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Electrophysiological estimates of the time course of semantic and phonological encoding during implicit picture naming

BERNADETTE M. SCHMITT,[a,b] THOMAS F. MÜNTE,[b,c] AND MARTA KUTAS[b]

[a]Faculty of Psychology, Department of Neurocognition, Maastricht University, The Netherlands
[b]Department of Cognitive Science and Department of Cognitive Neuroscience, University of California–San Diego, La Jolla, USA
[c]Department of Neurology, Medizinische Hochschule Hannover, Germany

Abstract

Two different event-related potential (ERP) components were used to investigate the temporal processing of semantic and phonological encoding during implicit picture naming. Participants were shown pictures and carried out a dual choice go/nogo decision based on semantic information (i.e., whether the picture was of an object or an animal) and phonological information (i.e., whether the picture's name starts with a vowel or a consonant). In addition to the already established lateralized readiness potential (LRP; related to response preparation), we introduce the N200 (presumably related to response inhibition) as a tool for measuring online language processing. Both, the LRP and the N200 data indicated that semantic processing began earlier than phonological processing. The data are discussed in the context of language production models. Therein, the LRP and N200 results, taken together, favor a serial or cascaded processing model of language production in contrast to a parallel processing account.

Descriptors: ERP, LRP, N200, Implicit picture naming, Language production, Temporal processing of semantic and phonological encoding

Psycholinguists interested in language production are concerned with how a concept in the mind comes to be a meaningful utterance. In general terms, theories of language production agree that the process of translating an idea to an utterance involves knowledge at the level of: (1) meaning, (2) syntax, such as word class, and (3) phonological form, such as phonemes and syllables (Bock, 1982, 1995; Dell, 1986, 1988; Garrett, 1975, 1988; Kempen & Huijbers, 1983; Levelt, 1989; Levelt, Roelofs, & Meyer, 1999). Moreover, it is generally acknowledged that these three processing levels are distinct based on investigations of brain-damaged individuals (for a review see Garrett, 1992, 1995; Miozzo & Caramazza, 1997; Rapp & Caramazza, 1995), the tip-of-the-tongue phenomenon (for a review see Brown, 1991), speech errors (for example, Dell, 1986, 1990), and reaction times (Levelt et al., 1991a, 1991b; Peterson & Savoy, 1998; Schriefers, Meyer, & Levelt, 1990), as well as electrophysiological data from intact individuals (Van Turennout, Hagoort, & Brown, 1997, 1998).

To speak fluently, different kinds of knowledge about words have to be accessed at a high speed, within milliseconds. Thus, one central research question is *when* information about a word's meaning, syntax, and phonology become available in real time. Behavioral data have suggested that a word's semantic and syntactic properties are retrieved before its phonological form is available (Dell & O'Seaghdha, 1991, 1992; Levelt et al., 1991a; Peterson & Savoy, 1998; Schriefers et al., 1990). Electrophysiological studies using lateralized readiness potentials (LRPs) have supported this order of processing by showing that semantic information is encoded about 120 ms prior to phonological information (Van Turennout et al., 1997) and that syntactic encoding precedes phonological encoding by about 40 ms (Van Turennout et al., 1998).

In this report we show that another event-related potential (ERP) component, namely, the N200[1] also can prove useful in investigating the time course of information processing. Previous work

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Address reprint requests to: Bernadette Schmitt, Maastricht University, Faculty of Psychology/Neurocognition, P.O. Box 616, 6200 MD Maastricht, The Netherlands. E-mail: b.schmitt@psychology.unimaas.nl.

[1]The N200 has been investigated in a variety of experimental tasks, such as the auditory oddball task as well as both auditory and visual go/nogo paradigms. Its sensitivity to physically deviant or infrequent sounds in tone sequences is usually discussed in terms of the "mismatch negativity" (reviewed in Näätänen, 1992). The interpretation of the N200 component in go/nogo paradigms as related to motor response inhibition in both monkeys and humans is discussed in Sasaki and Gemba (1993). For its interpretation as a more general inhibition component see Pfefferbaum et al. (1985).

has revealed N200 peak latency to be a sensitive index of the timing of information processing during visual perception (Thorpe, Fize, & Marlot, 1996, see below). Here we have used the N200 effect to examine the relative time course of semantic and phonological encoding during implicit picture naming, that is, during the process of getting access to a picture's name.

The N200

When 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 frontocentral sites (Gemba & Sasaki, 1989; Kok, 1986; Pfefferbaum et al., 1985; Sasaki, Gemba, Nambu, & Matsuzaki, 1993; Simson, Vaughan, & Ritter, 1977). Although its functional significance remains unknown (Eimer, 1993; Näätänen, 1982, 1992; Pfefferbaum et al., 1985), it does appear that a frontal N200 is elicited when a potential simple response is withheld. It has been suggested that the N200 amplitude is a function of neuronal activity required for "response inhibition" (Jodo & Kayama, 1992; Sasaki & Gemba, 1993). This hypothesis is supported by the results of studies with surface and depth (2.0–3.0 mm) electrodes in the prefrontal cortex of monkeys (Sasaki, Gemba, & Tsujimoto, 1989). In this study, potentials were recorded as the animals performed a go/nogo task on color discrimination (e.g., pushing a button when a green light came on and giving no response when a red light came on). As expected, nogo trials elicited an N200 both at the scalp and in the prefrontal cortex. Sasaki et al. also found that they could mimic the brain processes associated with N200s on nogo trials by stimulating the prefrontal cortex during go trials. More specifically, they could suppress the overt response on go trials by electrically stimulating the prefrontal cortex at the time that an N200 would normally have developed on a nogo trial (see also Sasaki & Gemba, 1993, for a comparison of data from humans and monkeys). These results thus link the N200 elicited in a go/nogo paradigm to response inhibition processes, occurring, at least in part, in the prefrontal cortex.

In a go/nogo paradigm an N200 is elicited when a person does not give a response. Thus, the presence of an N200 implies that the information, which can be used to determine whether or not a response is to be given, must have been analyzed. Thus, one can vary the information on which a go/nogo decision is based, and use the peak latency of the N200 effect (difference between go and nogo ERP) as an upper estimate of *when* the specific information must have been encoded.

Thorpe et al. (1996) used this logic to examine the time course of visual processing of pictures. Participants were asked to view complex visual scenes. They were asked to press a response button (go trials) whenever there was an animal in the scene, and not to respond with any button whenever the scene contained no animal (nogo trials). Thorpe et al. compared the ERPs elicited on go and nogo trials, and observed an enhanced negativity for nogo trials compared to go trials. The difference between nogo and go trials, known as the N200 effect, had its maximum around 150 ms after picture onset. The authors interpreted the peak latency of the N200 effect as the moment in time when sufficient visual information was available for a person to decide whether or not to respond. In addition to the peak latency of the N200 effect we also examined its latency of onset. The onset latency is the moment in time when go and nogo trial ERPs first diverge from each other at the scalp, and thus can be taken as the time by which there must have been enough information available to help the person decide whether or not to respond.

In the present study we aimed to delineate the temporal course of the availability of semantic and phonological information during implicit naming by making the go/nogo decision contingent on each in turn (during a binary decision involving both semantic and phonological information processing). To our knowledge, the N200 has not been used previously to examine language processing in this way. By comparing the relative latencies of the two N200 effects, however, we believe that we can say something about whether semantic encoding precedes, follows, or is coincident with phonological encoding.

