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Association Between Differentiated Processing of Syllables and Comprehension of Grammatical Morphology in Children With Down Syndrome

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Abstract

Our purpose in this exploratory investigation was to examine the relationship between degree of impairment in grammatical morpheme comprehension and event-related potential measures of differentiated processing of speech syllables in 10 children with Down syndrome. Results strongly support the hypothesized association. Graphs of the association indicate that children with less impaired grammatical comprehension had greater amplitude differences in event-related potentials to contrast of syllables within preselected poststimulus latency ranges. The theoretical and clinical ramifications of these results are discussed.

Down syndrome, which is the most common known chromosomal cause of mental retardation, is caused by a third chromosome 21 in 98% of the known cases (Chapman & Hesketh, 2000). About 50% of children with Down syndrome and mental ages (MAs) under 36 months have been reported to have communication and language skills that are delayed to a greater degree than is expected for their MAs (Miller, 1999). Although school-age children with mixed-etiology intellectual disability can have receptive language below MA (Abbeduto, Furman, & Davies, 1989), preschoolers or toddlers with mixed-etiology intellectual disabilities tend to have communication and language commensurate with their MAs (Miller, 1999). The etiological-group difference in developmental profiles tends to increase with MA and chronological age–CA (Miller, 1999) and may indicate that children with Down syndrome encounter more obstacles in acquiring language than do children with intellectual disabilities due to other etiologies (Yoder & Warren, 2004). Children with Down syndrome tend to have special problems (i.e., levels delayed below their vocabulary skills) with grammatical morphology in production (Fabretti, Pizzuto, Vicari, & Voterra, 1997) and comprehension (Chapman et al., 1991) modalities. Assessing grammatical morphology in the comprehension modality may be particularly useful in children with Down syndrome because such children frequently have less intelligible speech than expected because of their other language skills (Stoel-Gammon, 2001), thus affecting the validity of assessments of expressive grammatical morphology for this population. Grammatical comprehension presumably depends on stored grammatical knowledge. Grammatical knowledge of a particular language (e.g., English) is, at least partly, influenced by child-directed linguistic input.

Three popular theories hypothesize that one reason some children with Down syndrome have difficulty with grammatical morphemes is because they do not efficiently process the linguistic input that underlies grammatical knowledge. These theories are (a) rapid temporal processing (Tallal, Miller, Jenkins, & Merzenich, 1997), (b) surface accounts (Leonard, 1998), and (c) generalized slowing/limited capacity theories (Ellis-Weismer & Evans, 2002; Kail, 1991). An important common element in these theories is that all three hypothesize that the children with grammatical difficulties have trouble processing at least certain auditory information that includes, but is not necessarily specific to, linguistic units. Rapid temporal processing and surface accounts place much emphasis on the particular characteristics of the auditory stimuli children have difficulty processing and predict that these will also be sounds children have difficulty producing or comprehending. Rapid temporal processing theory suggests that sounds with rapid transitions between the consonant to the vowel (e.g., stop consonants), brief sounds, and sounds that are embedded within a string of other sounds are particularly difficult to process (Marshall, Snowling, & Bailey, 2001; Tallal et al., 1997). The surface account suggests the sounds that are difficult to process are those that have short durations (Leonard, 1998). In fact, Leonard explicitly pointed out that many of the morphemes that tend to cause problems for many children with disabilities do not show the characteristics of sounds that temporal processing theory suggests are problematic (e.g., stop consonants such as /*d*/).

In contrast, generalized slowing assumes that there is a progressive increase in the proportion of slowing with each successive information-processing step. The result is that information is lost because each step in the process is dependent on the amount of information available at the end of the preceding step. Phonological processing and storage are two steps in the processing of linguistic input (Ellis-Weisman & Evans, 2002). If children are inefficient in performing these steps, they will not process and store some of the linguistic information. A "triage" process is likely to occur in which linguistic input is simplified according to obligatory semantic information parameters (Leonard, 1998). Many morphemes do not always carry obligatory meaning (Leonard, 1998). For example, this simplification may result in reducing language input to component word roots without retaining the problematic morphemes (i.e., *run* instead of *runs*). Functionally, the result may be that the child processes fewer, and thus benefits from fewer, exemplars of grammatical morphemes in the naturally occurring language input directed to the child.

It is critical to note that generalized slowing theory does not assume that "difficult" phonemes are necessarily those that convey grammatical morphology. In fact, it would be completely compatible with the theory if the phonemes that convey a particular language's grammatical morphology were easy to process. In this theory, the grammatical information is lost because the difficult-to-process parts of the linguistic input require a triage process in which speech sounds that occur in the middle of a sentence that do not always carry meaning are dropped from the child's memory trace. We hypothesized that the extent of this processing triage relates to the general slowing of differentiating spoken syllables. However, this triage process does not necessarily result in dropping from memory difficult-to-process speech sounds. The exact speech sounds that many children with Down syndrome have difficulty processing have not been specified.

The theory that people with mental retardation, including children with Down syndrome, tend to perform mental processes more slowly than CA-matched peers was formally introduced after reviewing slower reaction times in participants with mental retardation than in CA-matched people in 45 studies (Kail, 1991). The generalized slowing occurred in all 45 studies and included visual and auditory, linguistic and nonlinguistic, tasks. Although the theory indicates that many types of stimuli are problematic, speech processing is our focus in the present study because it is most logically related to linguistic input processing.

The notion that slowing of auditory processing in children with Down syndrome may help explain why some children with this disorder have more difficulty with grammar than others is not original to us. Bates and Goodman (2001) noted the unusual pattern of grammatical development lagging behind lexical development in many children with Down syndrome and hypothesized that the source of this unusual dissociation may be general auditory-processing problems. We recognize that not all children with Down syndrome have grammatical deficits below their MA or lexical levels (Miller, 1999) and assume that not all children with Down syndrome have equally poor speech-processing ability. In this study, we tested whether individual differences in speech processing could account for variance in individual differences in grammatical deficits in children with Down syndrome.

