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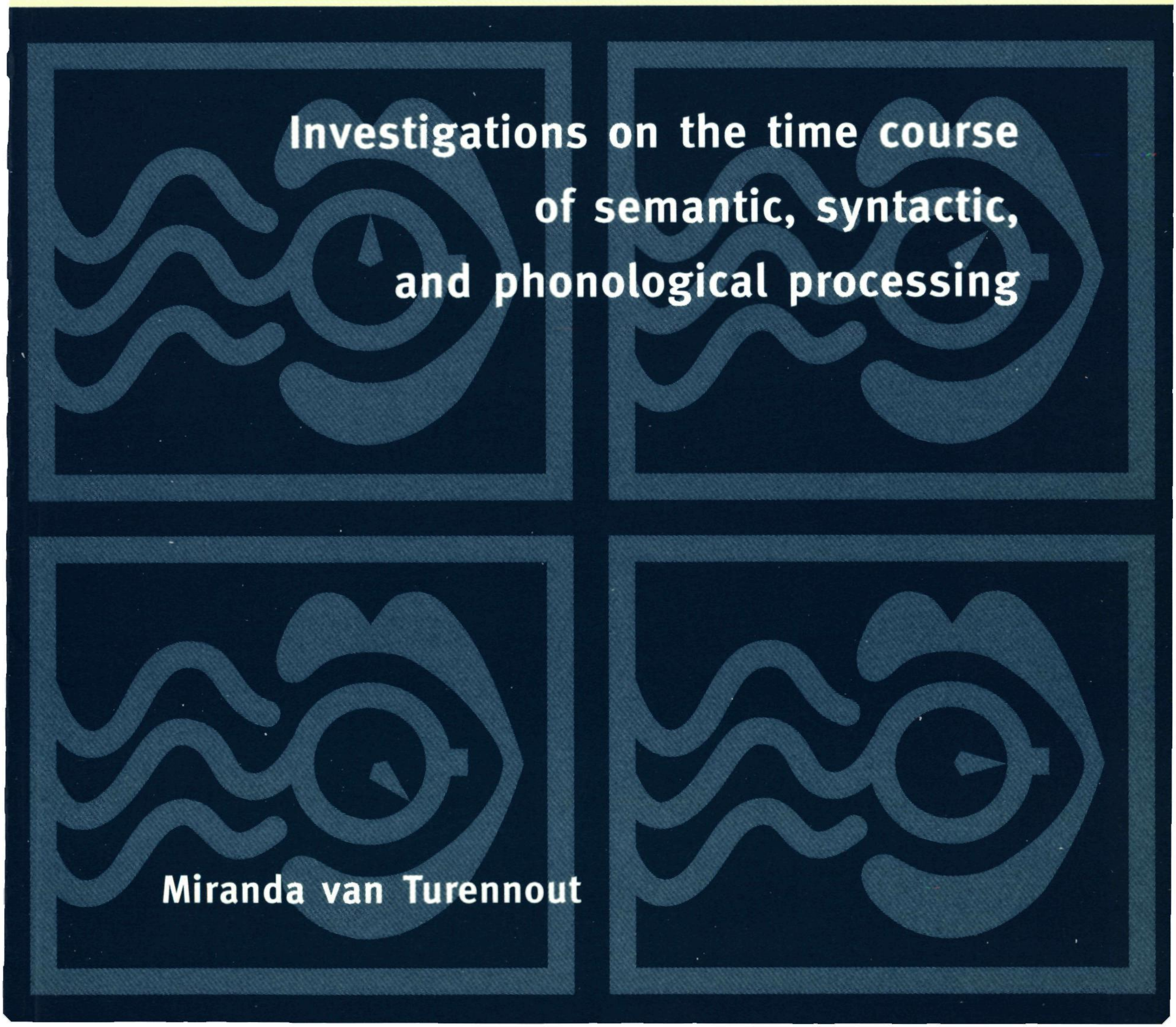
# THE ELECTROPHYSIOLOGY OF SPEAKING



## Investigations on the time course of semantic, syntactic, and phonological processing

Miranda van Turennout

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# THE ELECTROPHYSIOLOGY OF SPEAKING:

## Investigations on the time course of semantic, syntactic, and phonological processing

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op het gebied van de Sociale Wetenschappen

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# INTRODUCTION

CHAPTER 1

When we speak, we are in essence transforming a thought into a structured sequence of sounds. Although healthy adults can produce speech without much apparent effort, this capacity is considered to be one of the most complex human skills. To transform an idea into speech, a speaker has to retrieve word representations from memory that express the intended meaning, to structure them according to the syntactic rules of the language, to retrieve the sound pattern of the words, and to build an articulatory plan for the utterance. In normal conversation this is all done very rapidly: On average speakers produce 2 to 3 words per second (cf. Maclay & Osgood, 1959; Levelt, 1989). Moreover, the error rate is very low: On average speakers make only one word or word-sound error per 1000 words (Garnham, Shillcock, Brown, Mill, & Cutler, 1982). Given this speed and accuracy, it is very likely that most of the mental processes involved in speaking are automatic, that is they are executed without intention or conscious awareness (Levelt, 1989). Moreover, to achieve this high level of fluency, it is of crucial importance that the automatic processes involved in speaking are coordinated in time with great precision. This thesis is about timing in speech production. The focus will be on the time course of the automatic processes that precede articulation.

The traditional methods in speech production research have been the analysis of speech error data, and the reaction-time technique. These methods have been very useful for identifying the separate mental processes underlying speech production, and for generating hypotheses on their coarse temporal organization. However, to obtain a more precise insight into the temporal dynamics of the processes involved in speaking, an on-line measure is required that taps into these millisecond-level processes as they proceed in time. In this thesis, event-related brain potentials (ERPs) are introduced into speech production research. The ERP technique has been successfully used in various research areas of cognitive psychology, including the study of language comprehension (see Rugg and Coles, 1995, for an extensive overview of electrophysiological studies in cognitive science), but has so far not been applied to study the cognitive processes underlying speaking. One of the attractive characteristics of ERPs is that they provide a continuous measure of the brain's electrical activity as it occurs in real-time. Details of ERPs and how they are used in this thesis are described in the second part of this chapter. I will first present an outline of the theory of speech production that has served as a guideline for the present research.

