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Neuroscience Research 41 (2001) 293–298

Neuroscience Research

www.elsevier.com/locate/neures

Rapid Communication

Electrophysiological estimates of semantic and syntactic information access during tacit picture naming and listening to words

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Received 10 April 2001; accepted 3 August 2001

Abstract

We investigated the relative time courses of the accessibility of semantic and syntactic information in speaking and comprehension via event-related brain potentials (ERPs). Native German speakers either viewed a series of pictures (tacit picture naming experiment) or heard a series of nouns (listening experiment) and made dual choice go/nogo decisions based on each item's semantic and syntactic features. N200 peak latency results indicate that access to meaning has temporal precedence over access to syntactic information in both speaking (~ 80 ms) and comprehension (~ 70 ms), and are discussed in the context of current psycholinguistic theories.

Keywords: ERP; N200; Language production; Language comprehension; Syntactic encoding; Semantic encoding

Psycholinguists are interested in determining the nature and the time course of information processing during language comprehension and production. Within models of speech comprehension, going from the segregation of a speech sound to its meaning involves phonological encoding followed by syntactic and semantic integration (Cutler and Clifton, 1999). Electrophysiological data support such models with regard to the relative time course of access to phonological and semantic information (Bentin et al., 1999; Rodriguez-Fornells et al., 2001). Within models of speech production, it is generally assumed that going from an idea to an utterance involves activation of conceptual, semantic, syntactic, and phonological knowledge (Levelt et al., 1999; Indefrey and Levelt, 2000). This proposal has received support from several studies using event-related brain potentials (ERPs) to track the time course of phonological versus semantic encoding (Van Turennout et al., 1997; Schmitt et al., 2000; Rodriguez-Fornells et al., 2001), conceptual versus syntactic encoding (Schmitt et al., 2001), and syntactic versus phonological encoding (Van Turennout et al., 1998).

Schmitt et al. (2001), for example, found earlier access to conceptual (estimating an object's weight) than syntactic information (syntactic gender decision) during tacit naming. However, to date, ERPs have not been used to delineate the time courses of access to semantic (categorization) versus syntactic information during either noun generation or comprehension. Note that conceptual and semantic information differ in the sense that only the latter is linguistic (Bierwisch and Schreuder, 1992). We, therefore, undertook two ERP-experiments, one employing tacit picture naming and another employing a listening task, to fill in these gaps

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0168-0102/01/$ - see front matter
PII: S0168-0102(01)00286-3

in the time course of language production and comprehension, respectively.

Whenever an individual is asked to respond to one class of stimuli (go trials) and to withhold responses to another (nogo trials), the ERP on nogo (relative to go) trials is characterized by a large negativity (1–4 μV) between 100 and 300 ms after stimulus onset (N200), especially over fronto-central sites (Simson et al., 1977; Sasaki et al., 1993; Thorpe et al., 1996). N200 amplitude is assumed to be a function of neuronal activity required for 'response inhibition' (Gemba and Sasaki, 1989; Jodo and Kayama, 1992; Sasaki and Gemba, 1993). Response inhibition can be viewed as part of the executive control, which involves working memory (eventually verbal working memory) processes mediated by prefrontal cortex (Funahashi, 2001). The presence of an N200 under these conditions implies that the information used to determine whether or not a response is to be given must have been analyzed, i.e. was available. The nature of the information on which a go/nogo decision is based thus can be varied, and the peak latency of the N200 effect (difference between go and nogo ERP) used as an upper estimate on the time by which the specific information must have been encoded.

Here the go/nogo decision was based on semantic or syntactic information. The semantic decision was whether the experimental item represented an animal or an object. The syntactic decision was whether the item's name had feminine or masculine syntactic gender (Van Berkum, 1997). The experiment was carried out in German as this language has a rich syntactic gender system. As in a typical dual choice go/nogo paradigm, in one condition (go/nogo = semantics) participants were asked to respond (go trials) or to refrain from responding (nogo trials) depending on the semantic category of the stimulus (e.g. go = animal, nogo = object). In this condition the response-hand assignment was defined by the syntactic properties of the stimulus. In the other condition (go/nogo = syntax) the response contingencies were reversed, i.e. response preparation was based on semantics and the go/nogo decision was based on syntactic information (see Fig. 1).

Neurologically healthy, native German speakers gave written informed consent and were paid for their participation. Eighteen (mean age 30, five women) took part in the tacit picture naming study and sixteen (mean age 23 years, eight women) in the listening study. Data from two additional subjects were discarded due to excessive eye-blinking (1) and exceedingly high error rates (1).

