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Semantic memory and verbal working memory correlates of N400 to subordinate homographs

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Abstract

N400 is an event-related brain potential that indexes operations in semantic memory conceptual space, whether elicited by language or some other representation (e.g., drawings). Language models typically propose three stages: lexical access or orthographic- and phonological-level analysis; lexical selection or word-level meaning and associate activation; and lexical integration, sentence- and discourse-level operations. The exact stage that N400 reflects is unknown, although opinion favors lexical integration over lexical selection. Surprisingly, little research has assessed relationships between measures of semantic memory fund of information or verbal working memory capacity and N400. Subjects performed a homograph disambiguation comprehension task with minimal working memory load. Short sentences read: The *noun* was *adjective/verb*. The nouns were either homographs or unambiguous. The adjective/verb was disambiguating for the homograph, and congruent or incongruent for the unambiguous noun. The primary noun of interest was the subordinate homograph. Comprehension of the subordinate meaning should correlate with semantic memory stores, reflecting greater knowledge. If N400 primarily reflects lexical access operations, it should also correlate with measures of semantic knowledge. If N400 reflects lexical integration, it should correlate with measures of working memory capacity. Comprehension errors were associated with semantic memory stores, but not working memory capacity. N400 was related to working memory capacity, but not semantic knowledge, suggesting that N400 primarily reflects late-stage working memory operations. N400 to subordinate disambiguating words was larger with greater working memory capacity, and thus may index the absolute capacity of working memory rather than difficulty in contextual integration.

1. Introduction

The N400 event-related brain potential (ERP) is sensitive to linguistic processes (e.g., Kutas & Hillyard, 1980). Although first described to words incongruent with preceding context (e.g., He wanted to eat one more slice of *sleeve*), N400 is elicited by congruent words of relatively low cloze probability (e.g., *cake* rather than *pizza* in the sentence above), and by farther associates of index words (e.g., doctor–needle versus doctor–nurse). N400 amplitude serves as an index of the relative priming of terminal words, whether in sentences or word-pairs, largest for unrelated or incongruent words, and progressively smaller with increased association Precisely what language process is reflected in N400 remains undetermined.

Language models typically posit three processing levels. The first level, lexical access, reflects feature-based lexical entry based on written (orthographic) or spoken (phonologic) cues. The second stage, lexical selection, reflects the spread of activation of word-level meaning and associates in semantic memory stores. Semantic priming arises at this stage. The third stage,

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lexical integration, reflects the sentence- or discourse-level merging of word-level information with previously extracted and maintained context.

There is debate whether N400 reflects lexical selection (word-level) or lexical integration (discourse-level). Due to the inverse relationship between the degree of semantic priming and the ease of lexical integration, it remains difficult to determine what stage N400 reflects. Current opinion favors lexical integration. In a seminal study, Holcomb (1993) demonstrated that greater relative reaction time semantic priming to degraded stimuli did not show concomitantly greater N400 amplitude. Holcomb concluded that the similar N400 to degraded and non-degraded words reflected contextual integration processes, the ease of which was identical between normal and degraded stimuli after lexical selection.

Further evidence to support the notion of N400 as reflecting later-stage contextual integration would be demonstrated if N400 amplitude was associated with measures of verbal-working memory (or fluid memory), presumably subserved by similar frontal lobe mechanisms as contextual integration, but not with measures of semantic memory (or crystallized memory), putatively subserved by temporal–parietal circuits. This question has been largely unexamined in the literature. Gunter, Jackson, and Mulder (1995) reported larger N400s to incongruent sentence endings in a group of high working memory capacity subjects versus those with low working memory capacity. This is somewhat in that subjects with greater working memory capacity might be expected to show greater ease of contextual integration, and hence less N400.

In a separate line of research, we have examined comprehension of and N400 to subordinate homographs to explicate thought disorder in psychosis (e.g., Salisbury, Shenton, Nestor, & McCarley, 2002). Homographs are words that are spelled the same but have different meanings (e.g., an oak panel, a voting panel). This homograph disambiguation task has a low working memory load, consisting of four word long sentences reading: The *noun* was *adjective/verb* Comprehension of subordinate homographs, by definition infrequently used meanings, should index semantic knowledge or fund of information. If the N400 reflects lexical selection, then it should show similar relationships with semantic memory. If N400 reflects ease of contextual integration, then N400 should be smaller in those subjects with greater working memory capacity and flexibility, reflecting their greater facility with maintaining and accessing multiple memory traces simultaneously and integrating subordinate content. If, however, N400 directly indexes the capacity and flexibility of working memory mechanisms, suggested by the finding of Gunter et al. (1995), then N400 amplitude should be largest in those subjects with greatest working memory performance and independent from subordinate comprehension errors and semantic stores.

