ERP correlates of lexical analysis: N280 reflects processing complexity rather than category or frequency effects

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In the context of language processing, the N280 is an anterior negative event-related potential profile associated with the lexical categorization of grammatical function words versus content words. Subsequent studies suggested that this effect was related to word statistics including length and frequency in the lexicon. The current research tests the hypothesis that the N280 effect is related to an index of grammatical complexity. We recorded event-related potentials during a sentence reading task. Comparing content versus function words revealed the classic N280. Within function words, we compared the relative pronouns 'qui' and 'que' (which are identical for length and frequency) that in French indicate a subsequent simple (subject–subject) and complex (subject–object) relative clause, respectively. A left anterior N280 effect was observed only for 'que', supporting our hypothesis that the N280 reflects grammatical complexity that can be confounded with lexical category and statistical properties. *NeuroReport* 16:1435–1438 © 2005 Lippincott Williams & Wilkins.

Key words: Content words; Event-related potential (ERP); Function words; Language; Lexical categorization; N280; Syntactic complexity

INTRODUCTION

Behavioral studies [1] have shown that open class words or content words (e.g. nouns, verbs, adjectives, adverbs, etc.) and closed class words or function words (e.g. prepositions, relative pronouns, determiners, etc.) implicate distinct neurobiological processes. This process of 'lexical categorization' was first associated with a negative shift observed for the reading of function versus content words [2] and classified as a variant of the contingent negative variation [3,4].

Subsequent studies often reported this left frontal negativity peaking around 280 ms as the N280, which distinguished between closed class versus open class words [5–7]. Others argued, however, that the N280 reflected word length and word frequency, which are confounded with lexical categories, as function words are in general shorter and more frequent than content words [8–10]. Interestingly, ter Keurs *et al.* [11] observed an N280 for closed and not open class words that was not present for patients with Broca's aphasia who can perceive but not grammatically integrate function words [12,13], again suggesting a link between the N280 and some aspect of grammatical processing.

The current study attempts to aid in clarifying the functional significance of the N280. Part of the problem is that lexical category, word length and word frequency are often confounded. Our hypothesis is that the N280 reflects an index of the grammatical complexity of the upcoming processing that is triggered by the lexical item. To test this hypothesis, we should compare event-related potentials (ERPs) for words that indicate different levels of grammatical complexity, but otherwise have the same length, frequency and lexical category. French provides such an opportunity, by comparing responses to the relative pronouns 'qui' and 'que' in the context as in:

(1) Le chien **qui** chasse le chat enterre la balle. (*The dog **that** chases the cat buries the ball.*)
(2) Le chien **que** le chat chasse enterre la balle. (*The dog **that** the cat chases buries the ball.*)

Sentence (1) is a 'subject–subject' relative sentence in which the principal noun phrase (the dog) is the subject of both the main and the relative phrases. In contrast, in sentence (2), the principal noun phrase is the subject of the main phrase, and the object of the relative phrase, so it plays a double thematic role. This 'subject–object' syntactic construction was demonstrated to be of greater processing complexity [14,15], likely owing in part to increased processing costs [16], and the recruitment of specialized processes. Indeed, ERP [17] and brain imaging [18] studies have indicated that processing of the syntactically complex portions of such sentences is associated with distinctive patterns of cortical activation.

The interesting cross-linguistic point here is that while in English the same word 'that' is used in both cases, in French, these two functional roles are expressed by two different function words 'qui' and 'que' that have the same length and same frequency, 7121 per million for 'qui' and 9208 per million for 'que' [19]. Thus, by comparing the possible N280 effects associated with these two relative pronouns, we can

attribute any difference to an effect of processing complexity, because lexical category, length and frequency are fixed.

MATERIALS AND METHODS

Study participants: Twenty native French-speaking participants (10 men, 10 women), aged 21–35 years (mean 25.6±3.01 years), all right-handed as assessed by the Edinburgh Handedness Inventory (mean 0.74±0.13) [20], and free of neurological impairment or language deficits, entered the study. Participants were advised of the physical details of the experiment and gave their informed consent. They were seated 50 cm in front of a 14″ video monitor, on which sentences were presented.

