Effects of grammatical categories on children’s visual language processing: Evidence from event-related brain potentials

Christine Weber-Fox *, Laura J. Hart, John E. Spruill III

Department of Speech, Language, and Hearing Sciences, Purdue University, Hearilion Hall, 500 Oval Drive, West Lafayette, IN 47907-2038, USA

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Abstract

This study examined how school-aged children process different grammatical categories. Event-related brain potentials elicited by words in visually presented sentences were analyzed according to seven grammatical categories with naturally varying characteristics of linguistic functions, semantic features, and quantitative attributes of length and frequency. The categories included nouns, adjectives, verbs, pronouns, conjunctions, prepositions, and articles. The findings indicate that by the age of 9–10 years, children exhibit robust neural indicators differentiating grammatical categories; however, it is also evident that development of language processing is not yet adult-like at this age. The current findings are consistent with the hypothesis that for beginning readers a variety of cues and characteristics interact to affect processing of different grammatical categories and indicate the need to take into account linguistic functions, prosodic salience, and grammatical complexity as they relate to the development of language abilities.

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1. Introduction

Our focus was to examine developmental aspects of neural functions mediating processing of naturally occurring grammatical categories. These grammatical categories represent a variety of word types that vary in linguistic functions, semantic features, and quantitative attributes including length and frequency (Brown, Hagoort, & Ter Keurs, 1999; Kellenbach, Wijers, Hovius, Mulder, & Mulder, 2002; King & Kutas, 1998; Munte et al., 2001; Neville, Mills, & Lawson, 1992; Osterhout, Allen, & McLaughlin, 2002; Osterhout, Bersick, & McKinnon, 1997). Several event-related brain potential (ERP) studies in adults indicate that frequency and length characteristics of words of various grammatical categories are systematically related and strong determiners of the peak latency of the second negative component occurring between 280 and 400 ms (King & Kutas, 1998; Munte et al., 2001; Osterhout et al., 2002, 1997). That is, higher frequency words which are also characteristically shorter in length elicit a second negativity with an earlier peak latency than lower frequency words that are also typically longer in length. This second negative ERP component that peaks within a temporal window of 280–400 ms is thought to reflect the first manifestation of the availability of word-category information from the mental lexicon (Brown et al., 1999; Ter Keurs, Brown, Hagoort, & Stegeman, 1999). At the temporal electrode sites, peak latencies across grammatical categories were found to range from 280 ms for the most frequent category, articles, to 320 ms for prepositions, 350 ms for pronouns, 360 ms for auxiliaries, and 400 ms for the lowest frequency categories of nouns and verbs (Osterhout et al., 1997). However, other researchers have reported latency differences related only to the broader word class distinctions (i.e., closed-class words peaking earlier than open-class words), finding no systematic...
relationship to within class lexical frequency/length characteristics (Brown et al., 1999; Neville et al., 1992). The peak latencies of the second negative component elicited by closed- and open-class words were also found to be differentially sensitive to language proficiency, both in native English speakers and in Chinese-English bilinguals (Weber-Fox, Davis, & Cuadrado, 2003; Weber-Fox & Neville, 2001). In both populations, the peak latency of the second negativity elicited by closed-class words, but not open-class words, varied as a function of linguistic proficiency.

Amplitude differences of this component across grammatical categories also vary with word frequency, with larger amplitudes associated with lower frequency words (Munte et al., 2001). Kellenbach and colleagues (2002) found that these amplitude differences may be due in part to naturally occurring differences in semantic features (e.g., concrete, abstract, and visual-motor). Furthermore, distinctions in scalp distributions for this component were found to be related to different grammatical categories (Neville et al., 1992; Osterhout et al., 1997). Specifically, for the closed-class grammatical categories, a left hemisphere asymmetry was observed over temporal sites. In contrast, for nouns and verbs, the negativity tended to be slightly larger and later over the right hemisphere (Osterhout et al., 1997).

In a later temporal window (~400–600 ms), words from closed-class grammatical categories (e.g., articles, prepositions), when presented in sentence contexts, elicited a broad negative shift (BNS) that was not present in the waveforms elicited by open class grammatical categories (e.g., verbs, nouns) (e.g., Brown et al., 1999; Kutas & Van Petten, 1994; Munte et al., 2001; Neville et al., 1992; Osterhout et al., 1997). These later differences between the word classes are thought to relate to post-lexical semantic and syntactic processing (Brown et al., 1999; Ter Keurs et al., 1999). Taken together, ERP findings for adults indicate that the neural functions for processing different grammatical categories reflect their linguistic function, semantic features, and their quantitative attributes of frequency and length.

Little is known about the development of neural functions mediating the processing of words from finely differentiated grammatical categories. However, ERPs elicited by words grouped according to the broader categories of closed- and open-class words have been examined in children between the ages of 8 and 11 years (Neville, Coffey, Holcomb, & Tallal, 1993). The ERPs elicited by visually presented closed-class words were averaged across grammatical categories and included articles, pronouns, prepositions, conjunctions, and auxiliaries. Open-class ERPs were averaged across nouns, verbs, and adjectives. A negative component peaking around 400 ms was elicited in the children’s ERPs for closed- and open-class words. In typically developing children, the N400 was asymmetrical (larger over left anterior regions) for closed-class words but not for open-class words. This was consistent with previous findings in adults (Neville et al., 1992). The findings from this study indicate ERPs of children showed distinctions in processing open- and closed-class words; however, differences in the latencies of the second negative component were not adult-like. In adults, the peak latency of this component was earlier for closed-class words (280 ms) compared to open-class word (350 ms) (Neville et al., 1992).

In summary, the development of neural functions mediating the processing of different word classes is not completely adult-like for ages up through 11 years of age, and unlike adults, children may not process highly frequent closed-class words more quickly than lower frequency open-class words.