## A THEORETICAL FRAMEWORK OF SPEECH PRODUCTION

In describing the processing mechanisms underlying speaking, psycholinguistic theories usually distinguish between three levels: Conceptual processing, grammatical processing, and phonological processing (Bock, 1982; Bock & Levelt, 1994; Butterworth, 1989; Dell, 1986; Garrett, 1975, 1976, 1980; Kempen & Huijbers, 1983; Levelt, 1989). Corresponding to the distinction between these processing levels, models of speech production posit three types of word representations: *Concepts*, representing a word's meaning, *lemmas*, representing a word's syntactic properties, and *word forms*, incorporating a word's morpho-phonological characteristics.

### Processing levels in speech production

Speaking starts with *conceptualizing*, which can be defined as specifying the conceptual content of the utterance on the basis of a speaker's intention. There are many ways in which a speaker can express an idea. The exact content of the expression depends, among others, on the speaker's knowledge, as well as on the characteristics of the situation the speaker is in. A speaker has to select which of the many aspects of an idea have to be expressed (e.g., depending on the background knowledge of the listener, more or less details have to be included), and has to decide about the form of the expression (e.g., whether to use a statement or a question, whether to be ironic, etc.). Also, a speaker has to order the information, that is, to decide what information is to be provided first, and what will be said later. Furthermore it is important to keep track of one's own speech and to monitor whether the listener actually understood what was being said. These activities are all part of conceptualizing, and require a speaker's explicit attention (see Levelt, 1989, for a detailed description of conceptualizing). The end-product is a conceptual structure, or message (e.g., Garrett, 1975; Levelt, 1989), that represents the content of the utterance.

The conceptual structure is transformed into a linguistic structure during *formulation*. Formulation comprises grammatical encoding and phonological encoding. During grammatical encoding the lemmas that best convey the message are retrieved from the mental lexicon and organized in a grammatical framework of the utterance. Lemmas can be thought of as entries in the mental lexicon that relate a word's meaning to its syntactic properties, such as syntactic word-category and grammatical gender. For example, the lemma *draw* is categorized as a verb that can take a subject and an object, as in the sentence *Inge draws a beautiful bear.* In addition to lemma retrieval, grammatical procedures are initiated that use lemma properties to build up a syntactic structure of an utterance. These procedures involve functional processing, that is, assigning grammatical functions to the items in a sentence (for example, *Inge* is linked to the nominative function, and *bear* is linked to the accusative function). In addition, the grammatical procedures involve positional processing, that is, determining the order in which the lemmas are to be produced. The product of grammatical encoding is a surface structure consisting of an ordered set of lemmas that are not yet specified for their phonological form (for a detailed description of grammatical encoding see Bock and Levelt, 1994. See Kempen and Hoenkamp, 1987, and De Smedt, 1996 for computational models of grammatical encoding).

The sound pattern of the utterance is retrieved during the second part of formulation: phonological encoding. The function of phonological encoding is to generate a phonetic, or articulatory plan for the utterance. This process involves the retrieval of a word's morphemes, its segments, and its metrical structure. For example, in case of the lemma *draw*, marked for progressive tense, the word forms <draw> and <ing> are retrieved. The segmental spell-out for the word form <draw> includes /d/, /r/, /ɔː/, and the metrical information for <draw> specifies that it is monosyllabic. The spelled-out segments are then inserted in the metrical frame, and depending on the context in which the individual words appear a phonological word or phrase will be constructed (for details see, for example, Dell, 1986, 1988; Levelt, 1989; Levelt & Wheeldon, 1994; Meyer, 1992; Meyer & Schriefers, 1991; Roelofs (in press); Shattuck-Huffnagel, 1979, 1983). At a certain point in time during phonological encoding the speaker has to transform these phonological words into an ordered sequence of articulatory movements. It has been suggested that this translation process usually proceeds via the retrieval of an articulatory motor plan for each of the syllables as they occur in connected speech (e.g., Levelt 1989). Crompton (1982) was the first to suggest that syllables are stored as articulatory routines that are accessed during speech production. This idea was elaborated by Levelt (1992, 1993) and Levelt and Wheeldon (1994). Levelt and Wheeldon (1994) argued that high frequency syllables can be thought of as highly overlearned articulatory routines, in which phonetic segments have no independent existence. Although some evidence for this idea has been provided (Levelt and Wheeldon, 1994; Schiller et al., 1996), the existence of such articulatory motor programs for high frequent syllables has not yet been proven beyond reasonable doubt.

Empirical evidence for the distinction between lemma retrieval and word-form encoding has come from speech error data (e.g., Dell, 1986; Garrett, 1975, 1976, 1980, 1988), the tip of the tongue phenomenon (e.g., Brown, 1991; Vigliocco, Antonini, & Garrett, in press), data from studies of language impairment (e.g., Butterworth, 1989), and experimental studies (e.g., Levelt et al., 1991; Schriefers, Meyer, & Levelt, 1990). These data will be discussed in more detail in Chapters Two and Three.

The final stage in speech production is *articulation*. During articulation the phonetic plan is executed by the articulatory system, resulting in overt speech.

## A model of lexical access in speaking

As already has become apparent, the mental lexicon plays a crucial role in the generation of speech. Not only for the simple reason that speech consists of words, but also because lexical representations are assumed to mediate between the separate processing levels (e.g., Dell, 1986; Kempen & Hoenkamp, 1987; Levelt, 1989). The retrieval of lexical items from the lexicon on the basis of a conceptual structure is usually referred to as lexical access. In this thesis I will use the theory of lexical access that has been developed by Levelt and colleagues within the framework of speech production outlined above (e.g., Levelt, 1989). I have chosen to use this theory as a basis for the present research because it is one of the most extensive in the field, encompassing all of the processing levels involved in speaking. Moreover, in the theory clear assumptions are made about the temporal properties of the separate processing stages, and it generates hypotheses on the real-time process of lexical access. For example, the implementation of the theory in a network model by Roelofs (1992, in press) has generated explicit predictions about the latencies with which different word properties will be retrieved in a particular experimental situation. In this respect, it differs from the other models of speech production reported in the literature, such as the one developed by Dell and his colleagues (e.g., Dell, 1986; Dell & O'Seaghdha, 1991, 1992). Dell's model was primarily developed to account for speech errors, and, therefore, time information is not explicitly incorporated in the model. Although in this thesis I do not aim to distinguish between the two models, I will discuss their similarities and differences in more detail in Chapters Two and Four. Now, I will briefly describe the Levelt et al. theory in the form implemented by Roelofs (1992, in press) in a computer model. For a detailed description I refer to Levelt (1989, 1992, 1993), Levelt et al. (1991), Levelt, Roelofs, & Meyer (accepted), and Roelofs (1992, 1996, in press).