The LRP

The LRP is derived from the readiness potential (RP) that precedes voluntary hand movements, as in a button pressing task. The RP is a gradually increasing negative shift, beginning 1 s or so prior to movement onset (first described by Kornhuber & Deecke, 1965). About 0.5 s before movement onset the RP becomes lateralized, with larger amplitudes seen over the hemisphere contralateral to the response (Kutas & Donchin, 1974), at sites over the motor cortex (C3′ at left hemisphere and the corresponding C4′ at right hemisphere).

The LRP is derived from the RP, but is time locked to the stimulus to which the response is given. By averaging the lateralized activity to responses made with the left and right hand (given contralateral vs. ipsilateral recording), any asymmetry that is not related to response preparation cancels out. This is done via two subtractions: (1) the potential measured above the right motor cortex (C4′) is subtracted from the potential at the corresponding left motor cortex (C3′), and (2) all left-hand responses are subtracted from right-hand responses. What remains is the lateralized part of the readiness potential, that is, the LRP; the LRP is presumed to reflect the average amount of lateralization specifically related to the motor preparation of the responding hands. The LRP allows researchers to see motor-related brain activity before an overt or go response (Miller, Riehle, & Requin 1992; Mulder, Wijers, Brookhuis, Smid, & Mulder, 1994). Perhaps more importantly, the LRP also reveals motor activation even in the *absence* of any overt response. That is, the LRP reflects preparation to respond, even when the response is not executed, as in the case of nogo trials (cf. Osman, Bashore, Coles, Donchin, & Meyer, 1992). These characteristics make the LRP a suitable brain measure with which to study the time course of encoding of various levels of information during intended but not directly realized speech production (Van Turennout et al., 1997, 1998).

The Experimental Paradigm

We measured both the N200 and the LRP in a go/nogo paradigm to determine whether semantic encoding precedes phonological encoding, as predicted by serial models of speech production (Levelt, 1989; Levelt et al., 1999), as well as by cascading models (Dell, 1986, 1988; Dell & O'Seaghdha, 1992; Peterson & Savoy, 1998).

The experiment was carried out in German. In an initial practice session, participants were asked to name a series of pictures, to make sure that they knew the intended name of the pictures, which were used during the recording session. During the recording in the main session, participants were asked to make a binary decision, that is, to classify the pictures with respect to both their semantic and phonological features.

The semantic decision was to determine whether the picture was that of an animal or an object, which we assume, based on the picture categorization literature, involves semantic activation (for a review see Glaser, 1992). The phonological decision was to determine whether the depicted item's name started with a consonant or with a vowel. The instruction was, for example, "press the left button for an animal and the right button for an inanimate object. However, respond only if the picture's name starts with a vowel, and not if it starts with a consonant." Thus, depending on the outcome of these two decisions, a response was given with either the left or right hand, or not at all (see Figure 1 for an illustration).

The logic of the paradigm with regard to the N200 is as follows: In one condition, the responding hand was contingent on semantic information (*hand=semantics*), and the go/nogo decision was contingent on phonological information (*go/nogo=phonology*). The timing of the N200 effect (i.e., the difference between go and nogo response) then provides an upper limit on the moment in time when the phonological information must be available for determining whether or not to respond. In the other condition, the response contingencies were reversed; that is, the responding hand was contingent on phonological information (*hand=phonology*), whereas the go/nogo decision was dependent on semantic information (*go/nogo=semantics*). In this case, the latency of the N200 effect can be taken as an upper limit on availability of semantic information. According to either a serial or a cascading model of language production, semantic encoding is presumed to precede phonological encoding. It follows that the information to inhibit a response also should be available earlier when it is of a semantic than of a phonological nature. We would expect to see this difference in availability in an earlier N200 effect when the go/nogo decision was based on semantic than on phonological information. However, if semantic and phonological information was processed simultaneously, then we would expect to see no difference in the timing of their associated N200 effects.

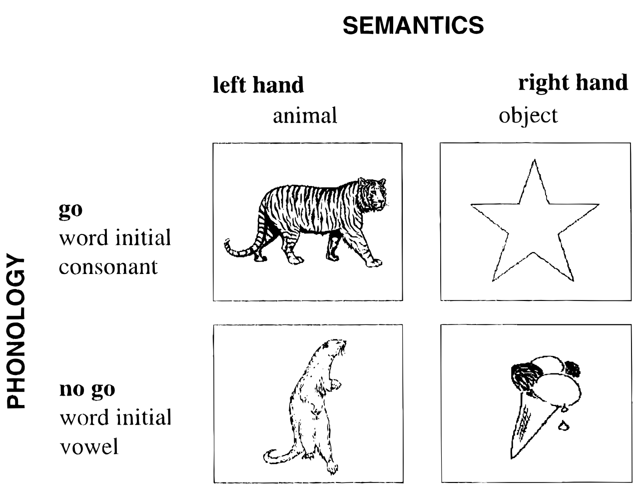

Figure 1. The illustration of the experimental design shows an example for the hand=semantics condition. The response hand was contingent on semantic information. The go-nogo response was contingent on phonological information. In the hand=phonology condition, the pictures were the same but the response contingencies were reversed: The response hand was contingent on phonological information. The go-nogo response was contingent on semantic information (see also Appendix B).

The logic of the dual choice go/nogo paradigm with regard to the LRP was similar, albeit based on response preparation rather than response inhibition. We assume that people prepare to respond as soon as they have some information available about which hand they are going to use, and this preparation is reflected in an LRP. If the responding hand is contingent on semantic information, and semantic encoding precedes phonological encoding (as assumed by serial and cascading models of speech production), then an LRP should develop for both go and nogo trials alike. However, as soon as the phonological information is encoded, indicating that no response is to be made, the LRPs for go and nogo trials should diverge from each other; that is, the LRP for nogo trials should drop back to baseline as the preparation is abandoned. In contrast, when the response contingencies are reversed (i.e., the responding hand is contingent on phonological information, and the go/nogo decision is contingent on semantic information), no LRP on nogo trials should develop. This difference is expected in both serial and cascading models, because their proponents assume that the early availability of the semantic information, indicating that no response is to be given, would effectively forestall the development of any preparation. Accordingly, no LRP should develop on nogo trials.

A potential concern with regard to using the dual choice go/nogo paradigm to probe language production processes is that during the recording session participants merely responded to pictures with a button press as a function of their semantic and phonological characteristics and did not actually name the pictures out loud. As the responses are contingent on semantic and phonological features of the object or its name, they must of necessity probe the availability of these two kinds of information. However, the push button response itself may not reflect language planning processes at all, but rather more generally the availability of different kinds of information, or memory codes. According to Paivio (1971), for example, semantic knowledge is represented dually both by a verbal and a pictorial code; task demands determine which code is retrieved in any given situation. Pictures are presumed to activate both pictorial and verbal codes, whereas word stimuli are first encoded verbally, and may or may not activate pictorial codes depending on a number of factors. We can thus view the current task from the perspective of this dual coding hypothesis rather than in terms of language production. On this view, the picture would activate a pictorial code, which participants could use to decide whether the picture is of an object or of an animal. In addition, the picture would need to activate a verbal code in order for participants to decide whether or not its name begins with a vowel or a consonant. In this analysis, the LRP and the N200 measures would indicate when the two codes become available. The absence of latency difference in these ERP measures for the two types of decisions would mean either that (1) the two codes become available at the same time, or (2) that the dual code view is wrong, and knowledge representation is more abstract, for example (see Pylyshyn, 1973). If, on the other hand, there is a latency difference in the ERP measures then we can infer that (1) there seems to be two different kinds of codes, rather than just one abstract representation, and (2) that one type of code is available earlier than the other type. So, even if one assumes that code availability in the present experimental task does not reflect language production, the ERP results of the present experiments are interesting with respect to the nature and time course of accessing different code types.