A set of 100 simple black-on-white line drawings consisting of two semantic categories (50 animals and 50 objects), each with half the names of feminine syntactic gender and half masculine, was used in the tacit naming experiment (see Appendix A). Twenty other pictures were used during practice trials. Pictures subtended about 8° of visual angle and 8° in width. The stimuli in the listening experiment were animal and object names (see Appendix A), spoken by a female speaker, recorded and digitized at 22.05 kHz. After A/D conversion each word was edited and silent periods at the onset of the stimuli were eliminated. Stimuli were presented via loudspeakers at a comfortable intensity. The four sets of items were matched in frequency of daily usage (CELEX database, see Baayen et al., 1993).

Both the stimuli and the procedures in the two experiments were identical with the exception of stimulus modality (pictures vs. spoken words). The experimental design was exactly as described in Schmitt et al. (2000).

Push-button response latencies were measured starting from item onset with the timeout point set at 1500 ms. Timeouts and errors (incorrect responses), were excluded from further analyses (about 4% in tacit naming, 8% in listening, no difference between conditions). Reaction times were averaged across left and right hand responses for go = semantics and for go = syntax conditions, separately for each experiment. Mean reaction times and results of the paired sample t-test comparisons are displayed in Table 1.

ERPs were recorded from the scalp using tin electrodes mounted in an electrocap (see Schmitt et al., 2000, Fig. 2, for a display of the used electrode montages). Bio-signals were recorded online and processed off-line according to standard methods (see Schmitt et al., 2000). A bandpass filter (zero-phase shift FIR; 1–5 Hz) was applied to the average N200 nogo minus go ERPs so as to remove slow drifts observed following the imperative stimuli in some participants.

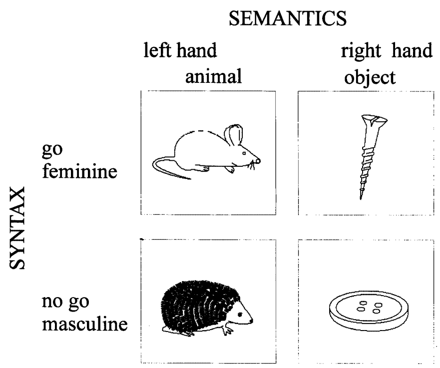

Fig. 1. This illustration of the experimental design shows an example from the go = syntax condition (tacit naming experiment). The response hand is contingent on semantic information. The go/nogo response is contingent on syntactic information. In the go = semantics condition, the pictures were the same but the response contingencies were reversed: in that case, the response hand would be contingent on syntactic information, and the go/nogo response would be contingent on semantic information. In the listening experiment, all else being equal, instead of the pictures we presented the picture names acoustically.

Table 1
Mean go reaction times, N200 peak and onset latencies, and paired sample t-test results for the semantic versus syntactic comparisons, separately for each experiment

	Tacit naming mean [ms (S.D.)]	Listening mean [ms (S.D.)]
Go reaction times		
Semantics	1020 (137)	1135 (161)
Syntax	1105 (161)	1141 (162)
Difference	85	6
	($t_{17} = 5.46$, $P < 0.01$)	(not significant)
N200 peak latencies		
Semantics	384 (140)	451 (68)
Syntax	464 (117)	520 (102)
Difference	80	69
	($t_{17} = 2.3$, $P = 0.03$)	($t_{15} = 2.4$, $P = 0.03$)
N200 onset latencies		
Semantics	255 (46)	413 (74)
Syntax	350 (40)	503 (74)
Difference	95	90
	($t_{17} = 9.7$, $P < 0.01$)	($t_{15} = 3.7$, $P < 0.01$).

Averages were obtained for epochs of 1000 ms starting 100 ms prior to stimulus onset, and measurements were taken relative to this pre-stimulus baseline (−100–0 ms). ERPs were averaged separately for each modality (pictures, words) and condition (go = semantics, nogo = semantics, go = syntax, nogo = syntax) for correct and artifact free trials only. Each average contained 200 trials minus rejected trials. In the tacit naming experiment there were 11% rejections on average (no difference between go or nogo conditions); in the listening experiment the number of rejected trials was 25.5% (no differences between conditions). The grand average ERPs elicited in the tacit picture naming experiment are illustrated in Fig. 2, and those elicited in the listening experiment are shown in Fig. 3.