Consistent with ERP evidence in children, behavioral findings indicate that word frequency is not the predominant cue in driving early word learning. Perhaps the most striking evidence is that in their earliest word learning, young children first produce nouns, which are least frequent, followed by verbs and adjectives which are also relatively infrequent (Bates et al., 1994). The most frequent categories, function words making up the closed-class category, are in fact the latest to emerge, typically when children have amassed a lexicon of over 400 words (Bates et al., 1994). Obviously, factors besides frequency contribute to early word learning and a general pattern of progression according to grammatical categories across early language development has been observed by a number of researchers (e.g., Bates et al., 1994; Bloom & Lahey, 1977; Brown, 1973).

Progressions in language development related to grammatical categories continue even beyond early language acquisition. The language abilities of school-age children for both auditory processing and reading also show distinctions according to word classes. Auditory word monitoring tasks in kindergarten children indicate that closed-class items are not segmented into words as readily as open-class words (Holden & MacGinitie, 1972), even when prosodic differences between the word classes are controlled (Ehri, 1975). In an auditory word-monitoring study of older children, Friederici (1983) found that children up through the age of 11 years were less sensitive to closed-class words (i.e., failed to respond as accurately) compared to open-class words. Parallel findings were reported for a study of the effects of word class on children’s reading (Bruskin & Blank, 1984). Bruskin and Blank (1984) observed that children aged up to 11 years were less accurate and slower in reading closed-class (function) words compared to reading open-class (content) words that were matched for length and frequency. However, it should be noted that when children were asked to repeat the last word heard during a pause in a story, children as young as 5 years of age performed as accurately on closed- and open-class words (Karmiloff-Smith, Grant, Sims, Jones, & Cuckle, 1996). The 4-year-old children in that study, however, performed more accurately on open-class words compared to closed-class words. In summary, the production of closed-class or function words typically occurs later compared to
There are a number of attributes typical of closed-class words that may contribute toward increased difficulties in accessing or processing (Echols, 1993; Herron & Bates, 1997). In a study of adults, accuracy, and speed of recognition of closed-class words were found to be more dependent on contextual and prosodic cues compared to recognition of open-class words (Herron & Bates, 1997). It has been argued that perceptual salience plays an important role in the early development or representations of words (Echols, 1993). Very early in language acquisition, 9-month-old infants have been shown to rely more strongly on prosodic than phonotactic cues for word segmentation (Mattys, Jusczyk, Luce, & Morgan, 1999). Prosodic factors were found to predict the words that young children produce when they are in the one-word stage, and further, 2–3-year-olds relied on prosodic cues to a greater extent than adults did in a word-learning task (Echols, 1993). A role for perceptual salience was also reported to be important for older children (ages 4–9 years) learning novel words (Aitchison & Chiat, 1981). Also, young school-age children were shown to rely heavily on prosodic cues for tasks requiring recognition and repetition of certain syntactic structures (e.g., subject and predicate phrases) (Read & Schreiber, 1982). Closed-class items are typically unstressed and do not normally occur in phrase-final syllable positions, therefore, they are not as perceptually salient as open-class words (Echols, 1993). The lack of perceptual salience is thought to contribute to the longer developmental time course in the acquisition of closed-class words. On the other hand, as Echols (1993) summarized, closed-class items typically occur much more frequently in both spoken and written forms, which would predict increased familiarity and ease in processing. In addition, it has been shown that a child’s productive vocabulary may not reflect their perceptual sensitivity to function words (Gerken & McIntosh, 1993). Children as young as 2 years of age identified pictures more accurately when the name was preceded by a grammatical article (Gerken & McIntosh, 1993). Furthermore, fourth-grade children (mean age 9; 4) were sensitive to grammatical primes in a reading task that required them to read target words aloud as quickly as possible (Bowey, 1996).

Given that the most frequent words (closed-class) are also the ones that display a more protracted developmental timecourse (Bates et al., 1994; Bloom & Lahey, 1977; Brown, 1973; Bruskin & Blank, 1984; Ehri, 1975, 1976; Friederici, 1983; Holden & MacGinitie, 1972; Karmiloff-Smith et al., 1996), we hypothesized that the peak latencies of the second negative component of children’s ERPs may not reflect the same systematic relationship to frequency/length characteristics as previously described for adults (King & Kutas, 1998; Munte et al., 2001; Osterhout et al., 2002, 1997). The current study examines developmental aspects of ERPs elicited in 9–10-year-old children in a visual sentence processing paradigm for different grammatical categories, including nouns, adjectives, verbs, pronouns, conjunctions, prepositions, and articles. The central aim of the present study was to determine how neural functions mediating the processing of these different grammatical categories reflect the developmental progressions described in behavioral research, and also to examine whether children’s processing of grammatical categories is systematically related to frequency/length characteristics. The results of this study will extend previous developmental findings (Neville et al., 1993) by examining word category processing on a more fine-grained level. This is important when considering that the different grammatical categories make up the broad closed- and open-class categories cover a wide range of linguistic functions, semantic features, and grammatical complexity, as well as characteristics of frequency and length.

2. Materials and methods

2.1. Participants

Participants were 30 (14 female) children aged 9; 5–10; 11 (Mean = 10; 4, SE = .09). All participants were native English speakers who were right-handed according to parental-report and confirmed by performance on an abbreviated handedness inventory (five tasks adapted from Oldfield, 1971). The participants had a negative history of neurological, speech, language, reading, or hearing impairments. All participants performed normally on the Oral Speech Mechanism Screening Evaluation—Revised (OSMSE-R, St. Louis & Ruscello, 1987). All participants also exhibited normal hearing in each ear as confirmed by hearing screenings at a level of 20 dBHL (the threshold of audibility for an average normal hearing listener at particular signal frequencies) at 500, 1000, 2000, 4000, and 6000 Hz presented via headphones. Also, each participant had normal or corrected-to-normal vision according to parental-report and confirmed by a visual acuity screening of each eye using a standard eye chart.