We will not review here the vast, ongoing research on code availability (see, e.g., Bavelier & Potter, 1992). Rather, we would like to make a link between theories of code availability and models of language production. As reviewed in Glaser (1992), contemporary theories of language production are based on the ideas of Paivio and others. During the last two decades of psycholinguistic research, the notion of codes has been applied to language processing and has been elaborated in detail for language production (Levelt, 1989; Levelt et al., 1999). If one assumes, as we do, that language-related codes are but some of the many different types of memory codes, then whether we talk generally in terms of memory codes or more specifically in terms of language-related codes, our push-button task probes access to these codes. From either theoretical perspective, the ERP signals elicited during the go-nogo task can inform us about the time course of semantic and phonological information access.

Furthermore, although the participants in our experiment were not required to name the pictures explicitly, nonetheless we believe that the experiment is relevant to issues within language production for several reasons: First, we used pictures as targets. In psycholinguistic experiments, pictures are the method of choice for activating information processing in language production because they are believed to engage the same encoding processes as those that occur naturally in a speaker putting an abstract idea into words (see Glaser, 1992). It was our intent to interpret the ERP recordings within this framework given this assumption. Furthermore, because our participants were trained to name the pictures before the main recording session was conducted, we believe that they had access to the correct picture name in the main session as well. Although they did not say the picture's name out loud, it is generally assumed that their internal speech planning mechanisms (implicit naming) were activated automatically by the presentation of the picture. We can take the correctness of their responses as evidence that they accessed the correct underlying linguistic information, that is, the name of the picture. Finally, it has been common in psycholinguistic research to use a wide range of indirect or non-naming tasks with picture stimuli, and to interpret the results in terms of language production per se. For example, indirect picture categorization tasks have been used to investigate semantic access during language production (see Glaser, 1992). Lexical decision (push-button responses about real words and pseudowords) during picture naming was chosen as a means of tapping into the time course of semantic and phonological access in language production (see Levelt et al., 1991a). In the study by Levelt et al., the dependent variable was mean "lexical decision latencies" from trials in which no overt naming took place. As it happens, the dual choice go/nogo paradigm we chose to use in the present study was based on the same logic and essentially the same paradigm as that introduced by Van Turennout et al. (1997, 1998) for estimating the time course of semantic, syntactic, and phonological encoding. Although they did have participants directly name pictures on some (filler) trials, the analyses and inferences were not based on data from these "naming" filler trials but rather from button presses on trials in which no direct—but delayed—naming was involved. Van Turennout et al. argued that their results relate to language production proper, that is, to intrinsic access of the picture's name upon its appearance needed to perform the required judgments. We appeal to the same logic in our study, however, not only for the LRP as they did but also for the N200.

Methods

Subjects

Fifteen native speakers of German participated in the experiment (4 women and 11 men, 26–36 years of age, mean 29 years). All participants but one were right handed. All were neurologically healthy and had normal or corrected-to-normal vision.

Stimuli

A set of 120 simple black-on-white line drawings was used consisting of two semantic categories: 60 animals and 60 objects. In each of the two categories, the names of half of the items started with a vowel and the other half with a consonant. Twenty pictures were used as practice stimuli. The remaining 100 pictures served as the targets (25 pictures in each semantic and phonological condition; see Appendix A). The depicted items were matched in word frequency using the CELEX database (Baayen, Piepenbrock, & Van Rijn, 1993). The mean lemma frequency per million was 22.9 ($SD = 31$) for names of animals starting with a vowel, 52.4 ($SD = 65$) for names of objects starting with a vowel, 44.6 ($SD = 98$) for names of animals starting with a consonant, and 49.8 ($SD = 45$) for names of objects starting with a consonant. Statistically these four groups did not differ, as shown by an analysis of variance (ANOVA) on frequency with group as factor, $F(3,96) = 1.05$.

Design

Each participant received eight different instruction sets, in total. In four instruction sets, the responding hand was contingent on semantic information and the go/nogo decision was contingent on phonological information, with left- and right-hand go and nogo responses counterbalanced for each item. The other four instruction sets were given for the reversed set of response contingencies. In these cases, the responding hand was contingent on phonological information, and the go/nogo decision was dependent on semantic information, again counterbalanced for left and right hand go/nogo responses for each item. Appendix B illustrates the eight different instruction sets and provides an example of the different responses to the same item, in this case the picture of a feather. Each picture was presented eight times to each participant, that is, once per condition. The order of conditions was randomized across participants.

Procedure

Participants were tested individually while seated in a soundproof chamber in front of a computer screen. They were first familiarized with the pictures during a practice block wherein each picture was shown with its name printed below it. The participants were asked to study each picture and its name, and to proceed to the next picture by pressing a button. In a second practice block the pictures were repeated without their names and the participants were asked to name them aloud—as fast and as accurately as possible. This procedure guaranteed that each participant knew and used the intended names of the pictures during the experimental run.

During the recording session, the participants did not name the pictures aloud, but rather were asked to carry out a dual choice go/nogo task. Because there were eight different instructions, each participant carried out eight different dual choice tasks, one per experimental condition (see Appendix B).

Each condition began with 40 practice trials (10 pictures of each semantic/phonological category), followed by 100 experimental trials (25 pictures for each semantic/phonological category, presented in two blocks of 50 trials). Between blocks there was a short break. Each block started with three warm-up trials that were excluded from further analysis. The order of the instructions was randomized across participants and the sequence of pictures was randomized in every block and for every participant. Each experimental block lasted about 5 min. The entire experiment lasted about 2 hr.

A trial began with the presentation of a fixation point in the middle of a high-resolution 21“ computer screen. After a randomized interval of 1,500–3,000 ms, the picture was presented in the center of the screen for 1,500 ms. Pictures subtended about 8° of visual angle in height and 8° in width (viewing distance 1.10 m). The picture was replaced immediately by the fixation point, indicating the start of a new trial.

Participants were instructed to rest their arms and hands on the elbow rest of the armchair and to hold their thumbs on the left and right response button. On go trials, participants responded by pressing one of the two buttons as quickly as possible. On nogo trials they did not press any of the buttons. Participants were instructed not to speak, blink, or move their eyes while the picture was on the screen.

Apparatus and Recordings

Push-button response latencies were measured from picture onset with the timeout point (the moment in time after which responses were registered as missing) set at 1,500 ms. Timeouts and errors, that is, wrong responses, were excluded from further analyses (about 14%, see Results for details).