Figure 1.1 depicts the structure of the Levelt/Roelofs model. In the model, the mental lexicon is conceived of as a network, and information is retrieved from the network by means of spreading activation (cf., Collins and Loftus, 1975; Dell, 1986; Harley, 1984; Stemberger, 1985). The lexical network consists of three layers of nodes. First, at the conceptual stratum there are concept nodes and labelled links between the nodes. Following Collins and Loftus (1975), each node represents a single concept, and the meaning of the concepts is stored via labelled conceptual links between the nodes. For example, the 'is-a' link between the concept *bear* and the concept *animal* specifies that bear is a subtype of animal. Each lexical concept (that is, a concept for which a word exists) is represented by an independent node.[1] The lexical concept nodes are linked to nodes at the second layer of the network: the syntactic stratum. The syntactic stratum contains lemma nodes, syntactic property nodes, and labelled links between them. At this stratum, the syntax of words is specified. For example the 'syntactic category' link between the lemma node *bear* and the syntax node *noun* indicates that the word bear is a noun. Lemmas also contain morpho-syntactic slots for parameters to be filled in during grammatical encoding, such as tense (e.g., present), number (single

[1] *The non-decompositional approach to lemma retrieval (cf. Collins and Loftus, 1975; Fodor, 1976; Fodor, Garrett, Walker, & Parkes, 1980) followed by Roelofs contrasts with decompositional theories (cf. Bock, 1982; Dell, 1986; Stemberger, 1985). In decompositional theories lemmas are not retrieved on the basis of a single conceptual representation, but are represented by sets of semantic features. For arguments why a non-decompositional approach was taken in the present theory, see Roelofs (1997).*

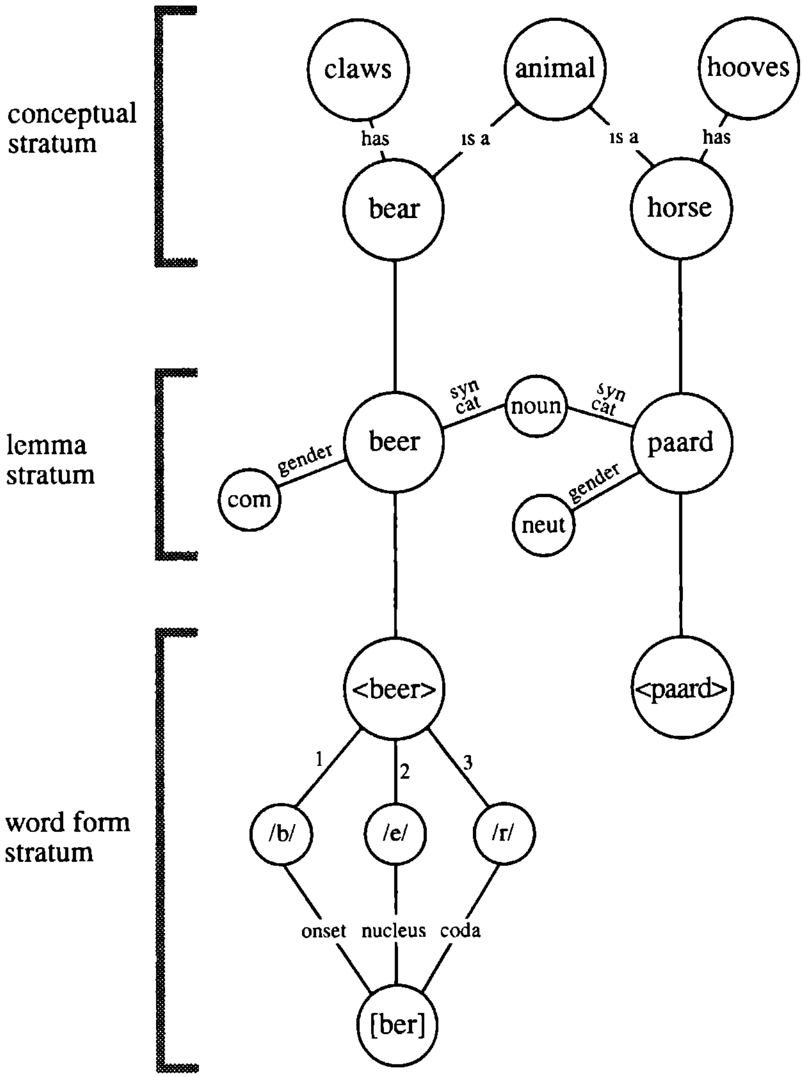


**Figure 1.1** *Fragment of the lexical network in the Levelt/Roelofs model of lexical access. The lexical network consists of three layers of nodes: In the conceptual stratum nodes represent lexical concepts. In the next layer, the lemma stratum, nodes represent lemmas and their syntactic properties. In the word-form stratum, nodes represent word forms and their phonological segments, and syllables.*

or plural), and person (first, second or third). The next stratum is the word-form stratum. The word-form stratum contains three layers of nodes. Word-form nodes are linked to lemma nodes and they represent roots and affixes. Word-form nodes point to segment nodes, and to the metrical structure of a word. The links between word-form and segment nodes indicate which segments are included in a word, and at which position in the word a segment occurs. In turn, each segments points to each syllable in which it can occur, specified for its position in the syllable. The actual syllables of a word are constructed on line, and depend on the phonological context in which a word appears.

As I mentioned above, an important characteristic of Roelofs' model is that it explicitly incorporates time information. I will shortly describe the manner in which words are retrieved in the model.

Lemmas are retrieved by means of forward spreading of activation in the network. As a result of message encoding, activation spreads through the conceptual network down to the syntactic stratum. Due to the spreading of activation at the conceptual layer a set of lemma nodes will be activated. The activational level of a lemma can be computed for each particular point in time. A lemma's activational level at point $(t + \Delta t)$ is determined by its activation at point $t$, and the rate with which this activation decays, plus the activational level of the connected nodes and the weights on the links between the nodes. The probability that a lemma indeed becomes selected at a particular point in time is given by the ratio of its own activational level and the activational level of other lemma nodes at that point in time (the Luce ratio). The expected lemma retrieval time can be computed given this ratio (see Roelofs, 1992 for details). Once a lemma has been selected, activation spreads to the word-form stratum. The important assumption at this point in the theory is that *only* selected lemmas will activate their word form. For the time course of word retrieval this assumption implies that lemma selection will always *precede* activation of the word form.