To test this question, we had to measure speech processing with sufficient temporal resolution to quantify individual differences with the Down syndrome sample. This is not a simple matter, particularly in children with Down syndrome. The motor movements of people with mental retardation are slower than those of individuals in the general population (Brewer, 1978). People with Down syndrome have slower reaction times than do other people with nonspecified mental retardation (Davis, Sparrow, & Ward, 1991). In fact, they have slower movement times to auditory information than to visual information (Welsh & Elliot, 2001). These findings suggest that behavioral assessments relying upon motor responses to auditory-processing stimuli may not provide a measure of speech processing that will allow us to test the processing–grammar association in children with Down syndrome because these behavioral responses are confounded by slow movement and reaction times.

As a potential solution to this problem, event-related potentials provide information about individual differences in cortical response to syllables within tens of ms of stimulus onset (Molfese & Molfese, 1979). *Event-related potentials* are portions of the electroencephalogram that are time-locked to stimulus onset. Brainwaves are composed of several deflections (peaks and troughs) in response to a stimulus (e.g., a speech sound). In addition, the shape of the event-related potential waves varies by different speech stimuli in typically developing infants, children, and adults. For example, there is replicated evidence that the amplitude of the second major positive deflection (Gelfer, 1987; Molfese, 1978) and of the third major positive deflection (Molfese, Burger-Jadisch, & Hans, 1991; Molfese & Molfese, 1979, 1980, 1985) varies according to particular consonant manipulations (e.g., place of articulation such as */da/* vs. */ga/*). There is also extant information regarding what latency range to expect event-related potential wave shape to vary by stimulus characteristics. However, it is important to note that the peak latency for major event-related potential deflections vary by age (Molfese et al., 2004). For example, the second major positive deflection tends to occur between 313 and 366 ms poststimulus in 5- to 8-year olds (Molfese et al., 2004), whereas it peaks between 150- to 275-ms poststimulus in adults (Dunn, Dunn, Languis, & Andrews, 1998). Therefore, a particular latency range of the event-related potential wave should vary by stimuli, thus providing information about the degree of differentiated processing of different spoken syllables.

Finally, passive event-related potential paradigms do not require the child to generate an active behavioral response during data collection (e.g., no hand-raising, verbal identification, or button-pressing is required). Many researchers have found that passive event-related potential procedures produce brain waves that vary by consonant manipulations in the stimuli, even when the stimuli are presented the same number of times (Molfese et al., 1991; Molfese & Molfese, 1979, 1980, 1985, 1988). Such a passive response paradigm would be useful in children with Down syndrome, many of whom have characteristics that may reduce the validity of active (e.g., behavioral) measures of speech-processing.

Certain event-related potential deflections to auditory stimuli have been found to be different for people with Down syndrome than for typically developing controls. The latencies of the second positive peak, the second negative trough (sometimes called P2 and N2—Seidl, 1997) and the third positive peak (or P300—Kaneko, Ehlers, Philips, & Riley, 1996) were longer (i.e., slower) than those seen in control participants. These results are compatible with a generalized slowing of auditory processing in children with Down syndrome. However, the extent to which slowing occurs is expected to vary across individuals within the Down syndrome population.

Although the hypothesis that differentiated processing of speech syllables is related to grammatical impairment in children with Down syndrome has not yet been tested, a similar hypothesis has been supported in another group of children with mental retardation. Key, Mervis, and Molfese (2004) studied this association in 4-year-olds with Williams syndrome. They found a positive association of the difference in the event-related potential wave for one syllable compared to that of another syllable (i.e., *ga* vs. *ba*) with receptive language standard scores. The difference in the event-related potential waves explained over 50% of the variance in receptive ability.

In the current study our goal was to test whether differentiated processing of spoken syllables is associated with degree of grammatical comprehension impairment in children with Down syndrome. Even without a typically developing control group, confirmation of this hypothesis would add to the literature in the following ways. First, the aspect of language that we tested is likely to be particularly vulnerable in children with relatively poor differentiation of syllables: grammatical morphology. Second, this is the first study in which the association of differentiated processing of syllables and grammatical impairment in children with Down syndrome has been directly examined. This is important because grammatical comprehension is specifically impaired beyond expected levels given the MAs in many, but not all, children with Down syndrome. Understanding why some children with Down syndrome have more difficulty comprehending grammar than do other children with the same syndrome could provide information that is relevant to designing or selecting effective interventions. Finally, a confirmation of the hypothesized association would support the construct validity of a passive measure of differentiated processing of syllables in a population that needs such a measure.

Method

Participants

Thirteen participants were recruited from the Down Syndrome Clinic at Vanderbilt Children's Hospital or the Child Language Intervention Program (CLIP) at the Vanderbilt Kennedy Center. Ten children with Down syndrome ranging in age from 4.33 years to 8.25 years were included in this study because each had a sufficient number of artifact-free event-related potential trials to produce sufficiently good signal-to-noise ratios in the event-related potential data. The descriptors and results reported here are on these 10 participants (6 males). Their diagnosis of Down syndrome was made by a physician, and trisomy of chromosome 21 was confirmed by genetic testing. Four of the children were right-handed, 1 was left-handed, and the remaining 5 showing no consistent preference. During the testing period, all participants passed a hearing screening conducted at 25 dB for 500, 1000, 2000, and 4000 Hz. Table 1 presents the means and *SD*s for the age, MA, intelligence, and grammatical-comprehension impairment level. As expected, percentile ranking on the Grammatical Morphology subscale of the Test of Auditory Comprehension of Language, third edition–TACL-3 (Carrow-Woolfolk, 1999) indicated that our sample was quite impaired as a whole (*M* = 5%, *SD* = 4.6%), with all but 1 participant falling below the 10th percentile. This participant scored at the 16th percentile on the Grammatical Morphology subscale.

Table 1. Means and *SD*s of Participants' Characteristics

Characteristic	Mean	*SD*
CA (in years)	5.9	1.4
Nonverbal MA[a]	3.5	.8
Nonverbal IQ[b]	66.7	8.7
Grammatical morphology comprehension impairment[c]	3.7	1.9

[a]Leiter–R age equivalency in years from Brief IQ scales. [b]Leiter–R standard scores from Brief IQ scales. [c]Test of Auditory Comprehension of Language, third edition (TACL-3) standard scores from Grammatical Morphology subscale. Unlike some tests, TACL-3 subscale standard scores have a population mean of 10 and *SD* of 3.