The language abilities of the children were assessed using two subtests of The Clinical Evaluation of Language Fundamentals—Revised (CELF-R, Semel, Wiig, & Secord, 1989). These included the Recalling Sentences (CRSS), and Semantic Relations (CRSR) subtests. In addition, vocabulary abilities of the children were assessed using the Peabody Picture Vocabulary Test—3rd Edition (PPVT-3, Dunn & Dunn, 1997). Each participant demonstrated language skills within normal ranges. Reading abilities of the children were also assessed using the reading comprehension subtest of the Peabody Individual Achievement Test—Revised (PIAT-R, Markwardt, 1989) to ensure that
reading abilities were adequate for performing the experimental task. All participants demonstrated age appropriate reading skills with a minimum of a fourth grade reading level.

2.2. Sentence stimuli

The stimuli for the ERP paradigm were a set of 122 sentences (Appendix A) that were taken from a subset of the stimuli used previously in a study of normally developing children and those with specific language impairment (Holcomb, Coffey, & Neville, 1992; Neville et al., 1993). Half of the sentences contained final words that violated semantic expectations (e.g., “Zebras have black and white dishes.”, “At night there are lots of stars in the truck”). The remaining 61 sentences were semantically appropriate (e.g., “The car ran out of gas.”, “Billy knows all the letters in the alphabet.”). The reading difficulty of the sentences was at a second grade level and the cloze probability for the final words in the sentences was >.80 for second and third graders (Holcomb et al., 1992; Neville et al., 1993). The words in medial positions of the sentences (i.e., excluding the initial and final) were coded according to grammatical categories. Table 1 lists the number of tokens, token variations, and word lengths (i.e., number of letters) of the different grammatical categories included in the current study. The mean word frequencies (log scale) for each of the grammatical categories are displayed in Fig. 1. As this figure illustrates, the relative frequencies across the grammatical categories are similar for the corpus of Francis and Kucera (1982) and the frequencies in print for the fourth and fifth grade levels reported by Carroll, Davies, and Richman (1971). The repetition of words throughout the sentence stimuli varied considerably as they would naturally. The repetition rate was low for the open-class categories of nouns, verbs, and adjectives and high for the closed-class categories of pronouns, conjunctions, prepositions, and articles (Table 2). In a previous study, repetition effects were found to impact only low frequency words (Rugg, 1990). Thus, it is unlikely that the high, naturally occurring repetition rates of the closed-class words (which are high frequency), affected the outcome of the current experiment. Two of the closed-class categories, conjunctions and articles, contained stimulus items that had particularly high repetitions (detailed in Table 2).

2.3. Event-related brain potential recordings

Scalp electrical activity was recorded with 32 electrodes secured in an elastic cap (Quik-cap). Electrodes were positioned over homologous locations of the two hemispheres according to the criteria of the International 10–10 system (American Electroencephalographic Society, 1994). The specific locations were: midline sites FZ, FCZ, CZ, CPZ, PZ, and OZ; medial lateral sites FP1(2), F3(4), FC3(4), CP3(4), P3(4), and O1(2); and lateral sites F7(8), FT7(8), T7(8), TP7(8), and P7(8). These recordings were referenced to linked mastoids. The electro-oculograms (EOGs) were bipolar recordings from the left and right outer canthi (horizontal) and left inferior and superior orbital ridge (vertical). The electrical signals were amplified within a bandpass of 0.1 and 100 Hz and digitized on-line at a rate of 500 Hz.

Table 1
Number of tokens, token variations, and length across grammatical categories

<table>
<thead>
<tr>
<th>Word categories</th>
<th>No. of tokens</th>
<th>Token variations</th>
<th>Length mean (SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-class Nouns</td>
<td>135</td>
<td>113</td>
<td>5.3 (.16)</td>
</tr>
<tr>
<td>Adjectives</td>
<td>49</td>
<td>40</td>
<td>4.9 (.26)</td>
</tr>
<tr>
<td>Verbs</td>
<td>119</td>
<td>86</td>
<td>4.7 (.14)</td>
</tr>
<tr>
<td>Closed-class Pronouns</td>
<td>40</td>
<td>14</td>
<td>3.2 (.42)</td>
</tr>
<tr>
<td>Conjunctions</td>
<td>43</td>
<td>5</td>
<td>3.6 (1.1)</td>
</tr>
<tr>
<td>Prepositions</td>
<td>76</td>
<td>12</td>
<td>3.3 (.05)</td>
</tr>
<tr>
<td>Articles</td>
<td>94</td>
<td>5</td>
<td>2.8 (.65)</td>
</tr>
</tbody>
</table>

Table 2
Repetition of stimulus words across grammatical categories

<table>
<thead>
<tr>
<th>Word categories</th>
<th>% of items repeated</th>
<th>Maximum No. of repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-class Nouns</td>
<td>9.63</td>
<td>3</td>
</tr>
<tr>
<td>Adjectives</td>
<td>10.21</td>
<td>3</td>
</tr>
<tr>
<td>Verbs</td>
<td>12.61</td>
<td>3</td>
</tr>
<tr>
<td>Closed-class Pronouns</td>
<td>100</td>
<td>9 (“I”)</td>
</tr>
<tr>
<td>Conjunctions</td>
<td>100</td>
<td>36 (“and”)</td>
</tr>
<tr>
<td>Prepositions</td>
<td>100</td>
<td>19 (“in”), 15 (“on”)</td>
</tr>
<tr>
<td>Articles</td>
<td>98.9</td>
<td>56 (“the”), 34 (“a”)</td>
</tr>
</tbody>
</table>
2.4. Procedures