In the word-form stratum, activation spreads forward from word-form nodes to segment and syllable nodes. Nodes are selected according to similar rules as described for lemma selection. For a detailed description, I refer to Roelofs (in press). For the purpose of this thesis, an important aspect of word-form encoding in the model is that a word form is constructed from left to right. When a word-form node has been activated by its lemma, it immediately activates all of its segments, and its metrical frame. The segments are associated to the syllable nodes within the metrical frame. The association proceeds from left to right: from the segment whose link is labelled first to the one whose link is labelled second and so forth. This implies that a word form is build up in a serial order, from its beginning to its end.

Computer simulations have shown that the model accounts for a variety of empirical findings. For example, it explains the classical reaction time curves for semantic interference effects in picture naming and picture categorizing (as obtained, for instance, by Glaser and Düngelhoff, 1984; see Roelofs 1992), it accounts for the dissociation between semantic and phonological effects obtained in picture-word interference studies (as obtained by Schriefers, Meyer, and Levelt, 1990), and it has been shown to fit a variety of reaction time data on phonological encoding (e.g., Roelofs, in press; see Levelt et al. (accepted), for an extensive overview).

In this thesis I will concentrate on the basic assumption in the Levelt/Roelofs theory that different aspects of a word are retrieved in a serial order: A word's semantic and syntactic properties are retrieved before its word form can be encoded, and the phonological form of a word is constructed from left to right.

Although there is ample evidence for the distinctiveness of lemma retrieval and word-form encoding, no direct evidence has yet been provided on their temporal parameters. In my opinion, this is in large part due to limitations of the standard methodologies in speech production research. First, analyses of speech errors do not provide information on the time course of *normal* speech production processes: Speech errors are by their very nature the result of a failing production process. More importantly, they are the end-product of a series of retrieval and encoding processes that have run their course before the error was produced. Therefore they cannot provide a critical test of the hypothesized temporal separation of lemma retrieval and word-form encoding. A second methodological limitation concerns the temporal precision with which reaction-time measurements can be related to the real-time production process. Although reaction-time research has provided insights into the coarse temporal organization of the processes involved in speaking (see, for example, Levelt et al., 1991), reaction times do not provide a continuous measure of the ongoing process. If we want to tap into the real-time aspects of speaking, then ideally we need to use a continuous measure. This was one of my main reasons to develop an experimental paradigm in which ERPs are used to track the time course of lemma and word-form retrieval in speech production. Before describing the experimental procedure, I will first give a brief general introduction on ERPs.

## EVENT-RELATED BRAIN POTENTIALS

In the 1970s, researchers working in the field of cognitive psychology started to use the electrical activity of the brain in the investigation of perception, attention, memory, motor control, and language processing. By now, there is ample evidence showing that regularities in electrical brain activity can be observed that are time-locked to an external event. These regularities are known as event-related brain potentials (ERPs), and can be used as indexes for ongoing perceptual and cognitive processes as they unfold over time. (See Rugg and Coles (1995) for an extensive review of the use of the ERP technique in cognitive psychology.)

### General description of ERPs

The variation in electrical activity that is produced by large populations of brain cells can be measured by electrodes placed on the scalp. The voltage variation over time occurring at the scalp is known as the Electroencephalogram (EEG). ERPs are part of the EEG. They represent a series of voltage changes within the EEG that are time-locked to the occurrence of an external event. For example, if a stimulus is presented to an individual, voltage changes occur in the EEG that are time-locked to the onset of the stimulus. These voltage changes make up the ERP, and reflect activity that is directly related to stimulus presentation. Whereas the strength of the EEG signal can vary between -100 and 100 microvolt, the amplitude of voltage changes in ERPs is much smaller, often not more than 5 microvolt. Because of their small amplitude, ERPs can usually not be observed in the raw EEG. To extract the ERPs from the spontaneous EEG, an averaging procedure is applied over a number of EEG epochs, each of which is time-locked to the same event. This means that similar stimuli are presented a number of times, and an average ERP is calculated over the individual EEG epochs that are time-locked to the onset of the stimuli. The assumption behind this procedure is that electrical activity that is not related to the stimulus event varies randomly over time across the individual epochs. The effect, then, of averaging these individual epochs is that the randomly distributed activity (the spontaneous EEG) will tend to average to zero, leaving an event-related activity that is time-locked to the stimulus presentation. The number of epochs that is required in an average to cancel out the randomly distributed activity depends on the amplitude of the ERP component of interest. In language research, as a rule, a minimum number of 25 trials is required for averaging to obtain an acceptable signal-to-noise ratio (Kutas & Van Petten, 1994).

The average ERP signal consists of a series of positive and negative peaks, usually referred to as components, that occur as a result of stimulus processing. A basic distinction that is often made, is the distinction between exogenous and endogenous components. Exogenous components are evoked by the physical characteristics of an external stimulus. They occur early in the ERP (with latencies of less than 100 ms), and are relatively insensitive to cognitive processes. Of more interest for investigations of higher cognitive functions are the so-called endogenous components. Endogenous components can occur several hundreds of milliseconds before or after an event (e.g., a voluntary movement, or the presentation of a word). Endogenous components vary as a function of task demands and instructions, and they reflect cognitive aspects of stimulus processing.

The relationship between the potentials recorded at the scalp and the activity that occurs in the brain is not completely clear. However, there is agreement on some aspects of the biological basis of ERPs (e.g., Nunez, 1990). To get an idea of the complexity of the brain's neuronal organization and the activity that it produces, consider that a cortical column area equal to 1 $mm^2$ contains about $10^5$ pyramidal cells (neurons). This means that it probably contains more than $10^9$ synapses. The activity of even a small portion of these synapses leads to a complex pattern of current flow and voltage variations within a very small part of brain tissue (Nunez, 1990). Recordings of the fluctuating potentials at this microscopic level are usually not of direct interest for researchers working on higher cognitive processes. Potentials recorded from the scalp offer a more selective view of the electrical activity in the brain. It is generally believed that the main contribution to the electrical activity recorded at the scalp is made by dipole sources originating from cortical layers containing cells that are aligned in parallel, with the same orientation. Scalp recorded potentials reflect post-synaptic (dendritic) activity. The most likely contributors to scalp recorded potentials are cortical pyramidal cells because they are large, and their dendritic processes are organized in parallel. The parallel organization of dendrites leads to a summation of their electrical fields and yields a bipolar field. Thus, electrical activity recorded at the scalp is believed to be a summation of post-synaptic potentials that are generated by a large number of pyramidal cells that are synchronously active (for detailed discussion of the physiology of ERPs, see Allison, Wood, & McCarthy, 1986; Nunez, 1981, 1990; Scherg & Picton, 1991; Wood, 1987).