Design Overview and Procedure

A concurrent correlational design was used to test the hypothesized association. The hearing screening, a test of auditory comprehension of language, and a nonverbal intelligence scale were administered to participants during the initial session. Children then participated in a desensitization procedure designed to reduce participant attrition due to movement during the event-related potential procedure. Each of these procedures is described below.

Measure of Nonverbal Intelligence and MA

The Leiter-R (Roid & Miller, 1997) is a test of nonverbal intelligence that was designed for people between 2 to 20 years of age. It was standardized using a national stratification plan based on the 1993 census statistics. Nationally representative proportions of key ethnic groups were included. The standardization was carefully constructed to accurately represent children's age, gender, and socioeconomic status (SES) in the four U.S. Census Bureau geographic regions. The Brief IQ was used and was the estimate of intelligence (IQ). The age equivalency score from these subscales was used as the MA estimate; IQ and MA are only used here as participant descriptors. Internal consistency and test–retest of the Brief IQ for 5 to 8 year olds ranged from .88 to .90 and .87 to .90, respectively. The Leiter-R Brief IQ is highly correlated with the Wechsler Intelligence Scale for Children (WISC-III), *r* = .85 (Roid & Miller, 1997).

Measure of Grammatical Morpheme Comprehension

The TACL-3 was designed to measure the receptive language ability in children from 3 to 10 years of age. Because our focus in this study was on the comprehension of grammatical markers, the Grammatical Morpheme subtest of the TACL-3 was our measure of interest. Grammatical morphemes sampled in this instrument include word endings (e.g., plural, past, progressive), negation, comparatives (e.g., bigg*er*), and tense and number variation for the *copula* (i.e., linking verbs) and *auxiliary* (i.e., helping verbs). The standard scores from this subscale were used in our analysis. We note that this standard score is an index of degree of ability compared to that expected on the basis of the participant's CA. Because all of the participants scored below their age expectancy, we labeled the construct these standard score quantify as "impairment for comprehension of grammatical morphemes." Unlike some tests, TACL-3 subscale standard scores have a population mean of 10 and *SD* of 3. Test–retest reliability of the standard scores from the grammatical morpheme subscale is reported to be .86. These scores correlated with another language test at .65 to .85, depending on the subscale of the criterion measure (Carrow-Woolfolk, 1999).

Event-Related Potentials

Event-related potentials were used to produce putative measures of differentiated processing of syllables. Here, we describe the stimuli, the presentation paradigm, the equipment, the data-collection procedure, the data-processing method, and the data-reduction methods.

Stimuli. Consonant–vowel syllables in which the consonant varies on place of articulation are among the most frequently studied stimuli in the event-related potential literature in which researchers have used speech stimuli to measure speech processing. *Place of articulation* refers to the place on the soft palate (velum), hard palate, alveolar ridge, teeth (dental), or lips (labial) that produce the primary point of constriction of the oral cavity associated with various consonants. Therefore, event-related potential procedures that use such stimuli enjoy some of the strongest evidence that event-related potentials measure speech processing (Molfese, Fonaryova Key, Maguire, Dove, & Molfese, 2005). Many earlier researchers using speech stimuli that varied on place of articulation manipulations were motivated by a rapid temporal processing theory (Tallal et al., 1997). However, using such stimuli in the current study should not be viewed as an intention to test this rapid temporal processing theory.

We selected stop consonants in the current study strictly because repeated demonstrations indicate that event-related potentials are sensitive to stimulus manipulations. For example, there is replicated evidence that the amplitude of the second positive deflection (Gelfer, 1987; Molfese, 1978), next negative deflection (Alho & Cheour, 1997; Molfese & Molfese, 1979, 1985), and the third positive deflection (Molfese, Burger-Judisch, & Hans, 1991; Molfese & Molfese, 1979, 1980, 1985) vary by place of articulation-stimulus manipulations. Given that the event-related potential waves of typically developing infants, children, and adults vary by consonant, one would expect participants with "good" differentiation of syllables to show more differentiation of event-related potential waves for a pair of stimuli than would participants with "poor" differentiation of syllables.

Nonword consonant–vowel syllables were selected as stimuli because our motivating theory required that we measure differentiated processing of syllables in a way that would not be confounded by semantic or grammatical aspects of the stimuli. That is, children may have different comprehension levels for real words, which would have confounded the measure of differentiated processing of syllables. Particular syllables were selected that can and do occur in real English words. Contrasts between syllables were used because the motivating theory for the research requires that we measure children's differential response to at least two different syllables.

We selected three contrasts: (a) *ga* vs. *da,* (b) *ga* vs. *ba,* and (c) *da* vs. *na.* The consonants /*b*/, /*d*/, /*g*/ vary in place of articulation. The /*d*/ and /*n*/ are made in a similar place, but vary in presence or absence of nasality (increased nasal resonance is created when the soft palate is lowered and air passes through the nasal cavity for /*n*/). The *na* stimulus was added to examine whether event-related potentials to a contrast that differs on nasality (i.e., *da* vs. *na*) is associated with degree of impairment of morphological comprehension. This /*d*/ vs. /*n*/ contrast is novel in the event-related potential literature.

In this study, quasi-natural speech, instead of synthesized speech, was used to maximize the probability that the results of the event-related potential procedure would be relevant to processing naturally occurring linguistic input. An adult female English speaker produced the syllables, which were digitally recorded via an external microphone connected to a MacIntosh G3 with OS 9.0.1. The consonant–vowel syllables were edited using Bias Peak Software (Berkley Integrated Audio Software, 2000) to ensure that intensity, duration, and format transitions were as close as possible across stimuli without affecting adult identification of the stimuli.

Stimuli presentation. The stimuli were presented through a speaker at 75 dB SPL(A) as measured at the ear. The speaker was positioned 80 cm over the midline of the child's head. An equiprobable stimulus presentation paradigm was used. The interstimulus interval varied between 1500 and 2500 ms. Varied interstimulus intervals were used to reduce the probability of habituation. Each of the four stimuli was presented 30 times in blocked random order (i.e., a *block* was composed of all four stimuli being presented once in a random sequence, and there were 30 such blocks, for a total of 120 trials). Stimulus presentation was controlled by the Electrophysiological Graphical Imaging System (EGIS) v. 3.0.1 (EGI, Inc.). No behavioral response was required from the child.