Both figures show data collected at midline electrode sites, separately for the go/nogo = semantics (left column) and for go/nogo = syntax (middle column) conditions. The rightmost column shows (nogo minus go) difference waves for semantics and syntax. The observed negativity in the difference waves is the N200 effect. The N200 effect peaked earlier in the go/nogo = semantics condition than in the go/nogo = syntax condition in both tasks. Also shown is the horizontal (HEOG) and vertical (VEOG) electro-oculogram indicating no contamination for the difference waves.

For the N200 peak latency analysis, ERP difference waves (nogo minus go) were quantified by mean amplitude measures relative to the pre-stimulus baseline separately for each participant and condition. Each individual's difference wave at the most frontal midline site was visually inspected, and the latency of the first most negative peak between 300–700 ms after item onset was measured. These peak latencies for each participant and each condition were then submitted to paired sample t-tests (semantics vs. syntax), separately for each experiment. The most frontal midline electrode (Fpz, midline fronto-parietal in tacit picture naming experiment; Fz, midline frontal in listening experiment) was chosen because the N200 effect is known to be largest frontally (e.g. Thorpe et al., 1996; Schmitt et al., 2000). The mean values and the results of the statistical comparisons are displayed in Table 1.

Onset latencies of the N200 effects (nogo minus go) were assessed with a 10% fractional area latency measure. Mean onset latency values and the results of the statistical comparisons are displayed in Table 1.

Bivariate Pearson correlations were carried out on go-reaction times and N200 peak latencies, and on go reaction times and N200 onset latencies, separately for each condition (semantics, syntax) and experiment (tacit naming, listening). Probability coefficients were Bonferroni corrected for number ($n = 8$) of correlations calculated. No significant positive correlations were found (as also reported by Thorpe et al., 1996). This lack of correlation between reaction times and N200 onsets or peaks suggests that N200 and reaction times do reflect different aspects of the task processing. At the moment, however, we cannot be more specific about what this difference might be (see VanRullen and Thorpe, 2001, for a related discussion).

In this study we used the high temporal resolution of electrophysiological measures to estimate the relative time courses of semantic and syntactic encoding during noun comprehension and production. The peak latency of the N200 effect (nogo minus go difference) provides an upper limit on the time by which information about whether an actual response needs to be made or withheld must have become available. Here, it clearly shows that semantic information became available prior to syntactic information in both tasks. The observed peak latency difference was 80 ms during tacit picture naming (similar to results of Schmitt et al., 2001, using weight estimation instead of categorization), and 69 ms when listening to nouns. Consistent with this pattern, the observed onset latency difference was 95 ms during tacit picture naming, and 90 ms in the listening task. While these dual choice go/nogo N200 effects are late (384–520 ms post stimulus onset) relative to those typically seen in simple go/nogo paradigms, they are consistent with the longer reaction times for simple decisions based on syntactic and semantic than on visual processes (see Schmitt et al., 2000, for details).

These ERP data provide the first estimate of the temporal aspects of semantic and syntactic information access during single noun processing. Granted that tacit picture naming indexes information access during intrinsic picture naming processing, our data support speech production models wherein semantic informa-