Each participant and parent completed the informed consent forms. The parent of each child also completed a case history form. All participants were encouraged to ask questions throughout the course of the experiment. The children selected a video to watch during the capping procedure and the electrode cap was then placed on the child. Once appropriate impedance levels were obtained (<5 kΩ), the children were seated comfortably in a sound-attenuating room. The children were positioned 160-cm from a 47.5-cm monitor and the experimental task was explained. Each trial began when the child pressed a button on the response pad. At the onset of the trial, a centered, white rectangular border appeared on the screen. Words were presented in white letters against a black background in the center of the white rectangular border which remained for the duration of a trial. Participants were instructed to refrain from blinking while the rectangular border was on the screen. The words were presented for 300 ms with a 400 ms blank interval between words (1 word/700 ms). The rate of word presentation was faster than that of previous studies (1 word/1000 ms: Holcomb et al., 1992; Neville et al., 1993). However, the rate of word presentation in the current study easily fell within reading rates for this age group, with the most conservative estimate falling between 120 and 145 words per minute for 4th and 5th graders (Harris & Sipay, 1985). The last word in each sentence was presented with the appropriate punctuation (period). Visual angles of the word stimuli were 0.5° to 5° horizontally and 0.5° vertically. The rectangular border remained on the screen for an additional 1500 ms after the presentation of the final word in the sentence and then a prompt “YES/NO?” appeared on the screen. Participants were instructed to press the “yes” button if the sentence made sense, or the “no” button if the sentence did not make sense. The response hands used to press the “yes” and “no” buttons were counterbalanced across the participants. Once the participants responded with a button press, the word “READY?” appeared in the center of the screen. The session was self-paced and participants controlled the onset of the next trial by pressing a button on the response pad. The trials were presented in two blocks that were counterbalanced across the participants. Each block lasted ≈20 min and varied slightly depending on the pace set by the individual participants.

2.5. Data analysis

For analyses of ERP waveforms, trials with excessive eye movements or other artifacts were excluded (18%), and the remaining trials were averaged according to grammatical categories for each participant. The averages were triggered 100 ms prior to the onset of the target words in the sentences (i.e., medial words: nouns, adjectives, verbs, pronouns, conjunctions, prepositions, and articles) and included a 600 ms epoch following the trigger.

Measurements of amplitudes in the ERPs were quantified relative to the pre-stimulus interval (−100 to 0 ms) that served as the baseline voltage in each participant’s averages. For the measurement of each ERP component, a temporal window was selected to be approximately centered on its peak in the grand averaged waveforms. The duration of the temporal windows were selected based on the approximate duration of the components and checked to ensure that the windows captured the peaks in the individual subject records.

For the ERPs elicited by the medial words (nouns, adjectives, verbs, pronouns, conjunctions, prepositions, and articles), measurements of peak latency and amplitude were made for temporal windows of 85–150 ms (P122), 50–200 ms (N128), 100–225 ms (N197), 100–250 ms (P220), and 250–400 ms (N359). In addition, the mean area amplitudes for the later broad components were measured within a temporal window of 450–600 ms. Statistical analyses of the ERP measures of amplitudes and peak latencies included ANOVAs with repeated measures for: seven grammatical categories (nouns, adjective, verbs, pronouns, conjunctions, prepositions, and articles) × 2 hemispheres (left and right) × subset of electrode sites. The subset of electrode sites used for the comparisons were based on visual inspection of the elicited waveforms to determine where reliable peaks could be measured and based on findings from previous studies (Neville et al., 1993; Osterhout et al., 1997). In addition, lateral electrode sites were selected for the repeated measures analyses because they provided a sample of ERPs from the left and right hemispheres that allowed for the examination of distributional effects within and between hemispheres. The subset of electrode sites used for each of the components of interest were as follows: N128 and P220 peak amplitude and latency (F7/8, FT7/8, T7/8, and TP7/8), P122 and N197 peak amplitude and latency (O1/2), N359 peak amplitude (F7/8, FT7/8, T7/8, and TP7/8), N359 peak latency (F7/8, FT7/8, and T7/8) and mean area amplitude of the late component between 450 and 600 ms (F7/8, FT7/8, and T7/8). Significance values were set at $p < .05$. For all repeated measures with greater than 1° of freedom in the numerator, the Huynh–Feldt ($H – F$) adjusted $p$ values were used to determine significance (Hays, 1994). The effect sizes, indexed by the partial-eta squared statistic ($\eta^2_p$), are reported for all significant effects. Tukey HSD (Honest Significant Difference) post hoc comparisons, which utilize the MS Error term from the original repeated measures ANOVA, were calculated for significant interactions involving multiple variables to determine which comparisons contributed to the significant $F$ values (Hays, 1994).

3. Results

3.1. Performance accuracy

All participants responded similarly and with near perfect or perfect scores in detecting semantic anomalies.
contained in the stimulus sentences. The mean (SD) percent correct obtained by the children was 97.9% (.07). Consistent with previous reports (Holcomb et al., 1992), robust N400’s were elicited by the semantic anomalies in these school age children (Fig. 2). These findings serve to confirm that the children comprehended the sentences accurately.

3.2. ERPs elicited by different grammatical categories

The ERPs elicited by the seven grammatical categories are shown in Fig. 3. It is evident from this figure that the neural functions for processing words from different grammatical categories share similar broad characteristics of the waveforms. A prominent P122–N197 complex can be observed at the occipital sites across the grammatical categories. Additionally, the N128–P222 components are clearly visible at anterior and temporal sites, followed by a large second negativity (N359). However, the waveforms across the grammatical categories are not identical. For example, differences in the left and right hemisphere asymmetry across categories are apparent for the large second negativity (N359) (Fig. 3). The analyses below describe the similarities and differences in the amplitude and peak latency measures of various ERP components elicited by each of the grammatical categories.