Equipment. A high-density array of 128 Ag/AgCl electrodes embedded in soft sponges and arranged into a geodesic net (Electrical Geodesics, Inc., Eugene, OR 97403) was used for the event-related potential procedure. One advantage that the electrode net affords is rapid net placement (i.e., between 5 and 15 minutes) and impedance checks. This was considered important for reducing attrition due to movement artifacts. In addition, the many closely spaced electrodes allow multiple estimates of event-related potential data from a grossly defined scalp region. Classical measurement theory indicates that averaging several highly correlated estimates of the same construct increases the reliability of the construct estimate (Crocher & Algina, 1986).

Data-collection procedure. Prior to data collection, all participants engaged in one to four 15-minute desensitization procedures to help them learn to be still during EEG recording. Prior to participant arrival for the EEG session, we soaked the 128-channel geodesic EEG net in a solution of potassium chloride and warm water, to which a few drops of baby shampoo was added as a surfactant, eliminating the need to abrade the scalp to reduce impedances. When the children arrived (individually), they were seated in a testing room with an experimenter present to prompt them to sit with their hands in their lap. Each child was allowed to watch a developmentally appropriate video without the audio track playing during net placement and data collection. The net was placed and adjusted on the child's head by positioning the vertex electrode over the intersection of the line between nasion and inion and the line between preauricular points. The nasion and Fz locations (Jasper, 1958) were used to ensure midline alignment. Following net placement and prior to the onset of the experimental trials, we measured the impedances. Any electrodes with impedances exceeding 40 kΩ were noted and adjusted. EEGs were recorded using Cz as the recording reference. During recording, elliptical filter settings were maintained at 0.1 Hz (high pass) and 30 Hz (low pass), and EEG and behavior were continuously monitored throughout testing. During periods of motor activity, we suspended stimulus presentation until the child's behavior quieted. Net Station 1.0 (EGI, Inc.) was used to record the electrophysiological data. The data were amplified 10,000 times and continuously sampled and stored. Subsequent data analyses were focused on a subset of this data stream that was sampled every 4 min over a 1-s period (250 samples per s), which included a 100-ms prestimulus period.

Artifact removal. Single trial event-related potentials were screened for movement artifacts using the default artifact rejection settings used in NetStation 3.0.2 (i.e., a software component of the EGI system). Participants had an average of 8 channels with unacceptably high artifact (range = 3 to 12). Those with over 12 "bad" channels were excluded. As mentioned earlier, the 10 participants reported on here are those that remained in the study after artifact removal. Following artifact screening, we averaged the EEGs within condition, then baseline was corrected. Data were re-referenced using an average reference. Finally, the event-related potential data were exported to a tab delimited Excel file.

Data reduction. We chose to reduce the number of significance tests to examine the hypothesized associations by reducing the number of event-related potential variables using a three-step process. First, we conducted a spatial principal components analysis (Dien, 1998) on the entire wave for all participants and all stimuli (250 time samples × 10 participants × 4 stimuli = 10,000 cases) and all 128 electrodes (i.e., the "variables") to determine which electrodes were most highly correlated with each other with the same algebraic sign. We averaged the values of electrodes (equally weighted) that loaded most strongly on the same factor with the same algebraic sign if the electrode's highest loading was above $|.40|$.

Second, we conducted a temporal principal components analysis (van Boxtel, 1998) to quantify the wave within the latency range that we judged was most likely reflect differentiated processing of speech syllables (176 to 512 ms poststimulus onset). As indicated earlier, much past research has indicated that the second major positive deflection (Gelfer, 1987; Molfese, 1978) and the third major positive deflection (Molfese et al., 1991; Molfese & Molfese, 1979, 1980, 1985) are sensitive to place of articulation manipulations in the stimuli. These deflections fall between 176 and 512 ms poststimulus in typically developing children at the age range of our sample of children with Down syndrome: 5 to 8 years of age (Molfese et al., 2004). For the temporal principal components analysis, we implemented a correlation matrix and varimax rotation to produce the factors. The number of factors derived was determined using the elbow in the scree plot and eigen values over 1.0.

Third, we tested our hypothesized associations with factor scores from the electrode cluster at which the maximum temporal principal components analysis factor scores occurred. Therefore, the event-related potential variables were the temporal principal components analysis factor scores from the 176- to 512-ms poststimulus latency range. We used the electrode clusters at which factor scores were at the maxima within each stimulus contrast and factor maxima for the absolute value of the mean

Results

Data Reduction

Spatial principal components analysis results. The scree plot and eigen values indicated that nine factors provided a parsimonious reduction of the data for spatial principal components analysis. These nine factors accounted for 80% of the variance in the data. Those with the greatest loading on the same factor with the same algebraic sign were averaged together as long as the loading was greater than |.40|. Nine clusters of electrodes were created; 119 of the 128 electrodes could be clustered using these procedures. The data from the nine electrodes that could not be clustered were not analyzed further. All electrodes that met the criteria for clustering were spatially contiguous. The electrodes that were averaged and the location of the nine clusters of electrodes are illustrated in Figure 1.

Temporal principal components analysis results. The scree plot and eigen values indicated that three factors provided a parsimonious reduction of the data in our latency range of interest (i.e., 176- to 512-ms poststimulus). These three factors accounted for 35%, 32%, and 26% of the variance in the data in this latency window, respectively, for a total of 92% of the variance in the event-related potential data of interest. The time samples that loaded above .40 for Factors 1, 2, and 3, were 312 to 512 ms, 232 to 440 ms, and 176 to 288 ms, respectively. These are illustrated in relation to the grand average wave (average across participants and electrodes by stimuli) in Figure 2. We also note that the latency window of interest (176 to 512 ms) included the ramp from the first negative peak going to the following major positive peak, the entire following major positive peak, and the second negative peak. Even though these peaks are apparent in the grand average wave, we note that these peaks were not necessarily present for all participants' waves at particular electrode clusters. Table 2 indicates the cluster locations at which the absolute value of the mean for these factor scores are at their maxima. The absolute value of the mean factor score was largest at the left frontal temporal, left occipito-parietal, the medio-frontal, and the right frontal temporal clusters.