The selectivity of the potentials occurring at the scalp has as disadvantage that not all neural processes underlying cognitive functions are reflected in the ERP. Moreover, due to the conductive properties of brain tissue, potentials recorded at particular scalp locations do not necessarily reflect activity in the brain region that lies directly underneath the electrode site. It is a complicated, and still unsolved problem to identify ERP sources directly from scalp recorded potentials. Most of the evidence for the neurophysiological basis of ERPs has come from other approaches, such as ERP studies in brain lesioned patients, intracranial recordings, and functional neuroimaging techniques (for discussion on this topic see Coles and Rugg, 1995; Knight, 1990; McCarthy and Wood, 1987; Nunez, 1990).

Cognitive psychologists usually take a 'functional' approach in defining and characterizing ERP components. In contrast to the physiological approach that attempts to determine the neuronal sources of the ERP, the functional approach attempts to define ERP effects in terms of specific cognitive processes.[2] In general, the following features are used to characterize a component: polarity, latency, distribution across the scalp, and the experimental manipulation by which it is elicited (cf. Donchin, Ritter, & McCallum, 1978; Kutas & Van Petten, 1994). A component has either a positive or a negative polarity, and is often appropriately labelled by either an N or a P. Latency is measured in milliseconds from stimulus onset, and in addition to their polarity label, components are usually labelled according to the latency at which their amplitude reaches its maximum.[3] Moreover, the graded distribution of latency and amplitude values over electrode sites can serve as one of the ways in which to distinguish between components, especially if components partly overlap in time.

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[2] *The identification of endogenous components is still a controversial issue. One of the major complications involves the problem of overlapping components. Multiple ERP components can be elicited by the same event. If these components occur within the same latency range the problem arises that it is difficult to distinguish between the components, and that it is problematic to establish in what way separate cognitive processes contribute to the observed potentials (cf. Coles & Rugg, 1995).*

[3] *An ERP component can also be named after the cognitive operation that it is supposed to reflect. For example, the so-called 'readiness potential' is a negative shift in the ERP signal that reflects when individuals 'make themselves ready' to move.*

A component is functionally described in terms of the experimental effects that it demonstrates. The experimental manipulations that a component is sensitive to, provide insight into which cognitive operation it reflects. Because cognitive processes are usually active in parallel, this is not a straightforward issue (see note 2). Carefully designed experiments are required to relate a component to a certain cognitive process. The most important components that have been related to language processing are the N400 (Kutas & Hillyard, 1980), and the Syntactic Positive Shift (SPS, or P600) (Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992). The component that is used in the present study is the lateralized readiness potential (cf., Coles, 1989). I will describe the main characteristics of these components below.

## Recording ERPs

An ERP is obtained by recording the difference in potential between two electrodes sites. The usual procedure is to relate each of the scalp electrodes to a single reference electrode, which is, for example, placed on the mastoid bone of the left or right ear (see for discussion on the influence of the position of the reference electrode, for example, Nunez, 1990). Electrode locations are usually described according to the 10-20 system (Jasper, 1958). In this system, the electrode sites are labelled in terms of the general cortical area (e.g., F = frontal, C = central, and P = parietal), and their position in the lateral plane (odd numbers refer to the left hemisphere, even numbers refer to the right hemisphere, and z refers to the midline position). Thus, for example, C3 defines a left central site, and C4 defines a right central site.

The ERP signal is amplified and filtered according to standard rules, and is digitized, usually with a sampling frequency of 200 Hz (see Coles, Gratton, Kramer, & Miller, 1986 for detailed information on signal acquisition). In the recording of the EEG, eye movements, blinks, muscle activity in the face and neck, tongue movements and other excessive motor activity produce serious electrical artefacts. To minimize the occurrence of these artefacts, participants are asked to relax, to sit still, to fixate their eyes, and to not blink during the recording epochs. However, in practice, there is always a small portion of trials on which the recorded brain activity is contaminated by artefacts. To detect more easily on which trials artefacts were caused by eye movements, pairs of electrodes are placed on the face near the eyes. The most common way to deal with trials that are contaminated by artefacts is to exclude them from the data set.

## ERPs and language processing

In 1980, Kutas and Hillyard were the first to report that semantically anomalous words appearing at the end of a sentence (as in: "He spread the warm bread with butter and *socks*") elicited a large-amplitude negative peak in the ERP signal that reaches its maximum value around 400 ms after the onset of the anomalous word. Semantically congruous words elicited the same ERP-profile, but the amplitude of the negative peak was much smaller compared to the anomalous endings. The study by Kutas and Hillyard (1980) was the first to show an ERP component that is sensitive to a manipulation of the semantic content of language stimuli. This component was labelled the N400, and the modulation of its amplitude by semantic context is known as the N400 effect. This discovery provided the starting point for a rapidly growing and exciting research area on the electrophysiology of language comprehension. Subsequent research has shown, for example, that the N400 amplitude is sensitive to a variety of subtle semantic manipulations, such as word expectancy, and semantic relatedness. Furthermore, the N400 is elicited by visual words as well as by auditory words. For a detailed overview of this research area see Kutas and Van Petten (1988, 1994) and Osterhout and Holcomb (1995).

Recently, an ERP component has been reported by Hagoort, Brown, and Groothusen (1993), and Osterhout and Holcomb (1992), that is sensitive to syntactic processing in sentence comprehension. When individuals are presented with sentences in which a syntactic error occurs (as in: "The spoilt child *throw* the toy on the ground"), a positive shift can be observed in the ERP waveform that starts at about 500 ms and extends for several hundred milliseconds. This component has been labelled the syntactic positive shift (SPS), or P600. Subsequent research has shown that the SPS can also be observed as a response to a violation of syntactic preference (e.g., Brown & Hagoort, 1997). The dependence of the N400 on semantic context, and the dependence of the SPS on syntactic context have made them important tools to study on-line sentence processing (for an overview of language-related ERPs, see for example Osterhout and Holcomb, 1995).