3.2.1. P122

The mean (SE) peak latency of the P1 (observed at occipital sites) for the children was 122.3 (1.8) ms and did not differ across grammatical categories, condition $F(6, 174) = 1.852, \ H–F_{p} = .10$. The peak amplitude of the P122 was also similar across grammatical categories, condition $F(6, 174) = 1.420, \ H–F_{p} = .22$.

3.2.2. N128

The mean (SE) peak latency of the N1 for the children was 128.2 (2.2) ms and did not differ across grammatical categories, condition $F(6, 174) = 1.882, \ H–F_{p} = .12$. The peak amplitude of the N128 was also similar across grammatical categories, condition $F(6, 174) < 1$.

3.2.3. N197

The mean (SE) peak latency of the N180, observed over occipital sites, for the children was 197.5 (2.7) ms. The effects of grammatical category on the peak latency of the N197 were not significant, condition $F(6, 174) < 1$. The peak amplitude of the N197 varied somewhat across grammatical categories, condition $F(6, 174) = 4.275, \ H–F_{p} = .001, \ v_{p}^{2} = .128$, with the largest peak amplitude elicited by conjunctions. Post hoc comparisons revealed that the negative amplitude of the N197 elicited by conjunctions was larger than that for pronouns and articles, Tukey HSD $p < .05$.

3.2.4. P220

The mean (SE) peak latency of the P2 component for the group of children was 220.1 (2.0) ms and was unaffected by grammatical category, condition $F(6, 174) = 1.276, \ H–F_{p} = .27$. As can be seen in Fig. 4, the peak amplitude of the P220 was similar for six of the seven grammatical categories. The P220 peak amplitude was greater for
conjunctions compared to nouns, adjectives, and articles, condition \( F(6,174) = 3.543, H–F p = .003, e_p^2 = .109, \) Tukey HSD \( p < .05. \)

The mean (SE) P220 peak latencies were 358.9 (3.1) ms and varied across grammatical categories with a range of 345.5 ms through 367.8 ms, condition \( F(6,174) = 6.951, H–F p < .001, e_p^2 = .193. \) The variations in peak latencies for this component across conditions are illustrated in Fig. 3 (top panel). The grammatical categories in this figure are arranged from the lowest word frequency (noun) to the highest word frequency (article) categories. As illustrated in this figure and unlike the findings in adults (e.g., Osterhout et al., 1997), the peak latency of the second negative component (N359) was not systematically earlier for the grammatical categories characterized by words that have a higher frequency and are shorter in length. Post hoc comparisons revealed that the peak latency of the second negative component elicited by conjunctions was earlier compared to those elicited by nouns, verbs, pronouns, and articles, Tukey HSD \( p < .05. \)

The peak latencies of the N359 elicited by pronouns were also longer compared to prepositions, Tukey HSD \( p < .05. \) It is interesting to note that the peak latencies of
the N359 elicited by the two most extreme cases, nouns and articles (i.e., lowest frequency/longest length vs. highest frequency/shortest length) did not differ. There was also an effect of hemisphere, $F(1,29) = 4.449, p = .044, \eta^2_p = .133$, on the peak latencies. Collapsed across conditions and electrodes, the mean (SE) peak latency over the left hemisphere, 355.3 (2.8) ms, was earlier than that over the right hemisphere, 362.4 (3.3) ms. The peak latencies are plotted for the left and right hemispheres in the bottom panel of Fig. 5.

The peak amplitude of the second negative component also differed across the grammatical categories, condition $F(6,174) = 8.478, H–F p < .001, \eta^2_p = .226$. The mean peak amplitudes across conditions are illustrated in Fig. 6 (top panel). Post hoc comparisons revealed that the peak amplitudes elicited by nouns and adjectives were larger compared to the N359s elicited by conjunctions, prepositions, and articles, and the N359 elicited by pronouns was larger compared to conjunctions (Tukey HSD, $p < .05$). The trend for peak amplitudes to be more negative over the left hemisphere did not reach significance for all grammatical categories collapsed, $F(1,29) = 3.238, p = .082, \eta^2_p = .100$. However, as can be seen in Fig. 6 (bottom panel), the differences in peak amplitudes across the left and right hemispheres were most pronounced for three of the four closed-class categories: conjunctions, prepositions, and articles. Follow-up analyses of this set of closed-class words (conjunctions, prepositions, and articles) revealed that the peak amplitude of the N359 was larger over the left hemisphere compared to the right hemisphere, $F(1,29) = 6.207, p = .019, \eta^2_p = .176$. This left hemisphere asymmetry was not, however, significant for the set of open-class words, nouns, adjectives, and verbs: $F(1,29) = 1.072, p = .31$. The amplitude of the N359 was smallest over temporal–parietal sites, which is evident in Fig. 3, electrode $F(3,87) = 19.133, H–F p < .001, \eta^2_p = .397$. In particular, the peaks at the temporal–parietal sites were considerably diminished for the grammatical categories within the closed-class words (refer to Fig. 3). For this reason, peak latency measures were not obtained for the temporal–parietal sites.

3.2.6. Late broad component (450–600 ms)

The mean area amplitude measure of the late broad component (450–600 ms) is illustrated for each of the grammatical categories in Fig. 7. The right hemisphere amplitude was greater than the left hemisphere amplitude...
only for the nouns and verbs, condition × hemisphere \( F(6, 174) = 3.817, H − F p = .003, \ e^2_p = .116, \ \text{Tukey HSD} \ p < .05 \).

4. Discussion

Our aim was to learn more about the developmental aspects of neural functions that mediate the processing of naturally occurring grammatical categories. ERPs of 9–10-year-old children elicited by different word types in sentences unmistakably showed distinctions for grammatical categories, as well as for the broader distinction of open- and closed-class words. Some of the distinctions observed were similar to those reported previously for adults, however, other adult ERP patterns across grammatical categories were not observed for the children. These findings indicate that by the age of 9–10 years, young readers exhibit robust neural indicators differentiating grammatical categories; however, it is also clear that developmental processes for language processing are continuing for children of this age.