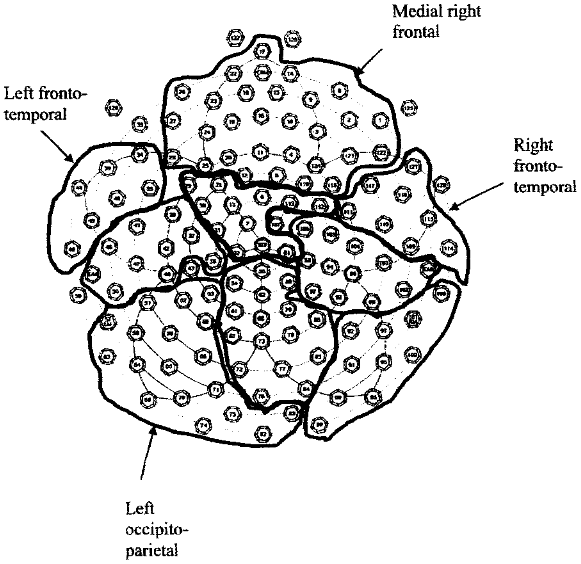

Figure 1. Nine clusters of electrodes produced by the spatial principal components analysis procedure.

Associations Between the Differentiated Processing of Syllables and Degree of Impairment in Comprehension of Grammatical Morphology

Table 3 indicates the Pearson correlation coefficients for the associations between the nine event-related potential variables (the three temporal principal components analysis factor scores for three contrasts) and the standard score from the TACL-3 Grammatical Morphology subscale. It is useful to note that all three contrasts and all three factors produced event-related potential var-

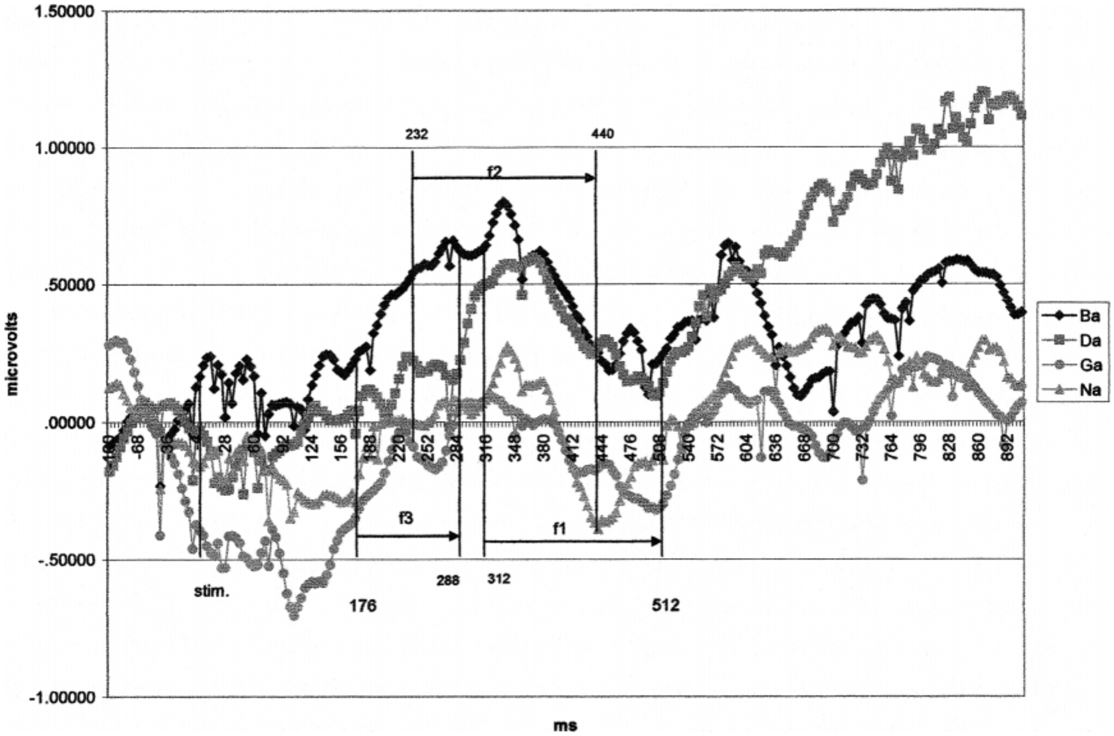

Figure 2. Grand average wave with the latency ranges of the time samples that load above |.40| on the three temporal principal components analysis factors illustrated.

iables that significantly correlated with grammatical comprehension impairment. These four event-related potential variables accounted for between 41% and 55% of the variance in the degree of impairment of morphological comprehension.

To better understand these associations, we created subgroups by splitting the sample at the median of the TACL-3 Grammatical Morphology standard score. The median standard score was four. Five children were in each subgroup. Figures 3 through 5 illustrate the event-related potential waves for the two syllables in the contrast for each of the two subgroups (i.e., above-median vs. below-median). These event-related potential waves were measured at the electrode cluster at which the indicated temporal principal components analysis factor score was at its maxima for the indicated syllable contrast. This was done for three of the four associations to demonstrate the consistency of the pattern, but the same pattern occurred in the fourth association as well. In all three figures, there is greater differentiation between event-related potential waves for the less impaired subgroup than the more impaired subgroup within the targeted latency range indicated by the temporal principal components analysis factor of interest. In the figures, the latency range quantified most by the factor is marked by the vertical lines with an arrow between them. For example, in Figure 3, difference in the event-related

Table 2. Scalp Locations for Electrode Clusters at Which Factor Scores are at Their Maxima by Factor and Stimulus Contrast

Stimulus contrast	Factor 1	Factor 2	Factor 3
da vs. *na*	Left fronto–temporal	Left occipito–parietal	Left occipito–parietal
ga vs. *ba*	Left fronto–temporal	Left occipito–parietal	Medial right frontal
ga vs. *da*	Left fronto–temporal	Left fronto–temporal	Right fronto–temporal

Note. Factor 1 = 312–512 ms, Factor 2 = 232–440 ms, and Factor 3 = 176–88 ms.

