, cross-spliced (explained below), and played through audio speakers for participants while they watched age-appropriate silent movies during EEG acquisition. The silent movie kept the subject alert and still during the task. The EEG task, including net placement, lasted no longer than 40 minutes.

Sentence Recording and Editing.

Sentences were developed then reviewed by experts in syntactic perception to guarantee that syntactic and phonological aspects were strictly controlled. Sentences were taken to an anechoic chamber to be recorded. Each original sentence ("Every year, the worker digs holes in the flowerbed.") and 'parallel' sentence ("Every year, the workers dig holes in the flowerbed.") was recorded twice to ensure speech clarity. Sentences were then processed with PRAAT software [6], using a cross-splicing method. Cross-splicing is used to create an incongruous sentence out of two previously correct sentences, ensuring that the incongruous sentence is spoken with natural intonation and rhythm. The subject (before the critical verb) of the original sentence and the predicate (after the critical verb) of the 'parallel' sentence were concatenated to make an incongruous correspondent of the original sentence ("Every year, the worker *dig holes in the flowerbed."), as shown in Figure 1.

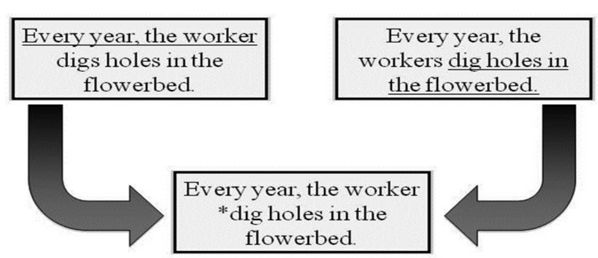

Figure 1. Cross-splicing combines the subject of one sentence and the predicate of a 'parallel' sentence into one incongruous sentence of the same layout.

EEG Acquisition and Processing.

EEG measures electrical responses on the scalp that are generated by large populations of neurons in the brain. Recording an EEG requires placing a net with many electrodes on the participant's head. Reference electrodes are placed with one on the center of the head and two more on the mastoids (behind the ears).

Before use, an EEG net soaked for at least one minute in a solution of 1,000 mL lukewarm water, 1.5 tablespoons potassium chloride (KCl), and roughly one-fourth teaspoon of baby shampoo. The KCl and shampoo served as conductors for the electrodes, which allowed them to measure electrical signals more accurately. Once the correctly-sized net soaked in the solution, the net was placed on the participant's head and more solution was pipetted directly beneath the electrodes as needed until impedances were lowered to < 50 kOhms.

Once the EEG was recorded, data was processed using various steps in Net Station [7]. The first step, high and low-pass filtering, cuts out EEG background noise unrelated to the task, narrowing down the EEG to data of interest. Next, data was segmented into epochs of trials. Then, artifact detection/ rejection disqualified trials that contained artifacts- blurs in EEG data such as blinks, yawns, or other movements that skew the data- retaining only the EEG signal that originated from pure cerebral sources. Due to excessive ocular artifacts, data from one subject was discarded from the preliminary results.

After artifact detection/rejection, post-processing took place. The first step of post-processing was bad channel replacement, which corrected bad channels within an epoch by replacing them with an interpolated average of the data on the surrounding channels. Next was re-referencing, where data on all channels was recalculated in relation to the average of the mastoid channels. Data was then exported to Matlab (Mathworks, Natick, MA) where the Event-Related Brain Potentials (ERPs) was found by averaging together the EEG segments time-locked to other events in each experimental condition. The Fieldtrip toolbox in Matlab computed the ERPs and tested significance/ correlations with behavioral data [8]. Through this analysis process, the P600 component becomes visible and can be compared between conditions.

Phonological Awareness.

In order to obtain behavioral measures of phonological awareness, the Comprehensive Test of Phonological Processing (CTOPP) [2] was administered. Three subests constituted the phonological awareness composite score: elision, blending words, and sound matching. Elision, the first subtest, required the participants to separate a word into its constituent sounds. For instance, a participant was asked to say the word "powder" without saying the /d/ sound, thus saying "power," The second subtest, blending words, reciprocated elision; the participant combined syllables spoken separately on a pre-recorded CD to create a viable word. For example, a recording would say-/pen/ /sel/- and the participant was expected to say "pencil." The third subtest, sound matching, had two parts. The first part showed a picture (for example, "rain"), and the participant was asked to identify one of the following pictures ("tape" "line" and "rope") that started with the same sound as the original picture. In this case, the word "rope" starts with the same sound, /r/, as "rain." The second part showed four pictures ("sack," was the original picture, "bat" "kick" and "soap" being subsequent pictures), and the participant was asked to identify the picture that ended with the same sound as the first picture. In this case, the word "kick" ends in the same sound, /k/, as "sack."