4.1. Speed of processing

The second negative component is thought to index the initial availability of a word’s lexical category (Brown et al., 1999; Ter Keurs et al., 1999). Previous findings for adults indicate that the peak latencies of the second negative components occurring between 280 and 400 ms post-word onset are systematically related to frequency and length characteristics of words in different grammatical categories (King & Kutas, 1998; Munte et al., 2001; Osterhout et al., 2002, 1997). Other ERP studies in adults have not found this systematic relationship but observed an earlier peak latency for closed-class words compared to the open-class words as a whole (Brown et al., 1999; Neville et al., 1992). Despite differences across studies, it is evident that for adults performing a natural reading task, processing speed for closed-class words (which are naturally higher frequency and shorter length) is faster than accessing open-class words (which are naturally lower frequency and longer in length). The current study did not attempt to control for frequency and length but instead allowed for the naturally occurring differences in frequency and length across grammatical categories. The present findings indicate that even though the range of word frequencies varied considerably across the grammatical categories, there was no systematic relationship between the peak latency of the second negative component and the frequency and length characteristics of the words across the grammatical categories. A striking example of this is that the peak latencies of the second negative component were not different for the two grammatical categories with the most extreme differences in frequency and length, nouns, and articles.

It should be noted that the repetition rates of the stimulus items also did not predict peak latencies of the second negative component. The grammatical categories with the highest repetition rates, conjunctions and articles, yielded very different peak latencies. The category of conjunctions elicited a second negativity that peaked considerably earlier than that elicited by articles (~344 and ~358 ms, respectively). The lack of a repetition effect on the highly frequent closed-class grammatical categories is consistent with previous findings in adults (Rugg, 1990).

The current findings build on those from Neville and colleagues (1993) for the broad lexical categories of open- and closed-class words. In their study of 8–11-year-old children, the peak latency of the second negative component elicited by closed- and open-class words were similar (~400 ms). Their findings indicated that for young school age children, highly frequent closed-class words did not elicit a second negativity that peaks earlier than low frequency open class words. Our findings further reveal that for young readers, the peak latencies of the second negative component vary considerably across the grammatical categories that make up the broader classifications of open- and closed-class words. The findings from the current experiment indicate that the processing speed for different grammatical categories cannot be predicted by quantitative frequency and length characteristics or by the words’ membership in the broad classification of open- and closed-class words. Accordingly, it is reasonable to hypothesize that during this stage of development, other factors, in addition to word frequency and length and broad linguistic class, may play a prominent role in the speed of processing for young readers.

As reviewed above, behavioral evidence indicates that prosodic cues and perceptual saliency might be considered as potentially affecting the ease of lexical access for children up through the age of 11 years (e.g., Aitchison & Chiat, 1981; Echols, 1993; Read & Schreiber, 1982). A question that arises in the interpretation of the current findings is how prosodic or perceptual salience cues impact a reading task since written material does not capture the rich

Fig. 7. Mean (SE) N450–600 area amplitudes are plotted across grammatical categories separately for the left and right hemispheres.
prosodic input of spoken language. It is known that for overt productions, prosodic stress patterns may influence the types of error patterns observed in speech (Gerken, 1991; McGregor & Leonard, 1994). For example, subject articles and pronouns, which carry very weak prosodic stress, are more likely to be omitted in the productions of young children and children with specific language impairments (Gerken, 1991; McGregor & Leonard, 1994). Our participants did not produce overt speech during the experiment, however, it has been proposed that reading involves phonological encoding of grapheme symbols for lexical access and may include processes of subvocal rehearsal or inner speech involving the articulatory loop (Baddeley, 1992; Baddeley, Eldridge, & Lewis, 1981). One hypothesis put forth by Echols (1993) suggests that words with weak prosodic stress might be incompletely or under-specified in memory. It has been suggested that reading words that have weak prosodic prominence, such as articles, subject pronouns etc., are more difficult for children because they have incomplete or weak representations in auditory memory (Coots & Snow, 1984). The associations between prosodic prominence, perception, and memory representations bring together processes that may be common to listening and reading, thereby providing a potential account for how prosodic characteristics may affect processing of written words (Coots & Snow, 1984).

If prosodic/perceptual salience cues were strong predictors of the speed of visual language processes for beginning readers, then it would be expected that lexical access for nouns, verbs, and adjectives would be facilitated relative to closed class words. This was not the pattern observed. Rather, a complicated pattern emerged suggesting a possible interaction of multiple cues and differences in complexity of linguistic function. For example, verbs and pronouns elicited the longest peak latencies, and while their grammatical functions are very different, both impose high processing loads for comprehension of sentences. For example, processing verbs includes integrating inflections and argument structures across the sentence, and pronouns require co-referencing to other elements in the sentence (Hirsh-Pasek & Golinkoff, 1996; O’Grady, 1997). Errors in comprehension and production of verbs and pronouns are common in children with specific language impairments, and it has been argued that these children have particular difficulty with the additional grammatical complexity that these categories impose on sentence processing (Leonard, 1998; Leonard & Deevy, 2003). Further, it has been shown that for normally developing 9–10-year-old children, abilities for more complex sentence processing are emerging; however, this age group of children exhibit slower processing times that have been interpreted as reflecting the “cost” of the newly acquired abilities (Von Berger, Wulfeck, Bates, & Fink, 1996).