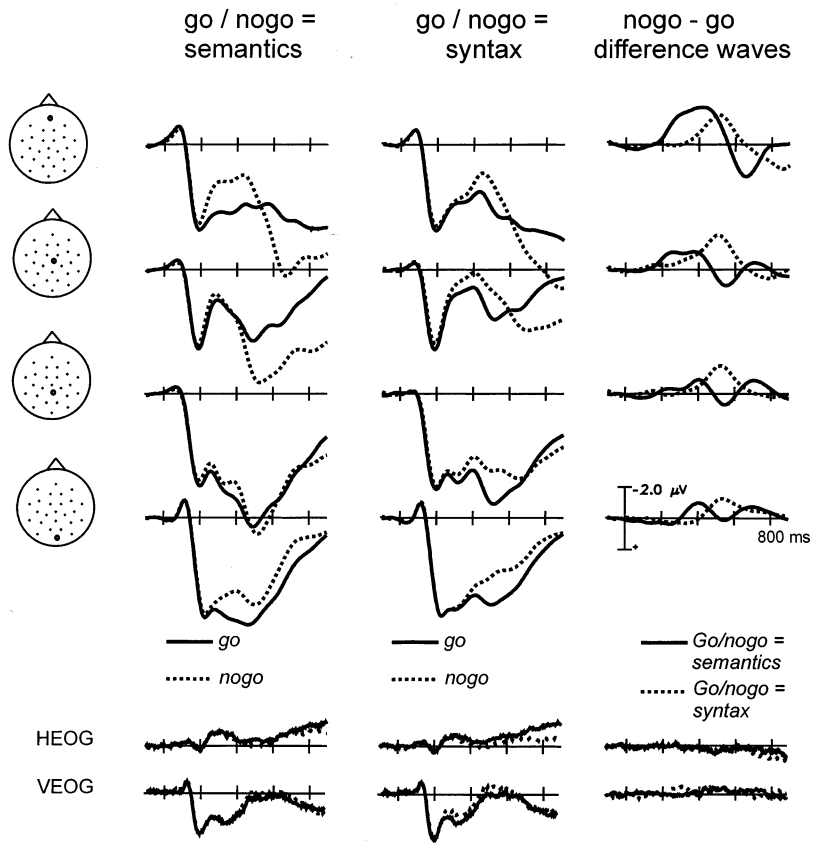

Fig. 2. Grand average event-related potentials (ERPs) from the tacit naming experiment on go and nogo trials in the go/nogo = semantics condition (left column), and the go/nogo = syntax condition (middle column). The ERPs are time-locked to picture onset. Both conditions are associated with a frontal negativity (N200) that is more negative for nogo than for go trials. In the right column, the 'nogo minus go' difference waves for the two conditions are shown superimposed. Displayed are data from 18 participants (200 trials per condition per participant, minus rejected trials) over four midline electrodes (from the front to the back of the head, see head icon for electrode positions). In this and the subsequent figure at the bottom, horizontal (HEOG) and vertical (VEOG) eye-movement signals are displayed per condition, and negative voltage is plotted up.

tion is available earlier than syntactic encoding; these include serial processing models (Levelt et al., 1991, 1999) as well as various models of cascaded processing (Dell and O'Seaghdha, 1991, 1992; Peterson and Savoy, 1998). The similarity in the time course of information activation here and in Schmitt et al. (2001) suggests that there may be no difference in the temporal availability of non-linguistic, conceptual information and linguistic, semantic information—an inference that awaits a direct comparison (in preparation). The present data do not support any models of language production wherein semantic and syntactic information are available at the same time.

Our data also do not support theories of language comprehension (see Cutler and Clifton, 1999) that assume parallel information access with syntactic and semantic integration occurring at about the same time as the N200 data suggest differences in availability over time as single nouns are comprehended. Note that we cannot say whether or not the two processes start in parallel. However, because we focus on lexical access times, we are more interested in information 'availability' than in 'general starting points' of information processing, and our data are clear in showing serial/cascading availability and not parallel availability.

Acknowledgements

The research reported in this paper was supported by a postdoctoral fellowship from the San Diego McDonnell-Pew Cognitive Neuroscience Institute and a grant of the German Academic Exchange Service (DAAD) to BMS, DFG grant MU1311/7-1 to TFM, a grant of the Spanish government to ARF, and grants HD22614 and AG08313 to M. Kutas. We thank Marjolein Meeuwissen and Joel Reithler for collecting the data for the second experiment.