Table 3. Pearson Correlation Coefficients for Associations Between Event-Related Potential (ERP) Variables and Impairment in Comprehension of Grammatical Morphology

Stimulus contrast	ERP variables Target electrode cluster, temporal principal components analysis factor[a]	TACL GM[b] standard score
da vs. *na*	Left fronto–temporal; factor 1 (312 ms–512 ms)	.64*
	Left occipito–parietal; factor 2 (232 ms–440 ms)	−.28
	Left occipito–parietal; factor 3 (176 ms–288 ms)	−.28
ga vs. *ba*	Left fronto–temporal; factor 1 (312 ms–512 ms)	−.35
	Left occipito–parietal; factor 2 (232 ms–440 ms)	.60
	Medial right frontal; factor 3 (176 ms–288 ms)	.67*
ga vs. *da*	Left fronto–temporal; factor 1 (312 ms–512 ms)	−.53
	Left fronto–temporal; factor 2 (232 ms–440 ms)	−.70*
	Right fronto–temporal; factor 3 (176 ms–288 ms)	.74*

[a] Latency at which time samples load on factor >|.40|. [b] Test of Auditory Comprehension of Language, third edition, Grammatical Morphology subscale.
*p <.05.

potential wave for *ga* versus that for *da* within the latency range for Factor 2 (i.e., 232 to 440 ms poststimulus) is about 12 microvolts for the less impaired subgroup and about 3 microvolts for the more impaired subgroup. When we view the different algebraic signs of the significant correlation coefficients in light of these graphs, it is clear that the different algebraic signs of the associations are only a reflection of the way the difference waves were computed (i.e., which sound was subtracted) and whether the electrical charge at the time samples that strongly loaded on the factor had a negative or positive polarity.

Exploring Potential Third Variable Explanations for the Significant Associations

We also explored whether additional variables could account for the findings. These were age, IQ, and MA. It should be born in mind that for the significant associations between event-related potential variables and grammatical comprehension to be explained by age, IQ, or MA, these latter variables would have to be significantly associated with the correlating event-related potential variable *and* grammatical impairment. This analysis revealed that age, IQ, and MA were nonsignificantly correlated with the TACL-3 Grammatical Morphology standard scores.

Discussion

The results of this exploratory study indicate that event-related potential difference waves to two consonant–vowel syllables were strongly associated with the degree of impairment in morphological comprehension. The effect sizes of these associations were strikingly high when compared to other bivariate associations in the psychological literature. We note that all three contrasts and all three latency ranges of interest produced event-related potential variables that were associated with grammatical impairment. Specifically, children with larger differences between brainwaves for the syllables in the contrast had less impaired grammatical comprehension than did children with more impaired grammatical comprehension. This is an intriguing finding because it suggests that a passive measure of differentiated processing of syllables is strongly related to the functional skill of comprehending grammatical morphemes. If replicated, this event-related potential procedure could be a promising technique for assessing this important perceptual ability, particularly in populations such as those with Down syndrome, that do not readily cooperate with active behavioral measures or whose etiology is associated with confounding factors, such as motor ability, reduced attention, and decreased motivation.

As in any exploratory study, there are unanswered questions and methodological weaknesses in the current study. The research design we used is a concurrent correlational design. “Third” variables that correlate with both differentiated processing of syllables and grammatical impairment can never be completely controlled in concurrent