Sentence material: Three types of sentences were presented: subject–subject sentences (SS), subject–object (SO) and filler sentences. SS sentences had a relative phrase introduced by the pronoun 'qui', and the preceding noun served as the subject of both the principal and relative proposition as in example (1) above. SO sentences had a relative phrase that was introduced by the pronoun 'que', and the preceding noun was the subject of the principal proposition and the object of the relative proposition, as in example (2). SS and SO sentences were made up of nine words, and the filler sentences were made up of 5–11 words. These filler sentences had simple and conjoined phrases, and were used as distracters so that participants would not become habituated to relative phrase sentences. Each of the three sentence types consisted of 36 distinct examples.

Stimulus presentation and timing: Words were presented at the center of the screen for 400 ms followed by a 400 ms pause, yielding an 800-ms stimulus onset interval. Participants were asked to silently read the sentence in order to respond to true–false questions that were pseudorandomly posed after one third of the sentences. Participants responded with the index finger of the right hand by pressing one of two left and right buttons for true and false, respectively, counterbalanced over the 20 participants. Non-responses were considered false. Half of the questions were true and the others false. In the two thirds of trials in which no question was asked, participants simply pressed a third button. In the remaining trials, the questions concerned the assignment of thematic roles described by the sentences.

Electroencephalogram recording: Scalp voltages were collected with a 65-channel Geodesic Sensor Net referenced to Cz and amplified with an AC-coupled, 65-channel, high input impedance amplifier (200 MΩ, Net Amps, Electrical Geodesics Inc., Eugene, Oregon, USA). Amplified analog voltages (0.1–200 Hz bandpass) were sampled at 500 Hz. Individual electrodes were adjusted to an impedance of <50 kΩ [21]. Trials were rejected from analysis if they contained eye movements, as monitored by an electro-oculogram.

Electroencephalogram analysis: Electroencephalogram recordings were segmented for a time period from 100 ms before to 900 ms after the onset of each word present in experimental sentences. Segments were then filtered with a 30-Hz low-pass filter, re-referenced to the right mastoid, and a baseline correction was applied on the basis of the first 100 ms. Six spatial domains, each composed of five electrodes, were defined: anterior left, anterior right, central, posterior left, posterior right and central posterior. The anterior left domain included electrodes 9, 13, 15, 16 and 20 (10–20: FC1, F3, F7, FC5, FT7), anterior right domain electrodes 56, 57, 58, 61 and 62 (10–20: FC6, FT8, FC2, F8, F6), central domain electrodes 5, 18, 30, 43 and 55 (10–20: CPz, C1, CP1, CP2, C2), posterior left domain electrodes 22, 25, 27, 28 and 29 (10–20: CP3, CP5, P7, P5, P1), posterior right domain electrodes 42, 46, 47, 49 and 50 (10–20: P2, CP4, CP6, P6, P8) and central posterior domain electrodes 33, 37, 38, 40 and 41 (10–20: PO3, O1, POz, O2, PO4) [22]. To study the N280 effect, scalp voltage values were obtained in a time window defined from 250 to 400 ms after stimulus-onset.

Open versus closed class: Responses for the 360 content words (216 nouns and 144 verbs) and the 288 function words (72 relative pronouns and 216 determiners) were analyzed in a three-way repeated-measure ANOVA on spatial location (central, left posterior, right posterior, central posterior, left anterior and right anterior), condition (content, function) and electrodes (five per location). Mean voltage amplitude, expressed in microvolts, was taken as the dependent variable.

The content words had a mean length of 6.8 letters (±0.6) (4–11), while the function words had a mean length of 2.5 (±2.2) (2 to 3) [$F(1,26)=24.59$, mean squared error (MSE)=2.63, $p<0.05$]. Function words had a mean occurrence frequency of 14 530 (±7792) (7121–23 889), while content words had a mean occurrence frequency of 28.9 (±31.3) (0.81–104.52).

Complex versus simple relative pronouns: The second analysis compared the two relative pronouns 'qui' and 'que' that have the same length, lexical category and comparable occurrence frequencies, both being highly frequent function words. These data were analyzed in a three-way repeated-measure ANOVA on spatial location (central, left posterior, right posterior, central posterior, left anterior and right anterior), condition (qui, que) and electrodes (five per location). Mean voltage amplitude, expressed in microvolts, was taken as the dependent variable.