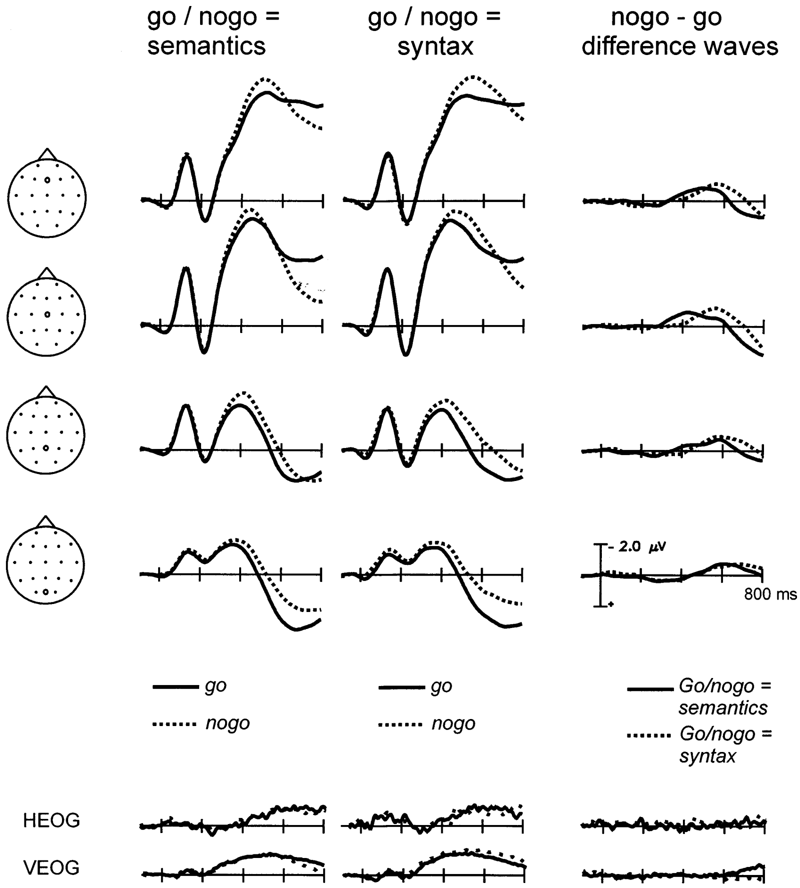

Fig. 3. Grand average event-related potentials (ERPs) from the listening experiment on go and nogo trials in the go/nogo = semantics condition (left column), and the go/nogo = syntax condition (middle column). The ERPs were time-locked to word onset. Both conditions are associated with a frontal negativity (N200) that is more negative for nogo than for go trials. In the right column, the 'nogo minus go' difference waves for the two conditions are shown superimposed. Displayed are data from 16 participants (200 trials per condition per subject, minus rejected trials) over four midline electrodes (from the front to the back of the head, see head icon for electrode positions).

Appendix A. List of the names of the pictures and acoustically presented nouns used in the experiments

Feminine syntactic gender		Masculine syntactic gender	
Animals	Objects	Animals	Objects
Ameise (ant)	Ampel (traffic light)	Adler (eagle)	Anker (anchor)
Antilope (antelope)	Banane (banana)	Affe (monkey)	Besen (broom)
Biene (bee)	Birne (pear)	Bär (bear)	Brunnen (well)
Ente (duck)	Blume (flower)	Elch (moose)	Bügel (hanger)
Eule (owl)	Brezel (pretzel)	Elefant (elephant)	Bus (bus)
Fledermaus (bat)	Brille (glasses)	Esel (donkey)	Drachen (kite)
Fliege (fly)	Dose (tin)	Fisch (fish)	Gürtel (belt)
Giraffe (giraffe)	Feder (feather)	Flamingo (flamingo)	Hammer (hamer)
Hyäne (hyena)	Gitarre (guitar)	Frosch (frog)	Hut (hat)
Katze (cat)	Hose (trousers)	Gorilla (gorilla)	Kaktus (cactus)
Kaulquappe (tad-pole)	Kanone (canon)	Hahn (cock)	Kamm (comb)
Krabbe (crab)	Kerze (candle)	Hai (shark)	Kessel (kettle)
Kuh (cow)	Kette (necklace)	Hirsch (deer)	Knopf (button)
Libelle (dragon-fly)	Lampe (lamp)	Igel (hedgehog)	Koffer (suitcase)
Maus (mouse)	Pfeife (pipe)	Löwe (lion)	Löffel (spoon)

Appendix A. (*Continued*)

Feminine syntactic gender		Masculine syntactic gender	
Animals	Objects	Animals	Objects
Mücke (moscito)	Pistole (gun)	Papagei (parrot)	Mantel (coat)
Qualle (jelly-fish)	Pyramide (pyramid)	Pelikan (pelican)	Pfeil (arrow)
Ratte (rat)	Säge (saw)	Pfau (peacock)	Pilz (mushroom)
Raupe (caterpillar)	Schere (sissors)	Schwan (swan)	Pullover (pull-over)
Schlange (snake)	Spritze (syringe)	Skorpion (scorpion)	Reifen (tire)
Schnecke (snail)	Tasse (cup)	Strauss (ostrich)	Rock (skirt)
Schwalbe (swallow)	Trompete (trumpet)	Tiger (tiger)	Schlüssel (key)
Spinne (spider)	Vase (vase)	Wal (whale)	Schuh (shoe)
Taube (pigeon)	Zange (pliers)	Wolf (wolf)	Toaster (toaster)
Ziege (goat)	Zitrone (lemmon)	Wurm (worm)	Trichter (funnel)

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