All three subtests were scored using CTOPP guidelines. Raw score and standard score for each task were recorded, which combined to construct the phonological awareness composite score and percentile. While a raw score shows how the participant performed on a single subtest, the standard score allows the researcher to compare scores across subtests. The composite score calculated a participant's score overall, whereas a standard score is the score from one subtest that is comparable to the standard score of another subtest. The CTOPP test takes 15 minutes to administer.

Testing for a Correlation Between Syntactic Processing and Phonological Awareness.

To relate behavioral measures to ERP results, the correlation between behavioral scores from the CTOPP assessment and single ERP values for participants were tested across ten subjects. These single ERP values were calculated by summing EEG amplitude values over significant clusters. More specifically, when there were significant differences in EEG amplitude in a pair of conditions, cluster sums were computed by summing together the ERP amplitude values at each electrode and time point for each condition. Correlations were then tested between the ERP cluster sum differences (differences in ERP amplitude between the violation and correct conditions) and participants' CTOPP assessment scores.

PRELIMINARY RESULTS.

Syntactic Processing.

Subject-verb agreement and tense agreement conditions for the ten participants were binned together to make two main conditions: syntactically correct and syntactic violation. Cluster randomization analysis on this pair of conditions revealed one significant cluster of electrodes (cluster p=0.048), showing increased amplitude for the violation condition. The cluster stretched from 430ms to 900ms, which is the expected range of the P600 component, after the onset of the critical-word at 0 ms.

Figure 2A compares ERPs from correct and violation conditions and illustrates a difference in the P600 between these conditions. This difference indicates that TLD participants detect grammatical violations in sentences when these violations include incorrect subject-verb agreement and incorrect tense agreement. The significant cluster (430ms to 900ms after the onset of the critical verb) is distinguished by dotted lines towards the middle and end of the graph. Figure 2B shows that as the critical verb unfolded, participants had a posterior negativity in response to correct sentences. This is most apparent at 550ms, when the topography of the cluster becomes more widespread (shown by a larger amount of electrodes that are significant in the cluster). When presented with violation sentences, a posterior positivity appears, once again becoming apparent at 550ms. Asterisks on the plot show electrodes belonging to the significant cluster at various time points.

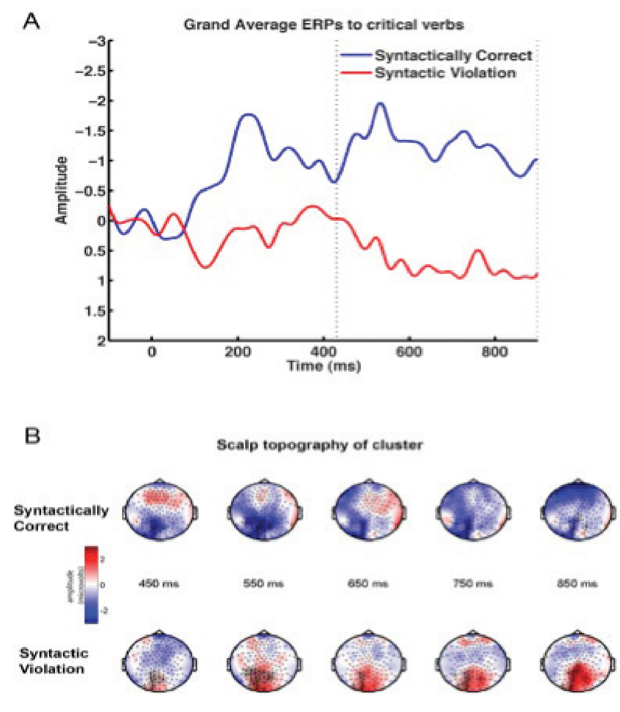

Figure 2. A) Grand Average ERPs for Correct vs. Violation conditions. There is a significant difference (p=0.048) between the two conditions at the cluster that falls between 430 ms and 900 ms (between dotted lines). Time is on the x-axis in milliseconds, and amplitude in microvolts is on the y-axis; negativity is plotted upwards, according to convention. B) Scalp topography of the Correct vs. Violation cluster. As the sentence progresses from the onset of the critical verb, there is a posterior negativity for correct sentences and a posterior positivity for violation sentences. Asterisks in the plots show electrodes belonging to the significant cluster. Blue indicates decreased amplitude and red indicates increased amplitude.