RESULTS

All participants performed the task correctly, with error levels below 15%, indicating that they were vigilant in trying to carefully read the sentences. A one-way ANOVA performed on the error rates including the factor sentence (3: filler, SS and SO) showed a main effect of this latter factor [$F(2,38)=28.03$, MSE=49.70, $p<0.05$]. Participants made significantly more errors following SO (20.8±10.29) sentences than SS sentences (8.33±8.54) ($p<0.05$), with no difference between filler (5±6.28) and SS sentences ($p>0.05$). This observation confirms that SO sentences are globally more difficult to parse than SS or other types of sentences.

Function versus content comparison: Figure 1a illustrates the time course of activity at representative electrodes from each of the left anterior (F7) and right anterior (F8) regions

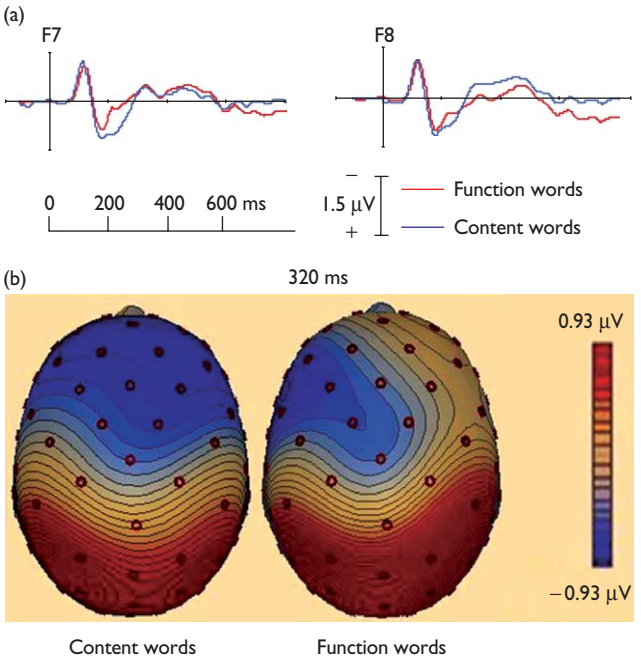

Fig. 1. (**a**) Grand averages for 20 participants in the function word versus content word conditions for representative electrodes from the left anterior (F7) and right anterior (F8) sites. Voltage scale from + 1.5 to − 1.5 μV. Time scale in milliseconds (**b**) Scalp topography for simple and complex conditions at 320 ms.

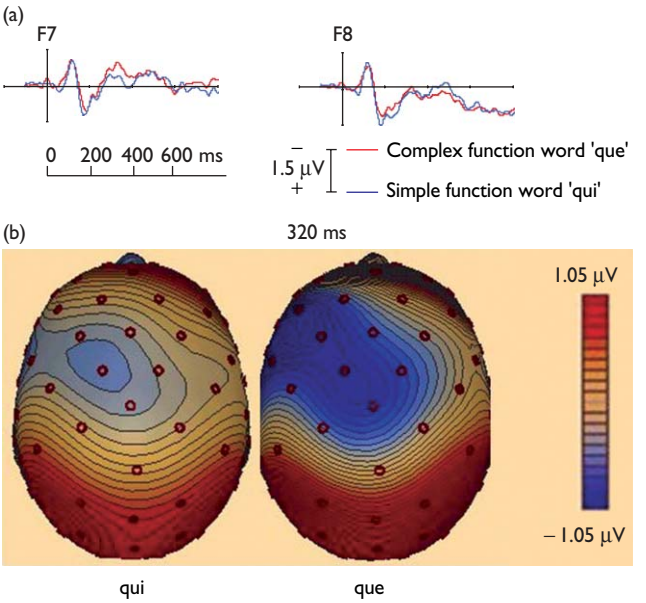

Fig. 2. (**a**) Grand averages for 20 participants in the complex versus simple pronoun conditions for representative electrodes from the left anterior (F7) and right anterior (F8) sites. Voltage scale from + 1.5 to − 1.5 μV. Time scale in milliseconds (**b**) Scalp topography for simple and complex conditions at 320 ms.

in response to function and content words. We see that in the 0–200 ms poststimulus period, the ERP profiles for the two conditions display a standard N1–P2 complex. Then, during the 250–400 ms window, we observe that for function words there appears to be a more negative response for the left anterior versus right anterior electrode, while for content words a bilateral negativity is found. This difference in the lateralization of negativity is reflected in Fig. 1b, which illustrates the spatial topography of the scalp voltages for the function and content conditions at 320 ms following stimulus.