The electroencephalogram (EEG) was recorded from 26 scalp sites using tin electrodes mounted in an electrode cap (Electro-Cap) with reference electrodes placed at the mastoids. The electrode-sites were spaced in a geodesic fashion (see Figure 2 for a comparison to the 10-20 system). Signals were collected using the

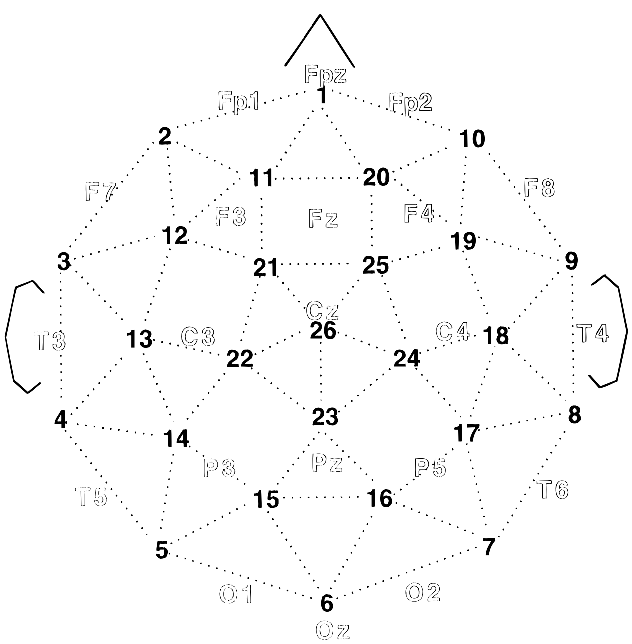

Figure 2. Schematic of the electrode array used in the experiments (thick labels). The electrodes are arranged on a series of four equally spaced concentric rings. The outermost two rings are composed of 10 equally spaced electrodes. The third ring is composed of five electrodes, and the last one is composed of a single electrode. The electrode sites corresponding to the International 10-20 system have been superimposed for comparison (thin labels). Note that electrode 1 corresponds exactly to Fpz in the 10-20 system, electrode 6 to Oz, and electrode 26 to Cz.

left mastoid electrode as a reference and re-referenced offline to the mean of the activity at the two mastoid processes. Blinks and vertical eye movements were monitored by electrodes placed on the right and left lower orbital ridge, also referred to the left mastoid. Lateral eye movements were monitored by a bipolar montage using two electrodes placed on the right and left external canthus. The eye movements were recorded in order to allow for later offline rejection. Electrode impedances were kept below 5 kΩ for the EEG and eye-movement recording.

Signals were amplified with a bandpass from 0.01 to 100 Hz and digitized at 250 Hz (4 ms resolution). Averages were obtained for 2,048 ms epochs including a 300-ms prestimulus baseline period. This epoch was chosen so that it began 200 ms before the critical statistical baseline interval (which was defined as 100–0 ms before stimulus onset). The epoch also extended the picture presentation time (0–1,500 ms) by 200 ms. The extended time window was chosen to guarantee an artifact-free baseline and response signal.

Trials of correct responses were inspected visually. Trials contaminated by eye movements or amplifier blocking within the critical time window were rejected from averaging by a computer program using individualized rejection criteria. The number of rejections did not reliably differ for the two response contingency conditions. On average, 22% of the trials in the hand=semantics condition and 21% of the trials in the hand=phonology were excluded from further analysis (including ERP artifacts and incorrect responses).

Both the LRP and the N200 were calculated for all 32 electrode sites. The LRPs were derived from the ERP signal by two subtractions (as described in the Introduction). For the LRP analysis only those electrode sites close to C4′ and C3′ were investigated, as these yield the largest RPs for hand movements (e.g., Kutas & Donchin, 1974). These were the middle central sides (electrodes 24 and 22, about 1 cm more dorsal and central from C4′ and C3′, see Figure 2). For the N200 ERP analysis only frontal electrode sites 1, 2, and 10 were investigated, as these yield the largest N200 effect (Thorpe et al., 1996).

Results

Push-Button Reaction Times

Pretest. The mean reaction times for simple choice left/right hand responses were collected in a pretest (13 German speakers, different from the participants of the main session). The results in this pretest should indicate how long it takes in general to make a phonological decision (e.g., press the left button, if the name starts with a vowel, press the right button if it starts with a consonant) or a semantic decision (e.g., press left if the picture is that of an animal, press right if it is an object). The same material was used as in the main recording session. Response hands were counterbalanced insofar as possible across participants. Errors (less than 2%) were excluded from the analysis. The mean reaction time for the phonological task was 841 ms ($SD = 136$). The mean reaction time for the semantic task was 617 ms ($SD = 138$). The observed 224-ms difference was significant, $t(12) = -8.66$, $p < .01$, indicating that the simple choice based on semantics could be carried out faster than the choice based on phonology.

Main experiment. The mean reaction times for correct go responses in the dual choice go/nogo task were averaged across left and right responses for 15 subjects (about 200 trials per condition).

The means were 1,053 ms ($SD = 137$) for the hand=phonology condition, and 1,097 ms ($SD = 161$) for the hand=semantics condition. A paired sample *t* test of the reaction times for the two conditions did not reveal a significant difference, $t(14) = 1.6$, $p = .12$.

Incorrect responses (timeouts, i.e., reaction times longer than 1,500 ms, and wrong hand responses) were excluded from the analysis. The error proportions did not differ for the two response contingencies; hand=semantics: 15.5% ($SD = 5.2$), hand=phonology: 13.1% ($SD = 3.4$), according to a paired sample *t* test, $t(14) = 2.04$, $p = .06$.

N200 Analysis

We assumed that the increased negativity for nogo trials in comparison with go trials reflected the moment in time by which the relevant information necessary to withhold a response must have been encoded. The time it takes to encode the relevant information might, therefore, be reflected in the peak latencies of the N200 effect, as discussed in the Introduction. In addition to the analysis of the peak of the effect we were also interested in the moment in time when the N200 effect started to emerge, that is, in its onset latency, which can add to the information about the temporal course of information processing.

Of greatest interest was whether the temporal characteristics of the N200 effect differed reliably for the two response preparation conditions (responding hand determined by semantics vs. responding hand determined by phonology). ERP difference (nogo minus go) waveforms were calculated for each of the two response preparation conditions. Figure 3 shows grand-average ERPs for 15 participants at midline sites (going from the front to the back of the head). Both response contingency conditions showed an N200 (see left and middle column of Figure 3), with nogo trials being more negative than go trials. However, as can be seen in the difference waveforms (nogo minus go) for both conditions (right panel of Figure 3), the two N200 effects were strikingly different. The N200 effect in the "hand=phonology, go/nogo=semantics" condition preceded that in the "hand=semantics, go/nogo=phonology" condition.

The description of the pattern of results was supported by statistical comparison of the ERP difference waveforms at three frontal electrodes (electrodes 1, 2, 10, see Figure 2). The frontal electrode sites were chosen based on previous studies reporting a frontal maximum for the N200 as a component of response inhibition.

Peak latencies. The ERP difference waves (nogo minus go) were quantified by mean amplitude measures relative to the prestimulus baseline (−100 to 0 ms before picture onset). For each participant, the peak latencies of the N200 effect were measured between 200 and 700 ms at each frontal electrode. For the peak latencies, an ANOVA was carried out with response preparation (hand=semantics vs. hand=phonology) and electrodes (the three frontal electrodes) as repeated-measures factors. The main effect of response preparation was significant, $F(1,14) = 12.3$, $p < .01$, reflecting a difference in peak latencies. When the go/nogo decision was contingent on semantic information (as was the case for the hand=phonology response preparation) the mean peak latency of the N200 effect was 384 ms ($SD = 83$ ms). In contrast, when the go/nogo decision was contingent on phonological information (hand=semantic) the mean peak latency of the N200 effect was 473 ms ($SD = 108$ ms). The mean latency difference (across the three electrode sites) of the two N200 effects was 89 ms. Neither the main effect of electrodes nor the interaction of Electrodes × Response Preparation was significant.