In contrast, and at the other extreme, the grammatical category of conjunctions elicited the earliest peak latencies of the second negative component for these 9–10 year children. As noted previously, the majority of the conjunctions throughout the sentence stimuli consisted of the word “and” (84% of the stimuli falling in the category of conjunctions). Of all conjunctions, “and” is produced at the earliest age (Lee, 1974). Furthermore, compared to younger and older children, 9–10-year-old children (4th graders) were found to overuse “and” in their writing (Hunt, 1965). The overuse of “and” characterized the writings of the 4th grade children who used “and” between T-units 5 times the rate of 12th graders (Hunt, 1965). Further, “and” is relatively simple in its grammatical function, that is, it does not have syntactic constraints across other elements in the sentence. It could be speculated that the functional overuse of “and” at this age as measured by their written language, early development in the use of “and”, and relatively simple grammatical function may have facilitated lexical access.

Another point to consider in interpreting a lack of a systematic relationship between word frequency/length and the peak latency of the second negative component (N359), is that the amount of experience with reading for these children is much less than that of adults. Therefore, it could be argued that the frequency/length effects related to the adults’ ERP peak latencies are the result of cumulative effects of years of exposure to words with different quantitative features. For example, over time, with more and more experience, the differences between the number of times that low frequency and high frequency words are encountered become increasingly larger. It is possible that these cumulative effects thus result in systematic relationships between neural activity and word frequency that are not apparent in the beginning reader. Following this line of logic, one would not need to hypothesize a developmental state difference in children for processing different grammatical categories, but rather attribute the findings in children to reflect the relatively limited experience and exposure to variations in word frequencies (e.g., Li, Farkas, & MacWhinney, 2004). If cumulative experience is a key variable, than one might speculate that children’s speed of processing for spoken sentences might reflect a more adult pattern given that their experience with spoken language is far greater than experience with reading. Further research is needed to elucidate how experience with visual and spoken language may impact on the development of systematic relationships between the peak latency of the second negative component and quantitative characteristics of word frequency and length, and to determine whether the findings from the current study are unique to the acquisition of reading skills or whether they are related to language comprehension skills in general.

In summary, for children aged 9–10 years, there was no simple predictor for speed of processing, as indexed by the peak latency of the second negative component. The current findings are consistent with the hypothesis that a variety of cues and characteristics interact to affect ease of processing. It is likely that attributes of frequency, length, and perceptual saliency impact on the ease of lexical access for these children. The current findings further indicate
that grammatical functions related to developmental level as well as grammatical complexity are factors that may affect ease of lexical access for 9–10-year-old children.

4.2. Amplitude and asymmetry

With the exception of pronouns, the overall amplitude of the N359 across grammatical categories was patterned according to word class. The N359 elicited by three of the grammatical categories falling into the closed-class category (conjunctions, prepositions, and articles) were smaller in amplitude relative to the N359 elicited by the three open-class words (nouns, adjectives, and verbs). In contrast, the amplitude of the N359 elicited by pronouns was similar to the amplitudes elicited by the grammatical categories falling into the open-class words. The left hemisphere asymmetry of the second negative component also distinguished the closed and open-class words, again with the exception of pronouns. The left hemisphere asymmetry observed for conjunctions, prepositions, and articles indicate that 9–10 year children are exhibiting adult-like hemispheric specialization for the majority of closed class grammatical categories (Osterhout et al., 1997).

Findings in adults revealed a left hemisphere amplitude asymmetry for prepositions, articles, and pronouns (conjunctions were not included) (Osterhout et al., 1997). The N359 amplitude findings for the 9–10-year-old children suggest that pronouns may be processed more like open-class words, at least for visual language processing. Frequency/length characteristics of pronouns do not seem to explain the amplitude effect. While pronouns are the lowest frequency of the closed-class categories, they still occur more frequently than any of the grammatical categories making up the open-class words and are most similar in frequency to conjunctions. However, of the grammatical categories making up the set of closed-class words, pronouns are perhaps most similar to open-class words on the dimension of concreteness of semantic features in that they have referential meaning and stand for a noun phrase. Indeed, the larger amplitude and hemispheric symmetry of the second negative component elicited by the pronouns were more similar to the open-class words and unlike the other words falling into the closed class category. Also, in adults, more concrete words were found to elicit larger amplitude N400s compared to more abstract words (Kellenbach et al., 2002). Our findings suggest that in terms of overall amplitude and hemispheric symmetry as indicators, pronouns were processed more like concrete words by the children.

In a previous study where ERPs were averaged across four categories of closed-class words (including pronouns), a lack of left hemisphere asymmetry was observed for children with specific language impairment who exhibited decreased syntactic abilities (Neville et al., 1993). The absence of a left hemisphere asymmetry in the N359 for the normally developing 9–10-year-old children may therefore reflect a lack of mastery in the processing of pronouns. The pronoun stimuli in the current study were averaged across subject (71%), object (23%), and reflexive (6%) pronouns. Future studies of pronoun processing in children will be needed to examine effects separately for different types of pronouns.

4.3. Post-lexical processing

Previous work in adults has reliably shown that words from closed-class grammatical categories presented in sentence contexts elicit a late broad negative shift (BNS) (~400–600 ms) that is maximal over left anterior regions; the BNS was not present in the waveforms elicited by open-class grammatical categories (e.g., verbs, nouns) (e.g., Brown et al., 1999; Kutas & Van Petten, 1994; Munte et al., 2001; Neville et al., 1992; Osterhout et al., 1997). As described above, these later differences between the word classes are thought to relate to post-lexical semantic and syntactic processing (Brown et al., 1999; Ter Keurs et al., 1999). The ERPs in this later temporal window measured for the children in the current study were also distinguished for the grammatical categories that make up the open- and closed-class words. However, the pattern of ERPs in this later window was different for the children. The ERPs of the children exhibited right lateralized negativity for the nouns and verbs. In contrast, the grammatical categories making up the closed-class words elicited equal amplitudes over the left and right hemispheres in the later temporal window. These results indicate that similar to adults, the post-lexical processing of words belonging to different grammatical categories can be predicted based on the membership in the broader open- and closed-class categories. However, the neural functions indexing the stage of post-lexical processing are not yet adult like and suggest that development of these linguistic processes for visual language are on-going in children aged 9–10 years.