These observations were confirmed in the repeated-measures ANOVA. Main effects were significant for location [$F(5,95)=20.89$, $MSE=2.96$, $p<0.05$] and electrodes [$F(4,76)=21.04$, $MSE=0.15$, $p<0.05$], but not for the lexical category [$F(1,19)=0.0003$, $MSE=2.74$, $p>0.8$]. The significant location × lexical category interaction [$F(5,95)=2.88$, $MSE=0.35$, $p<0.05$] confirms that the effect of the lexical category varies with respect to spatial domain.

Planned comparisons revealed that for function words, the anterior negativity was significantly more pronounced over the left anterior than over the right anterior zones ($p<0.05$). In contrast, content words displayed no significant right anterior versus left anterior lateralization difference ($p=0.26$). Thus, the distribution of the N280 effect varies according to the lexical category. Open class words induce bilateral N280 on anterior sites while closed class words result in N280 predominant on left anterior sites.

Simple versus complex function word comparison: Figure 2a illustrates the time course of activity at representative electrodes from each of the left anterior (F7) and right anterior (F8) regions in response to pronouns 'qui' and 'que'. Again, we see that in the 0–200 ms poststimulus period, the ERP profiles for the two conditions display a standard N1–P2 complex. Then, during the 250–400 ms window, we observe a more negative response for the left anterior versus right anterior electrodes for 'que', while this is not the case for 'qui'. Figure 2b illustrates the spatial topography of the scalp voltages 'qui' and 'que' at 320 ms following stimulus. Both display a negativity in the left anterior location, while this effect is much more marked for 'que' than for 'qui'.

These observations were confirmed in the repeated-measures ANOVA. Main effects were significant for complexity [$F(1,19)=5.261$, $MSE=9.09$, $p<0.05$] and location [$F(5,95)=21.69$, $MSE=3.36$, $p<0.05$] and electrodes [$F(4,76)=8.526$, $MSE=0.27$, $p<0.05$]. The location × complexity interaction was not significant [$F(5,95)=2.18$, $MSE=0.27$, $p=0.063$], indicating that this topographic distribution of scalp voltage is independent of the complexity – that is, the global N280 profile is present for 'qui' and 'que'.

Planned comparisons revealed that for the complex function word 'que', the anterior negativity was significantly more prominent for the left anterior than for the right anterior zones ($p<0.05$). In contrast, the 'simple' function word 'qui' displayed no significant right anterior versus left anterior lateralization ($p=0.28$). Likewise, the anterior negativity was significantly greater for the left anterior zones for the complex function word 'que' than for the simple function word 'qui' ($p<0.05$). These observations demonstrate that the N280 effect can be modulated by grammatical complexity associated with the processing of statistically equivalent function words.

DISCUSSION

The objective of the current study was to determine, within the lexical category of function words, whether an N280 effect could be modulated on the basis of grammatical processing complexity, controlling for word length and frequency. We first compared ERPs obtained for function and content words. As in related studies [5–7], we observed a left anterior N280 effect associated with function words versus content words. In our case, however, this effect cannot be attributed to any effect of vocabulary class alone as our function and content words also differed in terms of length and frequency. Indeed, other studies have clearly demonstrated that the latency of a left anterior negative component varied according to such parameters as length and frequency in sentential context [8–10]. To test the possible modulation of the N280 effect by syntactic complexity, we then compared N280 effects triggered by the two function words 'qui' and 'que', which differ only according to the complexity of the syntactic information they carry, while they have the same length and very comparable frequencies. Results from this analysis showed that these function words were associated with distinct ERP profiles in the N280 domain. While the nonsignificant complexity × location interaction indicated a similar N280 profile for both, the more complex 'que' displayed a significantly greater N280 effect with respect to the simple function word 'qui'.

CONCLUSION

The current results are consistent with the hypothesis that the N280 reflects the syntactic complexity indicated by a lexical element, independent of other confounding linguistic characteristics such as size, frequency or lexical category.

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