Onset latencies. The onset latencies were analyzed by a fractional peak latency analysis (see, for example, Smulders, Kenemans, & Kok, 1996). The latency of the onset of the N200 effect was defined as the latency when the potential reached 10% fraction of the peak amplitude; these were determined separately for the electrode sites 1, 2, and 10 (see Figure 2). For the onset latencies, an ANOVA was carried out with response preparation (hand=semantics vs. hand=phonology) and electrodes (the three frontal electrodes) as repeated-measures factors. There was a significant main effect of response preparation, $F(1,14) = 19.7$, $p < .01$. When the go/nogo decision was contingent on semantic information (as it was the case for the hand=phonology response preparation) the mean onset latency of the N200 effect was 206 ms ($SD = 65$ ms). In contrast, when the go/nogo decision was contingent on phonological information (hand=semantic) the mean onset latency of the N200 effect was 325 ms ($SD = 100$ ms). The mean onset latency difference (across the three electrode sites) of the two N200 effects was 119 ms. As for the peak analysis, in the onset analysis neither the main effect of electrodes nor the interaction of Electrodes × Response Preparation was significant.

Despite visual appearances, the positivity in the difference ERP prior to the N200 (see Figure 3, top right) was not significantly different from baseline. This finding was analyzed by means of one-tailed serial *t* tests against zero mean. The *t* tests were carried out stepwise with a step size of 4 ms. For each test from 0 to 1,100 ms after picture onset, data were averaged across a 40-ms window (i.e., ± 20 ms relative to the measurement point). Significant divergence from baseline was defined as the point at which four consecutive *t* tests showed a significant difference from zero. In the time interval encompassing the positive dip, no significant difference was obtained. This *t*-test analysis revealed a 112-ms difference in the duration of the two N200 effects, with a duration of about 276 ms in the go/nogo=semantics condition versus 164 ms in the go/nogo=phonology condition.

LRP Analysis

LRPs of 13 of the 15 participants were analyzed. Two participants were excluded from the analysis, because they did not generate a typical go LRP response. Four average LRP waveforms were calculated for each participant: (1) hand=semantics, go=phonology, (2) hand=semantics, nogo=phonology, (3) hand=phonology, go=semantics, and (4) hand=phonology, nogo=semantics.

Figure 4 shows the grand average of go and nogo LRPs (100 trials per condition, minus about 21% rejected trials) for the two response preparation conditions: hand=semantics (top panel), and hand=phonology (bottom panel), at middle central electrode sites (electrodes 24 and 22, see Figure 2). The typical LRP pattern for go trials were obtained in both conditions (hand=semantics, hand=phonology). A development of nogo LRPs was evident in the hand=semantics condition, but *not* in the hand=phonology condition.

The statistics support this descriptive analysis. LRPs were quantified by mean amplitude measures relative to the prestimulus baseline (−100 to 0 ms before picture onset). Their onset latency was determined by using one-tailed serial *t* tests against zero mean between 300 and 800 ms after picture onset, as described in the section of the N200 onset latencies.

The mean onset latency for the go LRPs in the hand=semantics condition was 440 ms after picture onset (from that time on all $t(12) < -1.85$, all $p < .05$). The mean onset latency for the go LRP in the hand=phonology condition was 384 ms after picture onset (from that time on all $t(12) < -1.87$, all $p < .05$). A

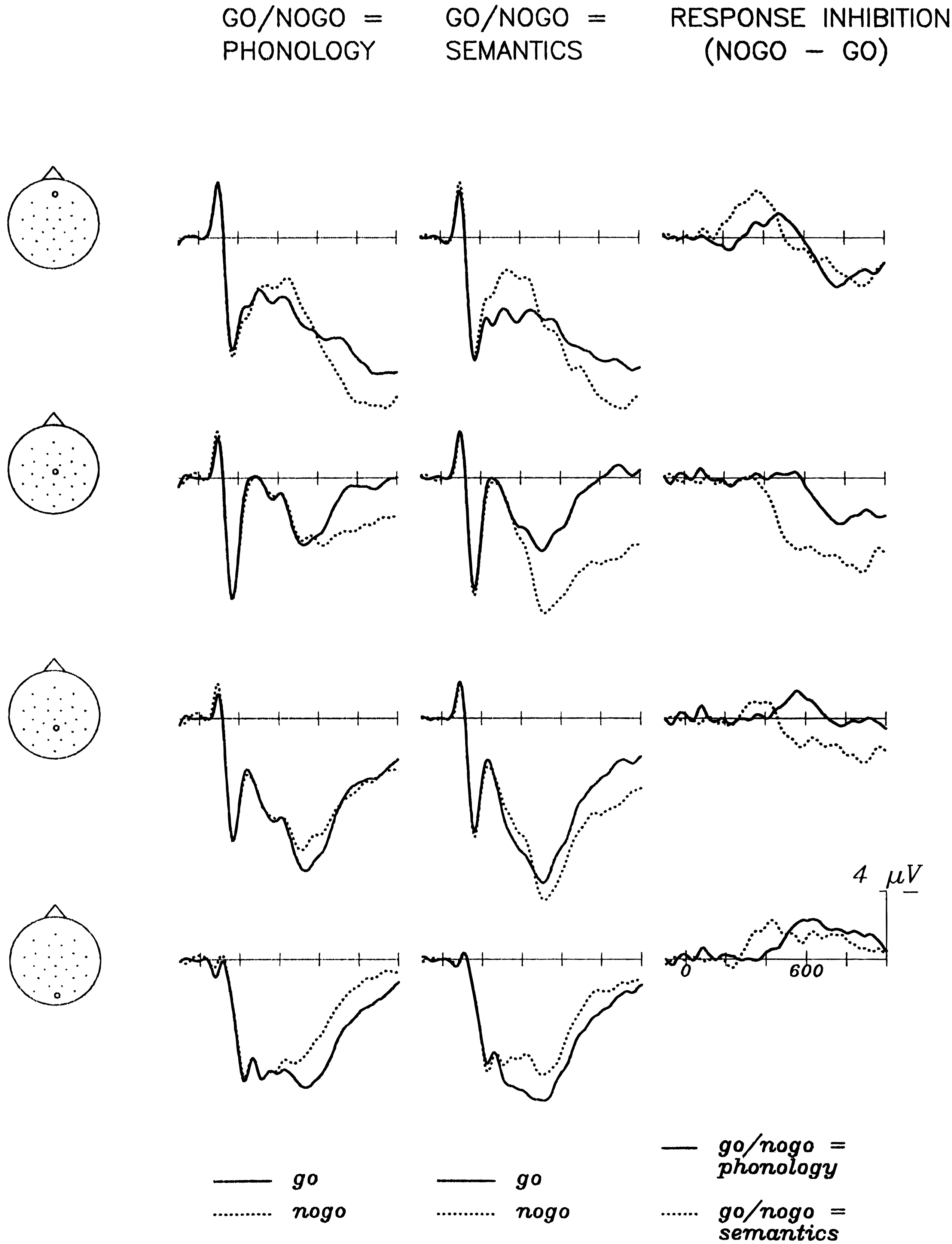

Figure 3. Grand-average event-related potentials (ERPs) on go and nogo trials in the hand=semantics condition (left column), and the hand=phonology condition (middle column). The ERPs were time locked to picture onset. Data of 15 participants were averaged (200 trials per condition per subject, minus rejected trials), and displayed for four midline electrodes. Both conditions were associated with a frontal negativity (N200) that was more negative for nogo than for go trials. In the right column, the "nogo minus go" difference wave (interpreted as response inhibition) for the two conditions are shown superimposed.