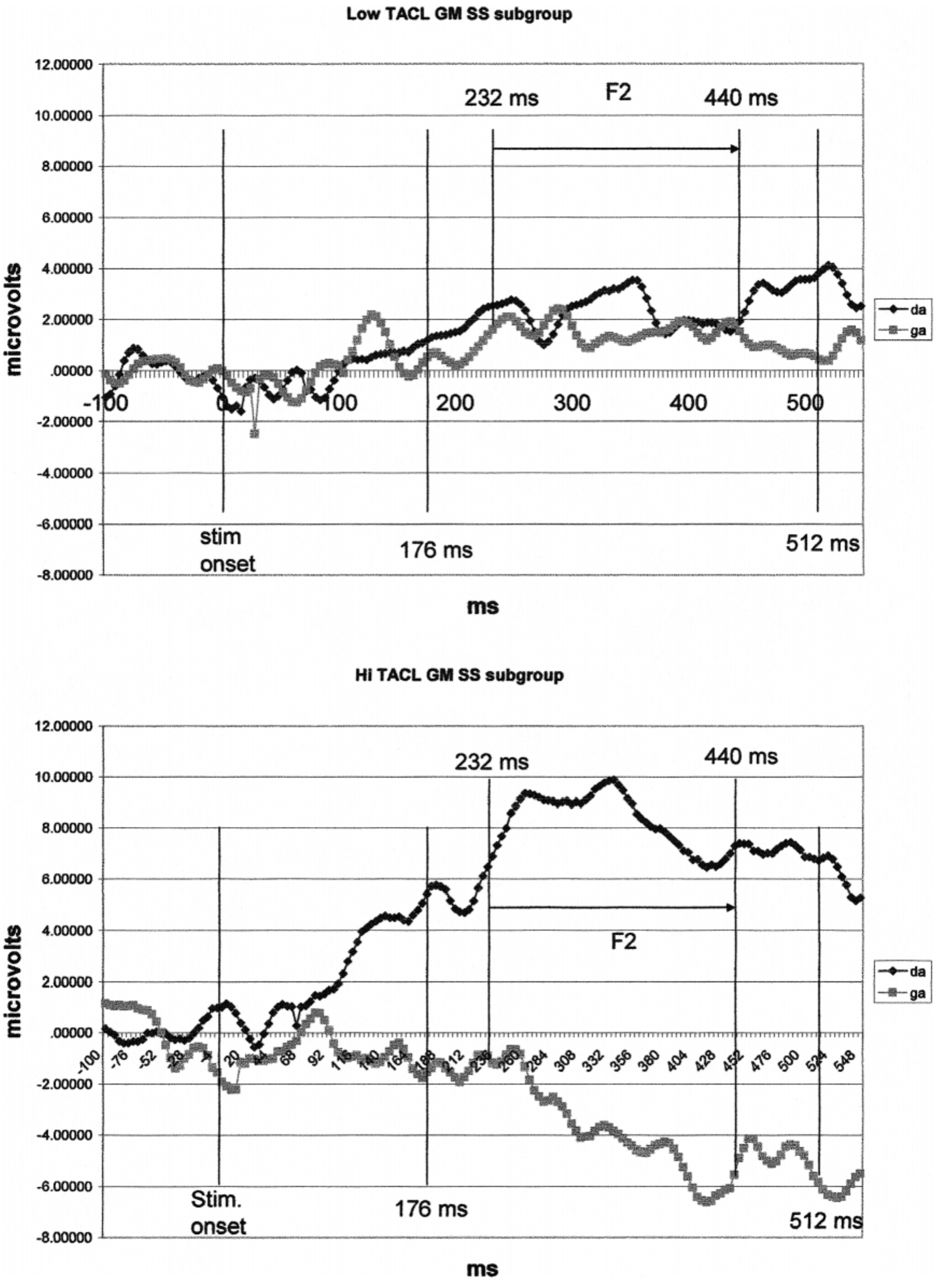

Figure 3. Event-related potential waves at the left fronto–temporal electrode cluster to *ga* vs. *da* by relatively mildly and relatively severely impaired grammatical comprehenders.

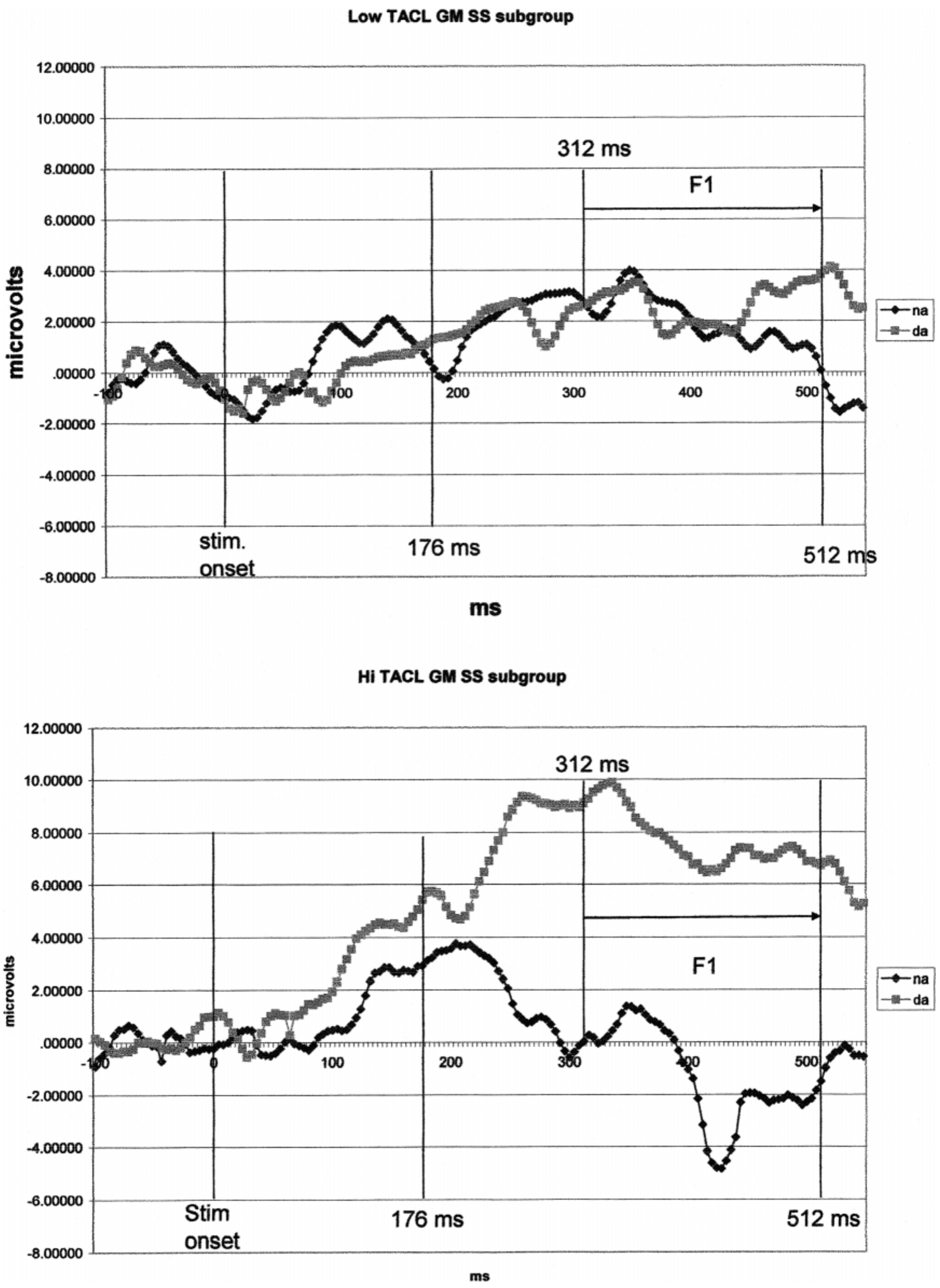

Figure 4. Event-related potential waves at the left fronto–temporal electrode cluster to *da* vs. *na* by relatively mildly and relatively severely impaired grammatical comprehenders.