2. Methods

Thirty normal subjects (10 F, mean age 24.4 ± 5.4 SD, all right-handed native English speakers) were tested. Sentences were presented one word at a time on a CRT 1 m from the subject. All sentences had the form: The *noun* was *adjective/verb* Words were presented for 1 s with a 250 ms inter-stimulus interval. After each sentence, the probe ‘OK?’ appeared on the screen for 2 s. Subjects were required to indicate whether the sentence was sensible to them or not with a button press (right thumb for sensible, left thumb for nonsensical). Four types of nouns were presented, 25 of each type: Unambiguous (e.g., The door was shut, The butter was melting, The lion was roaring); Dominant homograph (e.g., The panel was oak, The plane was flying, The horn was blaring); Subordinate homograph (e.g., The panel was voting, The plane was sharp, The horn was pointy); and Nonsensical (incongruent endings for unambiguous nouns, e.g., The radio was fluffy, The salad was printed, The hammer was cloudy). For description of the stimuli used and normative data bases, see Salisbury et al. (2002). WAIS-III (Wechsler, 1997) Information and Vocabulary scores were used for measures of semantic memory, and

WAIS-III symbol-digit coding and the Trails B test were used as measures of working memory. Procedures were approved by the local IRB and all subjects gave informed consent.

Electroencephalographic activity (EEG) was recorded from the scalp through 28 tin electrodes in pre-configured caps (ElectroCap International). Linked-earlobes were the reference, the forehead was the ground. Two electrodes located medially to the right eye, one above and one below, were used to monitor vertical eye movements and blinks. Electrodes placed at the outer canthi of the eyes were used to monitor horizontal eye movements. All electrode impedances were below 3 kΩ, and the ears were matched within 1 kΩ. The EEG amplifier bandpass was 0.15 (6 dB/octave rolloff) −40 Hz (36 dB/octave rolloff). Single trial epochs were digitized at 3.9 ms/sample (256 Hz). Each epoch was of 1100 ms duration, including a 100 ms pre-stimulus baseline. Averaging and artifact rejection were done off-line. ERP responses were digitally low-pass filtered at 8.5 Hz with a 24 dB/octave rolloff to remove ambient electrical noise, muscle artifact, and alpha contamination. Epochs from each electrode site were baseline corrected by subtraction of the average pre-stimulus voltage, and corrected for eye movement artifact using regression-based weighting co-efficients. Trials were again baseline corrected after eye-correction. Subsequently, epochs which contained voltage exceeding ±75 μV at F7, F8, Fp1, or Fp2 were rejected. Averages were constructed for the last word of the four sentence types for correctly comprehended sentences. N400 was measured as the mean voltage over a 50 ms window centered on the grand average peak for each sentence type.

3. Results

Subjects made significantly more errors in comprehending subordinate homograph sentences than to the other sentence types (F (3,87) = 47.9, $p < .001$, $\varepsilon = 0.47$, Fig. 1A). N400 amplitude was larger as the sentence ending was less associated with the noun's meaning (F (3,87) = 6.8, $p = .001$, $\varepsilon = 0.86$, Fig. 1B). The percentage of subordinate homograph errors was significantly associated with scaled WAIS-III Information ($r = −48$, $p = 014$) and Vocabulary ($r = −.64$, $p = .001$, Fig. 1C). The error rate was not associated with measures of working memory (Trails B: $r = −.05$, $p > .8$). WAIS-III Digit-Symbol: ($r = .13$, $p > .5$). By contrast, N400 amplitude to the subordinate homograph sentences was significantly associated with Trails B ($r = −.42$, $p = .048$), and weakly with WAIS-III Digit-symbol performance ($r = −.24$, $p < .26$, Fig. 1D), but not with measures of semantic memory (WAIS-III Information: $r = −.07$, $p > .7$); WAIS-III Vocabulary: ($r = −.04$, $p > .8$).

4. Discussion

Errors on this simple homograph disambiguation task in comprehending the weaker, subordinate meanings of ambiguous nouns were associated with measures of semantic memory skills, but not with measures of working memory. The disambiguation task had a relatively low working memory load and would not exceed the capacity of working memory. There were only four words, and two of those contained all of the semantic information (the noun and the sentence ending word). The other two words simply gave sentential, syntactic constraints, with no semantic information. Hence, it seems reasonable that facility with subordinate homograph meanings be related to greater knowledge or expertise in semantic memory, but relatively insensitive to the amount of information that can be simultaneously activated or manipulated in verbal working memory.