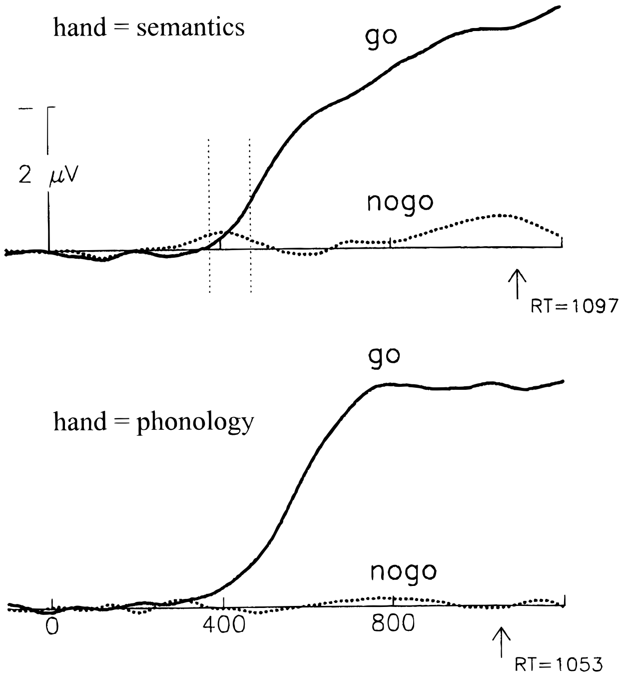

Figure 4. Grand-average lateralized readiness potential (LRP) on go (solid lines) and nogo trails (dashed lines) in the dual task that involves semantic and phonological decision on picture names (13 participants, 100 trials per condition, minus rejected trials). The LRP is time locked to picture onset. The two vertical lines indicate the nogo-effect.

comparison of the two go LRPs via a serial paired sample *t* test "go vs. go" revealed no difference of onset latencies, but a difference in slope (see Figure 5). The two go LRPs diverged significantly from each other between 728 and 752 ms, with the go=semantics condition being more negative, all $t(12) > 2.19$, all $p < .05$, two tailed.

Similar analyses for the onset of nogo LRPs revealed a significant divergence from baseline for the hand=semantics condition starting at 380 ms, which lasted until 436 ms after picture onset (in this time interval all $t(12) < -1.85$, all $p < .05$). In contrast, no significant divergence from baseline was obtained for the nogo LRP in the hand=phonology condition. A comparison of the go and nogo LRPs of the hand=semantics condition showed that they diverged from each other significantly at 460 ms after picture onset: from that moment on all $t(12) < -2.24$, all $p < .05$, two tailed.

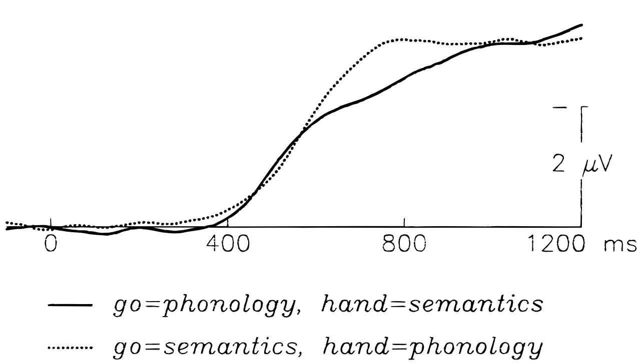

Figure 5. Comparison of the two go lateralized readiness potentials (LRPs).

Note that at frontal sites there was no LRP evident. Furthermore, the LRP did not seem to be influenced by the N200, because (1) there was no N200 effect at electrode sites C3′ and C4′, and (2) the changes in the latency of the N200 with condition did not effect the onsets of the go LRPs.

Discussion

The main goal of this study was to capitalize on the high temporal resolution of electrophysiological measures to estimate the time course of semantic and phonological information encoding during picture processing. To this end, we measured both the LRP, which has been used previously to address these issues, and the N200, which has not. As detailed in the Introduction, we chose to use the dual-choice go/nogo decision task to probe the accessibility of two different kinds of information, and our results show that in this task with pictures, semantic information becomes available prior to phonological information.

Even if the results of this dual choice go/nogo decision task had no bearing on language-production (planning) processes, they have revealed a clear difference in the availability of semantic and phonological codes, with semantic information becoming available approximately 90 ms prior to phonological information. Our results are thus consistent with a view of semantic memory wherein the knowledge related to the picture and/or its name might be represented in two different ways—as a readily accessible semantic representation and a somewhat less accessible (timewise) phonological representation. These results are in line with the suggestion that there are different representations, and at odds with a view that holds that pictures are represented in memory in a general, abstract form.

As mentioned in the Introduction, we would prefer to interpret our results in relation to current theories of language production. Our experimental task required that participants access the picture's name, and although the pictures were not named overtly, we buy into the common assumption that the processes accessing the picture's name in this type of task is for all intents and purposes no different than it is during overt naming. The theoretical advantage of this assumption is that there is only one knowledge representation for semantics and only one representation, albeit a different one, for phonology. As a consequence, different kinds of tasks such as naming or push-button responses give access to the same codes, thereby obviating the need for multiple, redundant semantic codes or multiple phonological codes (such as one for overt naming, one for implicit naming, and one for a dual-choice decision, etc.). Of course, this is an assumption and thus can undergo further testing; however, it is a simplifying assumption that has been made by many researchers in the field of language production. To reiterate, the following discussion of our results in terms of various language production theories is based on the assumptions that implicit access to the name of the picture (in our task) does not differ from accessing the name during overt picture naming, and does not differ from accessing the information during a decision task.

LRP

One goal of this study was to replicate the results of Van Turennout et al. (1997), that is, the relative time courses of semantic and phonological encoding. Instead of a between-subject design, as used by Van Turennout et al., we chose a within-subject design, to compare the two different response preparation tasks (hand=semantics, hand=phonology). We replicated Van Turennout et al.'s basic finding: a development of a nogo LRP in the hand=semantics condition, but not in the hand=phonology condition. Whereas Van Turennout et al. used word-initial phonemes (Experiment 1 and 2) or word final phonemes (Experiment 3), our task required a vowel versus consonant categorization. This slightly different task also yielded the outcome predicted by serial and cascading models of language production that semantic encoding would precede phonological encoding. Our finding thus generalizes the argument of Van Turennout et al., for the temporal course of processes during language production based on the LRP.

In the present study the go and nogo LRPs were indistinguishable for approximately 80 ms (i.e., between 380 and 460 ms after picture onset) and diverged thereafter. In line with van Turennout et al., we suggest that during this interval one of the hands was prepped to respond unaffected by phonological information, which apparently was not yet available for the go/nogo decision. However, after about 80 ms (460 ms after picture onset) the phonological information necessary to favor a go versus nogo decision seems to have become available, as reflected in the reliable divergence of the go and nogo LRPs.

N200

In addition to the data related to response preparation (i.e., LRP), the results of our study can be related to the time course of information related to response inhibition (N200). The N200 effect (response difference "nogo minus go") reflects the time by which information about whether or not to respond must have become available. We examined two different aspects of the N200 effect: (1) its mean peak latency, and (2) its latency of onset. In the extant literature (see Introduction), the peak latency has been taken as the moment in time by which specific information is available to support the decision for a particular response to be given or withheld. However, in terms of temporal course of information processing, the onset of the effect (of any effect in the ERP signal) might be as relevant as its peak (maximum). The average peak latency of the N200 effect was 89 ms earlier when the go/nogo response was contingent on semantic information than when it was contingent on phonological information. The mean difference in the latencies of the onsets of the two N200 effects was 119 ms.