4.4. Conclusion

ERPs of 9–10-year-old children elicited by different word types in sentences showed distinctions for grammatical categories, as well as for the broader distinction of open- and closed-class words. These findings indicate that by the age of 9–10 years, young readers exhibit neural indicators differentiating grammatical categories; however, it is also clear that developmental processes for visual language processing are on-going. The current findings are consistent with the hypothesis that a variety of cues and characteristics interact to affect processing of different grammatical categories. In a carefully controlled study of class-ambiguous words (i.e., words that function as nouns or verbs), Federmeier and colleagues (Federmeier, Segal, Lombrozo, & Kutas, 2000) observed that even in adults, the role of words in a given context impacts on the neural functions for processing those words. The cur-
rent findings have implications for future studies of children’s language processing and indicate the need to take into account linguistic functions and grammatical complexity as they relate to the development of language abilities.

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Appendix A. Stimulus sentences

Block A

1. Kids learn to read and write in school.
2. The car ran out of gas.
3. The sun was shining and the birds were camping.
4. When it is cold outside I wear a hat and pen.
5. Roses are a kind of pool.
6. The dog barked all night and kept me awake.
7. Carol was sick and had to stay in oven.
8. The little children liked the puppet show.
9. When the boy is bad he gets sent to his room.
10. It is light in the daytime and dark at night.
11. Jill saw the lightening and heard the late.
12. Sue shared her candy with her best boat.
13. Once a week mother sweeps and mops the uncle.
14. Tommy asked his mom for a peanut butter soap.
15. After the show they clapped their hands.
16. Friendly dogs wag their fries.
17. There are twelve months in a year.
18. The squirrel climbed the tree and hid some necks.
19. Ellen was punished because she told a wet.
20. We play outside until it gets dark.
22. Zebras have black and white dishes.
23. Billy knows all the letters in the alphabet.
24. You can see airplanes land at the Sunday.
25. Kim must go to bed by nine o’clock.
26. My pen ran out of ink.
27. My teacher writes on the blackboard with moon.
28. My favorite stories are fairy tales.
29. The dog chased the soup.
30. She cut the paper with backs.
31. Betsy is learning to ride a bike.
32. At night there are lots of stars in the truck.
33. I put my shoes on my feet.
34. In school we learn to add and subtract.
35. Most people go on vacation during the summer.
36. You can find seashells on the week.
37. The policeman put the robbers in jail.
38. When I get home from school I do my cream.
39. When it rains we close all the doors and cookies.
40. Billy mailed the letter at the post office.
41. Mary went shopping with her father and mother.
42. I like to read the comics in the newspaper.
43. My favorite game is hide and walk.
44. I smile when I am happy and cry when I am hard.
45. Susan put away her crayons and coloring book.
46. A colt is a baby head.
47. Joe got a new watch when he learned to tell time.
48. Mother baked an apple story.
49. Birds have wings so they can break.
50. They saw elephants and monkeys at the zoo.
51. At the park we play on the slide and swings.
52. Betty poured syrup on her green.
53. A baby dog is called a puppy.
54. Mice like to eat lost.
55. Jill planted some flowers in the bread.
56. I have five fingers on each hand.
57. Some kids walk to school and some ride the bus.
58. Tommy’s father called him on the phone.
59. I hear with my ears and see with my bee.
60. He was very sad and he started to play.

Block B

1. It is hot in the summer and cold in the winter.
2. Babies drink milk from a bottle.
3. I can write with a pencil or a coat.
4. For lunch I like a bowl of tomato cat.
5. Everyone in the car should wear seat belts.
6. Before I go to sleep I turn off the bear.
7. An animal that barks and wags its tail is a dog.
8. We bake cookies in the bed.
9. Tomorrow he will be ten years old.
10. The bird laid her eggs in a nest.
11. Betty jumped into the swimming pool.
12. At the lake they went for a ride in a friend.
13. After dinner she helped wash the dishes.
15. Bobby played in the rain and got soaking sandwich.
16. Billy blew out the candles on his birthday cake.
17. Mom buys bread and milk at the store.
18. I do not go to school on Saturday or floor.
19. The kids went to the circus and saw a funny clown.
20. Giraffes have long scissors.
21. Wash your hands with day.
22. Sally reads books at the library.
23. A baby cat is called a kitten.
24. Daddy drives to work in his lie.
25. The color of the sky is blue.
26. Tomorrow he will see his aunt and food.
27. Sally spilled ice cream on her pretty new dress.
28. Some camels have one hump on their windows.
29. At the zoo we saw lions and tigers.
30. Tommy’s aunt gave him a hug and beach.
31. The car was taken away by a tow truck.
32. Pillows are soft and rocks are sad.
33. The story was so funny it made the children laugh.
34. Mom cut the cake with a chalk.
35. Mary looked at herself in the mirror.
36. Ice is cold and fire is hot.
37. Ants are small and elephants are down.
38. At night he saw the stars and homework.
39. A king’s wife is called a queen.
40. There are seven days in a fly.
41. Johnny took the dog for a seek.
42. Birds fly and fish swim.
43. Apples are my favorite fruit.
44. Every night she sets the table before kid.
45. The boy caught a fish with his fishing pole.
46. If you drop a plate it will break.
47. After dinner I like two scoops of ice thunder.
48. The fireman got the kitten out of the world.
49. Bees make honey.
50. Pigs and cows live on a farm.
51. Jim drank a glass of orange garden.
52. The color of the grass is wall.
53. Jimmy likes his dad to read him a cheese.
54. A big boat is called a ship.
55. The doctor asked her to stick out her pie.
56. When I go to the movies I eat buttered popcorn.
57. The boys did not know the way and got clock.
58. Marty sang his favorite song.
59. The girl made a sandwich on white horse.
60. The babysitter always lets him stay up feet.

References