Phonological Awareness.

Overall, there was a mean standard score of 111.82 and a mean percentile of 72.73 for the phonological awareness composite score from the CTOPP behavioral test. This is nearly one standard deviation above the population average, which sets a feasible basis for comparison for what can be expected from the SLI group. Table 1 shows mean standard scores for each task.

Table 1. Mean TLD standard scores for each of the tasks on the CTOPP behavioral test. The above-average scores set a basis for comparison for the SLI group.

Task	Elision	Blending Words	Sound Matching	Phonological Awareness Composite
Mean Standard Score	12.09	12.64	10.67	111.82

The Relationship between Syntactic Processing and Phonological Awareness.

The CTOPP phonological awareness composite score vs. EEG cluster sum had an R-value of -0.174 and a p-value of 0.631, showing no significant correlation between syntactic processing and phonological awareness. However, because the TLD group serves as a control group compared to the SLI group, there is still a possibility of finding a significant correlation between syntactic processing and phonological awareness after completing data acquisition from children with SLI and acquiring data from additional participants with TLD.

DISCUSSION AND CONCLUSION.

Syntactic Processing.

The P600 component, measured by EEG, shows detection of syntactic violation in the brain approximately 600 milliseconds after the onset of the critical verb. A larger or more defined P600 effect exemplifies greater detection of sentence violations, whereas a less defined P600 effect shows a lack in detection. It was hypothesized that the P600 component would be less defined for children with SLI, because children with TLD are predicted to be able to distinguish between syntactically correct and incorrect sentences more efficiently than those with SLI [1].

Preliminary results show that children with TLD have a well-defined P600 effect, meaning that they are indeed able to detect grammatical violations in sentences. This is expected of children with TLD, as it shows a difference in the brain when processing sentences that are correct versus sentences that are incorrect. As we finish our data collection, we expect to see a smaller P600 from the children with SLI , indicating weaker grammatical detection skills than children with TLD. The data used in this study may serve as a basis for future studies testing potential treatments and rehabilitation procedures for children with SLI. For instance, the P600 variable may serve as pre- versus post-treatment measure of treatment efficiency. For example, a child with SLI who has been successfully treated would have a P600 more similar to children with TLD than untreated children with SLI.

Phonological Awareness.

In the present study, phonological awareness was measured behaviorally, using the CTOPP test. Based on previous studies, it was hypothesized that children with SLI should have a lower phonological awareness composite score on the CTOPP test, as their phonological awareness is likely to be less developed than children with TLD [9]. Our preliminary results show that children with TLD have mean standard and composite scores nearly one standard deviation above the population average on the CTOPP behavioral test, showing that children with TLD in this sample have well-developed phonological awareness thus far. It is expect that children with SLI will have scores that are below average on the CTOPP test, demonstrating weaker phonological skills.

In the future, behavioral data acquired in the present study may be used to obtain a better understanding of the phonological aspects in SLI. By understanding the difference between children with SLI and children with TLD phonologically, future studies can aim to improve treatment and narrow down rehabilitation measures to target specific children with SLI. If treatment proves effective, then behavioral scores of children with SLI should improve and begin to resemble scores of children with TLD.

The Relationship between Syntactic Processing and Phonological Awareness.

Because most or all children with SLI have problems with syntax and many also have phonology difficulties [4], it was hypothesized that there would be a correlation between the two when processing language. In this study, single ERP values per participant and behavioral scores from the CTOPP assessment were tested for a positive correlation. Any correlation between the two aspects of language can contribute to the growing understanding of the human brain and its processes.

The preliminary findings in the group of children with TLD show no significant correlation between syntax and phonology. However, due to the relatively small number of participants and because the TLD group serves as a control to the SLI group, this preliminary result is inconclusive. It is still hypothesized that there will be a positive correlation between the two conditions in the future when children with SLI are introduced into the study.

If a correlation between syntactic processing and phonological awareness is found in children with SLI, then future studies can potentially integrate the two measures in treatment and rehabilitation efforts or even search for the interactions of different brain processes responsible for the correlation. However, if no correlation is found, future studies may be able to unravel the mysteries of language impairment and possibly discover the reason why both syntactic processing and phonological awareness are apparent in SLI.

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