There were two experimental findings for N400. The amplitude of N400 was modulated by sentence type. Of primary interest for determining whether N400 reflects lexical integration or lexical selection is the difference between the N400 to the unambiguous congruent ending and the dominant homograph ending. Since both endings comprise strong associates, the ambiguous nature of the homograph, which is reflected in the structure of semantic memory,

may have an effect on the size of the N400. However, one cannot rule out differences in associate strength in this data set, with the disambiguating dominant words having slightly weaker associate strength than the unambiguous associates. Further study with precisely matched endings is currently underway to examine this effect.

The second effect of primary relevance to deciding what stage of language processing N400 primarily reflects is the finding that the amplitude of N400 to subordinate homograph endings that the subject correctly comprehended was unrelated to measures of semantic memory performance, but was associated with measures of verbal working memory. These results support the notion of N400 as reflecting post-lexical access processes related to frontal lobe verbal working memory mechanisms. However, the size of the N400 was greatest in those subjects that had the largest capacity and greatest working memory flexibility, similar to the finding of Gunter et al. (1995). This effect appears to run counter to N400 reflecting the ease of integration, as one might expect those subjects with greater working memory skill and flexibility to integrate subordinate material more easily. Hence, in this case of subordinate associates N400 appears to be an index of the absolute capacity and flexibility of verbal working memory mechanisms.

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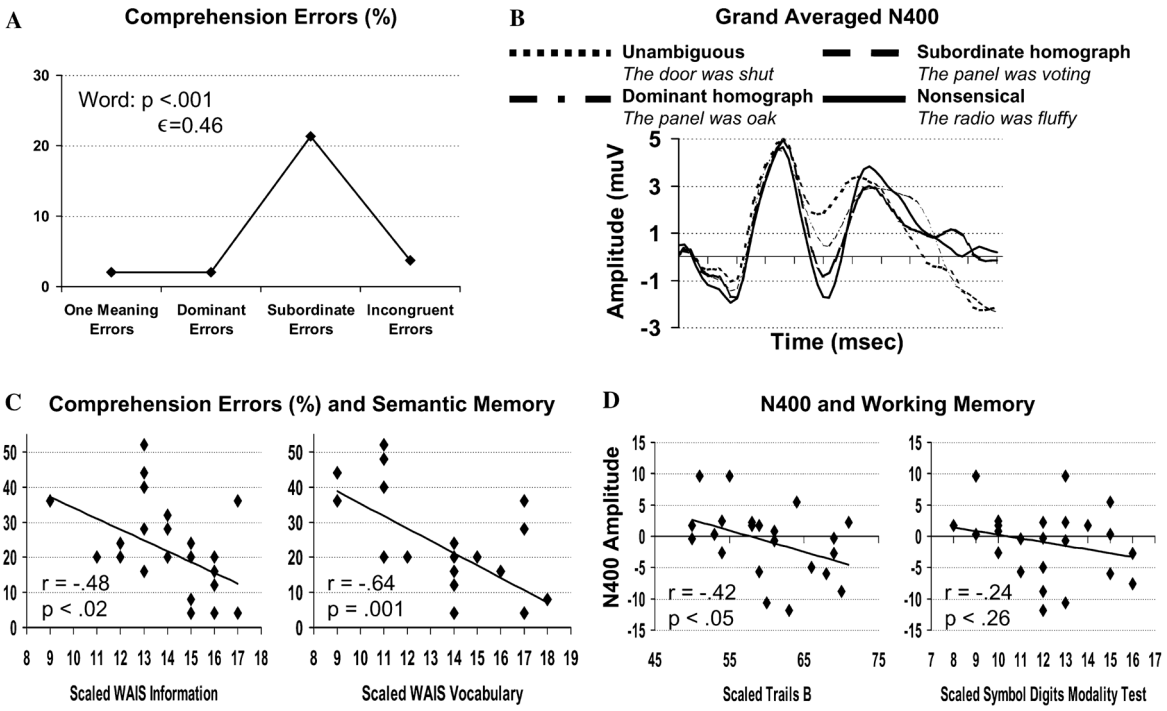

Fig. 1.

(A) Percentages of sentences misjudged by participants. (B) The group mean N400 ERPs to the last word of the different sentence types. Note that N400 becomes larger as associative strength decreases. (C) Relationship between the error rate on subordinate homograph sentences and measures of semantic memory. (D) Relationship between N400 amplitude on subordinate homograph sentences and measures of working memory.