This difference in the timing of the N200 effects in the two conditions accords well with the relative timing of the observed LRP results. Both the N200 latency data and LRP data suggest that in this experiment semantic information was available ahead of phonological information by about 80–90 ms (or about 112 ms if one considers the onset of the N200 as relevant).

Taken together, the LRP and N200 data reveal the temporal course of semantic and phonological information processing in this experiment. As mentioned in the Introduction, we believe that these data are relevant to the time course of language production because they index information access during intrinsic picture name processing. If this assumption is granted, our data support any model of speech production that is based on semantic encoding beginning prior to phonological encoding; these include any serial processing models (Levelt et al., 1991a, 1999) as well as various models of cascaded processing (Dell & O'Seaghdha, 1992; Peterson & Savoy, 1998).

Our interpretation of the results outlined above is predicated on the assumption that the N200 effects in the two experimental conditions reflect nothing but the availability and use of semantic and phonological information during this intrinsic language production. However, there is at least one other possible explanation; namely, that the N200 effects based on semantic processing preceded those based on phonological processing because the semantic task was easier, in this case. On this account, both semantic and phonological processing might start at the same time, but semantic information would be encoded first simply because the analysis operations and choices for the semantic task could be carried out more quickly than for the phonological task. As a result, the N200 effect would begin and peak earlier when the go/nogo decision was based on semantic than phonological information by virtue of the particular task parameters used rather than the order of operations during language production in general. This interpretation gets some support from a direct comparison of the two go LRPs (see Figure 5). It appears that the go LRPs in the two conditions do begin at about the same time. Moreover, the steeper slope of the LRP in the go=semantics than that in the go=phonology condition is consistent with faster and/or easier semantic processing. The pattern of reaction times from the pretest also suggests that the semantic task was easier than the phonological task. Specifically, with our materials and task, a simple left/right-hand decision based on the semantic information was about 224 ms faster than the decision based on phonological information. However, if this were the entire explanation for the observed pattern of effects in the main (dual choice) experiment, then we would expect the go reaction times to be significantly faster when the no/nogo decision was contingent on semantic than on phonological information. This was not the case. The go response times for the two response conditions in the main experiment did not differ significantly; there was only a slight trend for go decisions in the go/nogo=semantics condition to be about 44 ms faster than in the go/nogo=phonology condition.

Neither simple choice nor dual reaction times nor LRP onsets mirrored the pattern of N200 onset and peak latencies. Moreover, the differential slopes for the two go LRPs occurred much later than their associated N200s. Thus, although the differential difficulty of semantic versus phonological processing may account for the simple reaction times and LRP slope differences, it remains to be shown whether, and if so, to what extent, the N200 effect per se is sensitive to such a difference in task difficulty. More importantly for present purposes, however, even if we were to accept a parallel processing account of the difference in latency of the N200 effects in the two experimental conditions, it would be at odds with the observed pattern of LRP data. As discussed previously, the development of a nogo LRP only in the hand=semantics (and not in the hand=phonology) condition is most consistent with some type of serial or cascade processing account of language production.

Clearly the two dual choice go/nogo tasks we asked the participants to perform are not pure instances of language production or even information processing but decision tasks from which we drew inferences about the temporal course of information processing during (implicit) language production. Our aim was to get an estimate of when specific types of information became available. Admittedly, it is on the decisions that we focused. However, these decisions were based on two different types of information (semantic and phonological) that are considered to be essential for routine and accurate language production. Following Thorpe et al. (1996), we interpreted the observed N200 peak as the moment in time when information was available and *not* merely the moment of a certain decision. At minimum, our data show that a decision based on semantic information is processed faster than a decision based on phonological information. We viewed the presence of an N200 as evidence that the information on which N200 elicitation was contingent (i.e., information determining whether or not a response was to be made) must have been analyzed, at least to some extent. Accordingly, we took the onset and/or the peak latency of the N200 effect as an estimate of the time by which the specific information needed to make a correct decision must have been encoded. We think it but a small and logical inference that the information on which a decision is based is available somewhat prior to and certainly by the moment that decision is rendered. Thus, it seems not unreasonable to view the moment of the decision as providing an upper limit on the time of semantic and phonological encoding during implicit naming.

The present study also shows that it is possible to partial out the processing of specific information types while a presumably automatic process, such as implicit access to a picture's name, runs its course. The N200 effect seems to be especially useful in revealing the relative timing of the various subcomponents of a complex cognitive task such as language production. Traditionally, psycholinguistic theories have made no distinction between the automaticity of visual and linguistic encoding, presuming all "stages" to be highly automatic. Hence we can use the N200 to get access to intermediate linguistic information in the same way that it was used by Thorpe et al. (1996) to gain intermediate access to nonlinguistic, visual information. For the present study, we assumed that the two N200 effects we observed reflected two intermediate products during language production, namely those of semantic and phonological information encoding. The LRP data, likewise, reflect intermediate or partial linguistic output during the highly automatic processes of (delayed) implicit naming as first argued by Van Turennout et al. (1997, 1998).

Interesting, but thus far unexplained, is the observed difference in the duration of the two N200 effects. Its duration is about 276 ms in the go/nogo=semantics condition versus 164 ms in the go/nogo=phonology condition—a 112 ms difference. Together with the difference in duration of the N200 effects there is also a difference in their amplitudes, with that of the go/nogo=semantics being about twice the size of that in the go/nogo=phonology condition (see Figure 3). This amplitude difference may be related to processing speed, as suggested by Sasaki and Gemba (1993), who found that prefrontal potentials (related to voluntary movements of a monkey's hand) were larger for quick than for slow movements. We too found this pattern: faster semantic processes were associated with higher amplitudes than the slower phonological processes. However, for the moment, we have no explanation for the amplitude difference of the effects.

Timeline of LRP, N200, and Reaction Times

Figure 6 depicts a timeline along which the five dependent variables can be compared descriptively (i.e., the N200 onset and peak, the go LRP onsets, the simple choice reaction times from the pretest, and the dual choice reaction times for go responses in the main experiment). The timeline shows clearly that the mean latencies for all dependent measures are shorter in the go/nogo=semantics condition (top panel) than in the go/nogo=phonology condition (bottom panel). Thus, overall, a go/nogo decision based on semantics is processed faster than a decision that is based on phonology. In terms of a psycholinguistic model of speech processing the data show that semantic information of a picture is available earlier than phonological information of the picture's name, and is therefore more in line with serial and cascade models of speech production, which assume (1) early visual encoding, followed by (2) semantic encoding, and (3) phonological information processing. However, we admit that in the present experiments, the semantic decision might have been based on visual cues rather than nonvisual semantic cues. Thus, future studies are needed to support that aspect of this proposed timing.