In contrast to the successful use of the ERP technique in language comprehension research, the investigation of brain potentials preceding and during speaking has been controversial. The main reason for the controversy has been the contamination by neuromuscular artefacts of the brain potentials during speech. The muscular activity during articulation causes serious artefacts in the ERP signal, and excludes a valid interpretation of the results. The relatively few ERP studies on speech production that have been reported in the literature concentrated on brain potentials preceding articulation. In line with the early ERP work on language processing, the focus of these studies was on discovering hemispheric specialization for speech production processes. McAdam and Whitaker (1971) were the first to report that brain potentials preceding speech are larger at left than at right electrode sites. Grözinger, Kornhuber, and Kriebel (1975, 1977) also claimed that some portion of the lateralized activity that can be observed before the articulation of words was specifically related to speech production. However, in addition they reported that activity of the articulatory muscles can already be observed 300 ms before speech onset. Brooker and Donald (1980) performed a series of experiments in which they investigated in detail the contribution of muscular activity to the earlier reported ERP asymmetries. On the basis of their results they concluded that "Prevocalization potentials appear to be severely confounded by muscle artifact ... the results suggest not only that muscle artifact confounds lateral EEG placements during vocalization, and that it can produce apparent EEG asymmetries, but also that the confounds are so complex and subtle that one or two myogenic recording channels may not be sufficient to control for these confounds." (Brooker and Donald, 1980, p. 242). Although in later studies attempts were made to avoid many of the identified sources of artefact, as yet the problems have not been solved (see Wohlert, 1993 for an overview).

The research presented in this dissertation focuses on the time course of the different cognitive processes underlying speech production. Because of the artefacts that are evidently caused by the physical realization of speech, the research does not aim to use or to identify ERP components that reflect semantic, syntactic, and phonological processing during speaking. Instead, a new experimental paradigm is used in which the lateralized readiness potential (LRP) is used to track the time course of speech production in an indirect way. The LRP paradigm provides the possibility to tap into separate processing stages of speech production before articulation has started. I will first describe

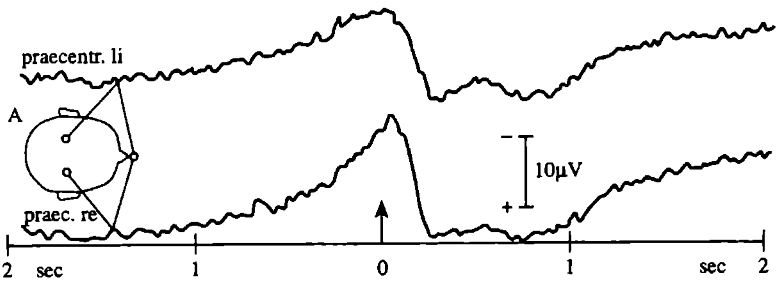


**Figure 1.2** *Readiness potential or Bereitschaftspotential during voluntary movement of the left hand. The negative going potential during movement preparation is larger over the contralateral (right) hemisphere. Average of 512 movements. Zero is the onset of movement in the electromyogram. (After Kornhuber and Deecke, 1965)*

the characteristics of the LRP, and then explain the experimental paradigm.

## The lateralized readiness potential

The lateralized readiness potential is a motor-related brain potential that *precedes* a specific hand movement. In 1965, Kornhuber and Deecke reported that when a person prepares to make a self-paced finger movement, a slow, negative potential develops on the scalp. They called this potential the Bereitschaftspotential, or readiness potential, and their classic finding is shown in Figure 1.2. The same finding was independently reported by Vaughan, Costa, and Ritter (1968). As can be observed in Figure 1.2, the readiness potential is a ramp-shaped negative potential that starts to develop about 800 to 1000 ms prior to the movement and that reaches its maximum amplitude at about the time of the overt movement. Some time before movement onset, the readiness potential becomes more negative over the scalp site contralateral to the moving hand. Kutas and Donchin (1974, 1980) showed that this asymmetry is largest for central sites (C3 and C4) and is evident for both left and right hand movements. In their 1980 study, Kutas and Donchin varied the extent to which individuals could anticipate response hand (left or right hand), and response timing (the moment at the which the response had to be given). They found that the readiness potential was sensitive to the presence of prior information about the response. The readiness potential started to develop earlier when individuals were informed about the moment at which the response should be given, compared to when no prior information about response timing was available. The extent to which individuals had knowledge about which hand to use for the response affected the lateralization of the readiness potential. That is, the lateralization of the readiness potential appeared to be dependent on the moment at which a choice was made about the responding hand. These results led Kutas and Donchin to conclude that "... at least a portion of the readiness potential is a manifestation at the scalp of neural activity related to the preparation for a motor response." (1980, p. 110).

The suggestion that the asymmetry of the readiness potential can be used as an index of motor preparation has been supported by a number of findings. First, there is neurophysiological evidence showing that the lateralized part of the readiness potential is generated, at least in part, by the motor cortex. This evidence includes findings obtained by single-cell recordings in monkeys (e.g., Arezzo & Vaughan, 1976; Miller, Riehle, & Requin, 1992; Requin, 1985; Riehle & Requin, 1989) and findings obtained by magnetic field recordings (e.g., Okada, Williamson, & Kaufman, 1982). Second, the amount of lateralization of the readiness potential appears to be directly related to the onset of overt motor behavior. That is, an overt response is initiated at the moment at which the lateralized readiness potential has reached a particular threshold value (Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988). Third, various studies have shown that the readiness potential can start to lateralize even when a response has not yet been completely specified (see Coles, 1989; Coles, Smid, Scheffers, & Otten, 1995). For example, it has been shown that in reaction time tasks lateralization of the readiness potential is affected by the presence and validity of prior information about the target stimulus (e.g., Gehring, Gratton, Coles, & Donchin, 1992), by fast guesses about the target stimulus (e.g., Gratton et al., 1988), and by the partial evaluation of the target stimulus (e.g., Gratton et al., 1988; Miller & Hackley, 1992; Osman, Bashore, Coles, Donchin, & Meyer, 1992; Smid, Mulder, Mulder, & Brands, 1992). Taken together, these findings provide converging support for the idea that the lateralized readiness potential provides a real-time measure of selective response preparation.