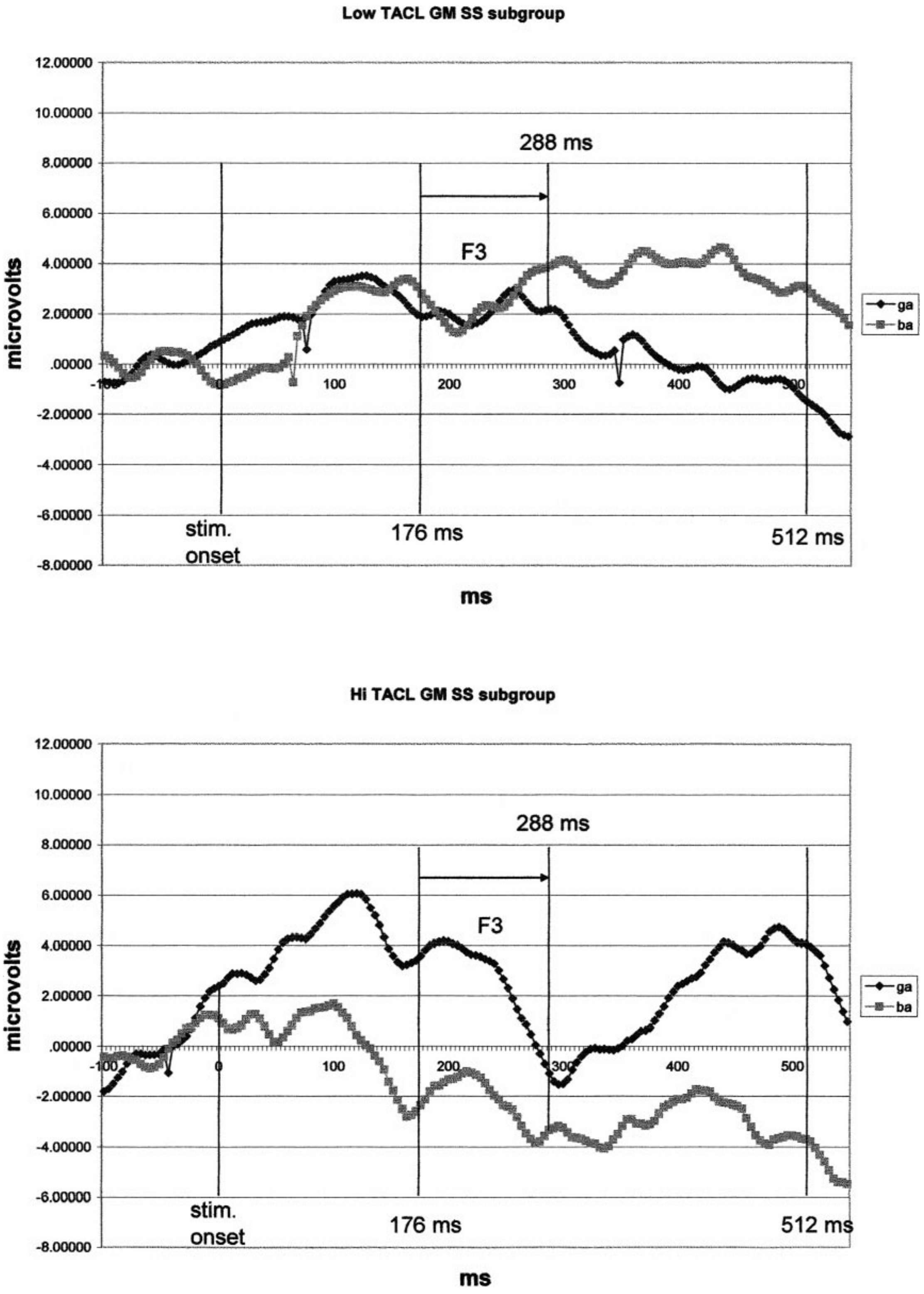

Figure 5. Event-related potential waves at the medial right frontal electrode cluster to *ga* vs. *ba* by relatively mildly and relatively severely impaired grammatical comprehenders.

correlational designs and, thus, offer potential noncausal explanations for the associations. Because nine significance tests were conducted without adjusting the alpha, a subset of the results may be sample-specific (i.e., a result of inflated experiment-wise error). The alpha level was not adjusted because the sample size was only 10 and because the event-related potential variables were not independent of each other. Using Bonferroni's correction on the alpha would have unnecessarily inflated type II error rates because this approach to alpha adjustment assumes that significance tests are independent (Blair & Karniski, 1994). The event-related potential variables were not independent of each other due to the use of same syllable across the contrast using /*ga*/ or /*da*/ and temporal contiguity and overlap of latency ranges quantified by the factor scores. Ultimately, the field must depend on replication across studies to identify associations that are representative of the population.

There is evidence to suggest that these findings are not sample specific. Although no researchers have examined the grammar impairment–event-related potential association in children with Down syndrome, a similar study was conducted by Key et al. (2004) with children who have Williams syndrome. Interestingly, one of their event-related potential variables that strongly correlated with receptive standard scores was measured at a very similar electrode cluster (left and right frontal), poststimulus latency (175 and 268 ms), and stimulus contrast (*ga* vs. *ba*) to a correlating event-related potential variable in the present study. In our study, event-related potential difference waves to the *ga* vs. *ba* contrast in the 176- to 288-ms poststimulus latency range at the right medial frontal cluster correlated strongly with morphological impairment, $r = .67$. This degree of similarity in the correlating event-related potential variable across these two studies is very encouraging. However, future replication work with children who have Down syndrome is warranted before generalizing past the present sample.

If future replication occurs, then our theories of why children with Down syndrome have particularly impaired grammatical comprehension may need to include the notion that many children with Down syndrome have deficit differentiated-processing of syllables. The present study was not designed to address this hypothesis. However, it is important to note that such theories could predict that the impact of slow or incomplete processing of syllables affect other aspects of language (e.g., lexical or syntactic aspects of grammar) and cognition (e.g., general intelligence). Such associations have been noted in other studies (Key et al., 2004). Studies that test such theories could include a comparison group of matched typically developing children. This would be necessary to allow quantification of the degree to which children with Down syndrome have atypical differentiation of syllables. Clearly, this would require comparisons between children with Down syndrome and matched children who are typically developing on event-related potentials to syllable contrasts.

Further, in future work in this area, investigators should determine whether the grammatical development of children with particularly poor differentiated processing of syllables benefit from treatments that provide grammatical input at times and in ways that such children are most likely to process. Present empirical studies have not definitively identified which treatments are most effective in doing this. However, theory does suggest that providing adult grammatical input immediately after children's grammatically incomplete or inaccurate utterances (i.e., grammatical recasts) may be one effective way to aid children's processing of the grammatical input (Camarata, Nelson, & Camarata, 1994).

We do not interpret the present findings as supporting special skills training on active discrimination of specific contrasts to improve grammar comprehension. Such attempts to remediate basic processes in the service of eventually affecting higher order skills have historically been unsuccessful or less successful than more direct methods of addressing the higher order skills (Arter & Jenkins, 1979; Fuchs & Fuchs, in press).

In summary, the results of this study provide the first step toward (a) understanding why some children with Down syndrome have more difficulty comprehending grammatical morphology than others and (b) developing a valid passive measure of this processing ability in a group of children whose characteristics render behavioral speech-processing measures invalid: children with Down syndrome.

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