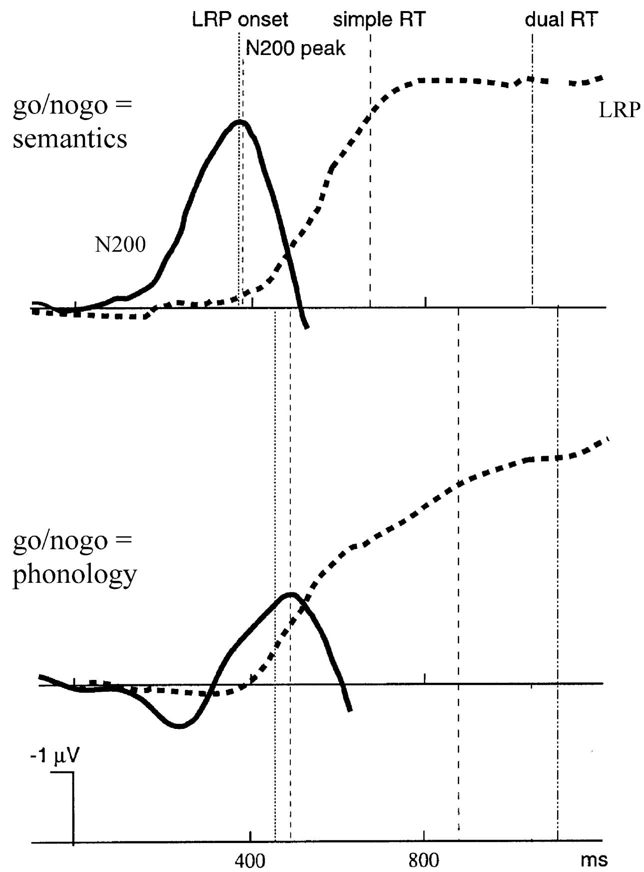

Figure 6. Timeline of N200, lateralized readiness potential (LRP), and reaction times for the hand=phonology condition (top panel) and the hand=semantics condition (bottom panel).

Note that although the N200 and the LRP are plotted on the same timeline in Figure 6, their values were measured at different electrode sites. In the literature, the N200 and LRP are considered to be independent ERP components, where components are defined in terms of their neural generators. In our data, this independence is reflected in their different distribution across the scalp; the LRP is not present at frontal sites, and the N200 is not present at central sites (see Figure 3). Furthermore, because the N200 also precedes the LRP in the ERP signal, we think it unlikely that the two signals actually influence each other or that the measurement of one of them is contaminated by overlap from the other. That said, we do not rule out the possibility of a functional dependency between the two insofar as they reflect response inhibition and response preparation processes.

The timeline in Figure 6 reflects the temporal sequence of neural response inhibition and motor preparation similar to that described by Fuster (1997). Fuster argued that following early visual processing in the parietal and inferotemporal cortex, the information is evaluated by the prefrontal cortex. Our frontal N200 effect may reflect this evaluation. According to Fuster, once evaluated the information is sent by the prefrontal cortex to the motor cortex. It is this activity that is presumed to be reflected in the LRP. This scenario, if accurate, would suggest a functional dependence between response preparation (go LRP) and response inhibition

(N200) processes. Functional dependence of this sort might be reflected in the N200 amplitude and the slope of the go LRP, as shown in Figure 6. In the hand=phonology condition the N200 amplitude was greater and the LRP slope was steeper than in the hand=semantics conditions. This functional dependency might also be reflected in the latency of the N200 and the LRP slope. Late response inhibition (as in the hand=semantics condition), for example, could lead to a go LRP that is not as steep as that following early response inhibition (hand=phonology). Interestingly, the latency difference in the N200 effects across the conditions did not seem to impact the onset of the go LRPs, which were similar in both conditions. We should not forget, however, that the N200 effect is a difference between ERPs elicited by go and nogo trials, whereas the go LRP reflects preparation for a movement that is eventually executed. Thus, the exact nature of the relationship between these two ERP components and their associated neural generators awaits further investigation.

In summary, we used two different ERP components to investigate the temporal processing of semantic and phonological encoding during language processing. In addition to the previously proposed LRP (related to response preparation) component, we introduced the N200 effect (related to response inhibition) as a powerful tool for measuring online processing of language processing. Both the LRP and the N200 results indicate earlier onset of semantic processing compared with phonological processing. Insofar as the task employed involves implicit picture naming (as is assumed), the results are relevant to theories of language production. We found that the LRP and N200 together favor a serial or cascaded processing model of language production in contrast to a parallel processing account.

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APPENDIX A

Pictures Used in the Experiment

Animal names starting with vowel	Animal names starting with consonant	Object names starting with vowel	Object names starting with consonant
Aal (eel)	Bär (bear)	Akkordion (accordion)	Banane (banana)
Adler (eagle)	Biene (bee)	Achse (axle)	Besen (broom)
Affe (monkey)	Fliege (fly)	Ampel (traffic light)	Blume (flower)
Alligator (alligator)	Frosch (frog)	Ananas (pineapple)	Brezel (pretzel)
Ameise (ant)	Giraffe (giraffe)	Angel (rod)	Brunnen (well)
Amsel (blackbird)	Hyäne (hyena)	Anker (anchor)	Bügel (hanger)
Amöbe (amoeba)	Hahn (rooster)	Apfel (apple)	Brille (glasses)
Antilope (antilope)	Hai (shark)	Ass (ace)	Bus (bus)
Assel (wood louse)	Hirsch (deer)	Ast (branch)	Drachen (kite)
Auerhahn (wood grouse)	Katze (cat)	Auspuff (muffler)	Feder (feather)
Eber (boar)	Kaulquappe (tadpole)	Ei (egg)	Gitarre (guitar)
Echse (lizard)	Kuh (cow)	Eis (ice cream)	Hammer (hammer)
Eichhörnchen (squirrel)	Libelle (dragon fly)	Ellipse (oval)	Hose (pants)
Einhorn (unicorn)	Löwe (lion)	Erdbeere (strawberry)	Hut (hat)
Elch (elk)	Maus (mouse)	Erdnuss (peanut)	Kaktus (cactus)
Elefant (elephant)	Mücke (mosquito)	Iglu (igloo)	Kanone (cannon)
Elster (magpie)	Pelikan (pelican)	Insel (island)	Kamm (comb)
Emu (emu)	Pfau (peacock)	Oboe (oboe)	Pfeife (pipe)
Ente (duck)	Schlange (snake)	Ofen (oven)	Pyramide (pyramid)
Esel (donkey)	Schnecke (snail)	Ohrring (earring)	Reifen (tire)
Eule (owl)	Schwan (swan)	Olive (olive)	Schere (scissors)
Igel (hedgehog)	Spinne (spider)	Orange (orange)	Spritze (syringe)
Oktopus (octopus)	Tiger (tiger)	U-Boot (submarine)	Trompete (trumpet)
Opossum (opossum)	Wal (whale)	Ufo (ufo)	Trichter (funnel)
Otter (otter)	Ziege (goat)	Urne (urn)	Zange (a pair of tongs)

APPENDIX B

Illustration of the Eight Different Instructions for the Example of Presenting the Picture "Feather"

8 different instructions (1–4 hand=semantics; 5–8 hand=phonology)	Executed response of the picture "feather" (object, consonant)
1 Press left if animal, press right if object; press only if its name starts with a consonant	Semantics right, phonology GO
2 Press right if animal, press left if object; press only if its name starts with a consonant	Semantics left, phonology GO
3 Press left if animal, press right if object; press only if its name starts with a vowel	Semantics right, phonology NOGO
4 Press right if animal, press left if object; press only if its name starts with a vowel	Semantics left, phonology NOGO
5 Press right if consonant, press left if vowel; press only if object	Phonology right, semantics GO
6 Press right if vowel, press left if consonant; Press only if object	Phonology left, semantics GO
7 Press left if vowel, press right if consonant; Press only if animal	Phonology right, semantics NOGO
8 Press left if consonant, press right if vowel; Press only if animal	Phonology left, semantics NOGO