Not all lateralized activity occurring at the scalp can be attributed to motor preparation. Therefore, if one wants to use the asymmetry between the electrical activity above the left and the right motor cortex as a measure for response preparation, it is important to eliminate all lateralized activity that is not specifically related to motor preparation. To achieve this, a procedure was developed by Coles, Gratton, and Donchin (1988) and De Jong, Wierda, Mulder, and Mulder (1988) which applies to an experimental situation in which the interest is not on the left or right hand response per se. Rather, the research focus is on examining the occurrence of response preparation for either a correct or an incorrect response, independent of whether this response is executed with the left or the right hand. The procedure involves the following (see Figure 1.3). First, for each trial, the amount of lateralized activity is obtained by subtracting potentials recorded from above the left motor cortex (C3') from potentials recorded from above the right motor cortex (C4'). These differences are averaged separately for trials on which the left hand would have been the correct response hand, and for trials on which the right hand would have been the correct response hand. In the second step, the average lateralization obtained for the left-hand trials is subtracted from the average lateralization obtained for the right-hand trials.[4] The idea behind this procedure is that lateralized activity that is *not* specifically related to response preparation will be the same on *both* left- and right-hand trials, and will therefore be eliminated by the second subtraction. The resulting measure is the LRP, reflecting the selection and preparation of a response hand (Coles, 1989; Coles et al, 1988; De Jong et al., 1988).

### Using the LRP to detect partial information transmission

The LRP has been used in a variety of studies to assess the interaction between information processing and motor control (see Coles et al., 1995, for an overview). In particular, the LRP has been used to detect transmission of partial information between perceptual and motor processes (e.g., Coles, 1989; De Jong et al., 1988; Miller & Hackley, 1992; Osman et al., 1992; Smid et al., 1992). Some of the most compelling evidence that response preparation can start on the basis of partial stimulus information comes from studies in which the LRP technique is combined with a two-choice reaction go/no-go paradigm (e.g., Miller & Hackley, 1992; Osman et al., 1992; Smid et al., 1992). In this paradigm, one attribute of a stimulus indicates a left- or right-hand response,

[4] *The procedure described here corresponds to the one described by De Jong et al. (1988). They initially called the resulting measure the corrected motor asymmetry. The procedure is similar to the one described by Coles et al. (1988). Coles et al. (1988, 1989) average the lateralization obtained for the left hand trials with the lateralization obtained for the right hand trials, instead of subtracting the lateralization obtained on the left- and right-hand trials.*

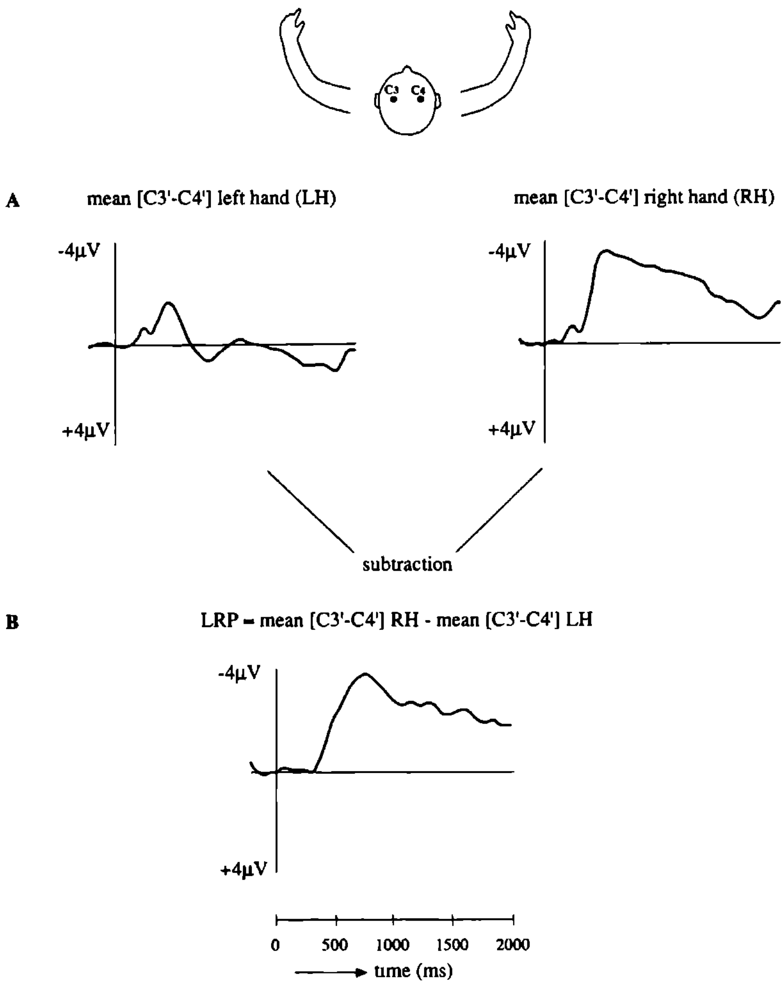


**Figure 1.3** *Derivation of the Lateralized Readiness Potential (LRP). First, on each trial, for each sample point, the difference is obtained between potentials recorded from electrode sites C3' and C4', located above the left and right motor cortices. These difference waveforms are averaged separately for trials in which the left versus the right hand is cued (A). Second, to cancel out lateralized potentials that are not specifically related to response preparation, the waveform obtained for the left-hand trials is subtracted from the waveform obtained for the right-hand trials (B). The resulting LRP reflects the average amount of lateralization occurring as a result of the motor preparation of response hands. The LRP deviates from the baseline in upward direction as soon as response preparation for the cued response hand occurs.*

while another attribute of the same stimulus indicates whether or not the response has to be given. The distinction between response hands is usually determined by an easily identifiable stimulus attribute while the go/no-go distinction is determined by a more difficult to discriminate stimulus attribute. For example, Miller and Hackley (1992) presented individuals with large and small Ss and Ts, and assigned these stimuli to left hand, right hand, or no-go responses. Letter shape determined left versus right response hand, and letter size indicated whether the response should be given or withheld. Thus, for example, a large T would indicate a left hand response, whereas a small T would indicate not to respond, and a large S would indicate a right hand response, whereas a small S would indicate not to respond. In earlier studies, it was established that with these stimuli shape is distinguished more rapidly than size. The idea behind the paradigm is that if response preparation begins as soon as stimulus information is perceived, the stimulus attribute that becomes available early during the perceptual analysis (i.e., shape) could be used to prepare a response hand before the slower attribute (i.e., size) becomes available to distinguish between go/no-go.

The critical predictions in the Miller and Hackley study concerned the presence of an LRP on no-go trials. If shape information would be used to differentially activate response hands before the stimulus size is fully analysed, one expects to observe an LRP on both go and no-go trials. The results showed that, indeed, an LRP initially developed on no-go trials at about the same latency as on go-trials, but after some time returned to baseline without producing an overt response. This indicates that partial stimulus information activated the correct response hand before complete stimulus information became available to distinguish between go and no-go.

Similar results were obtained independently by Osman et al. (1992) and by Smid et al. (1992), who used the same experimental paradigm but different stimulus sets. An important finding in the Osman et al. (1992) study was that they could separately manipulate the moment at which an LRP started to develop, and the moment at which the go and no-go LRP started to diverge. They found that the onset of the LRP could be delayed by prolonging the amount of time required to make a response hand distinction. This manipulation, however, did *not* affect the moment at which the go and the no-go LRP started to diverge. Importantly, at the same time they found that the moment of go/no-go divergence was influenced by the discriminability of the go/no-go stimuli, while this manipulation did *not* have any effect on LRP onset. This pattern of results clearly indicates that the LRP is differentially sensitive to the time course of the processes that lead to response hand selection, and to the time course of the processes that lead to the go/no-go distinction.

A study by Miller, Riehle, and Requin (1992) provided neurophysiological evidence that activity in the primary motor cortex is indeed affected by preliminary stimulus information. Single neurons were recorded in the primary motor cortex of a monkey while the monkey was performing a two-choice decision go/no-go task. The results showed that shortly after stimulus onset a large portion of the responses of sensory neurons (M1 neurons whose responses are time-locked to stimulus presentation) and of sensorimotor neurons (M1 neurons that connect between sensory neurons and motor neurons) were similar on go and no-go trials.[5] This finding corresponds well to the initial development of the LRP on go and no-go trials observed by Miller and Hackley (1992) and by Osman et al. (1992). At a later point in time, responses of motor neurons (i.e., neurons whose responses are time-locked to the execution of the response) were found to be much larger on go trials than on no-go trials. This finding corresponds well to the increasing development of the LRP that was observed on go trials.

Taken together, these studies provide strong evidence that the LRP is a real-time measure of the selection and preparation of motor responses. Moreover, they show that preliminary stimulus information is transmitted to the motor system, and used for response selection before complete stimulus information is available. The sensitivity of the LRP to response selection implies that the LRP can be used to determine whether and when a motor response is selected. Moreover, when combined with the two-choice go/no-go paradigm, the LRP can be used as an index of the relative moments in time at which different aspects of a stimulus become available for response selection. These characteristics of the LRP open the way for applying the LRP to questions concerning the time course of processes underlying speech production. The idea is as follows.

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[5] *For a review on the distinction between sensory, sensorimotor, and motor neurons, see Requin, Riehle, and Seal (1988).*

### Using the LRP in the study of language production

To use the LRP to detect the separate moments in time at which different aspects of a word become available, an experimental situation is required in which these aspects are related to response preparation. The response conditions have to be chosen in such a way that the influence of one type of information on response preparation can be distinguished from the influence of the other type. As was explained above, a procedure that meets this requirement is the two-choice reaction go/no-go paradigm, which is the paradigm that is used here. In addition, a picture naming task is used to initiate the speech production process. Picture naming has become an established experimental task in speech production research (see Glaser, 1992, for an extensive overview). Before a picture can be named, it has to be perceptually analysed. Moreover, the depicted object has to be conceptually identified and its name has to be retrieved from the mental lexicon. The plausible assumption behind the picture naming task is that it involves all processing stages of speech production: On the basis of the conceptual identification of the picture the appropriate lemma is selected, followed by the construction of the word form, and articulation.

If the distinct processing levels in speech production operate under different time courses, the information generated at these levels will be available at separate moments in time. Thus, for example, if lemma retrieval precedes phonological encoding in time, syntactic information about a word will be available earlier than word-form information. Based on the findings of the LRP studies mentioned above, it is plausible to assume that distinct types of information can be transmitted to the motor system as soon as they become available during the speech production process. This means, for instance, that if during picture naming syntactic information is retrieved earlier in time than phonological information, a response can be selected on the basis of syntactic information before phonological information has become available for response preparation. Then, the initial development of the LRP will be influenced by syntactic information alone. Only at a later moment will phonological information affect the LRP. By observing LRPs on no-go trials and comparing these waveforms with those on go trials, it is possible to determine the relative moments in time at which different properties of a word become available. This is the general research strategy that is used in this thesis. A more detailed description of the paradigm will be given in Chapter 2, and in Chapter 3.

## AIMS AND STRUCTURE OF THE THESIS

The first aim of the thesis is to validate a new experimental paradigm in speech production research, in which the LRP is used to study the time course of the separate processing stages underlying speaking. The second aim is to find evidence for a temporal separation between the distinct stages of speech production. In Chapter 2, I will concentrate on the separation in time between retrieving a word's semantic and phonological properties. In Chapter 3, I will focus on the temporal separation between grammatical and phonological encoding in noun phrase production, and on the corresponding distinction between lemma and word-form retrieval. The third aim of the thesis is to explore the temporal parameters of word-form encoding: Chapter 2 investigates the relative timing of the phonological encoding of a word's beginning and its end. A summary and general discussion of the main findings in the thesis will be provided in Chapter 4. In addition, an attempt will be made to estimate the speed with which a word form can be constructed.

# ELECTROPHYSIOLOGICAL EVIDENCE ON THE TIME COURSE OF SEMANTIC AND PHONOLOGICAL PROCESSES IN SPEECH PRODUCTION

*Miranda van Turennout, Peter Hagoort, & Colin M. Brown*

CHAPTER 2

## ABSTRACT

The temporal properties of semantic and phonological processes in speech production were investigated in a new experimental paradigm using movement-related brain potentials. The main experimental task was picture naming. In addition, a two-choice reaction go/no-go procedure was included, involving a semantic and a phonological categorization of the picture name. Lateralized readiness potentials (LRPs) were derived to test whether semantic and phonological information activated motor processes at separate moments in time. An LRP was only observed on no-go trials when the semantic (not the phonological) decision determined the response hand. Varying the position of the critical phoneme in the picture name did not affect the onset of the LRP, but rather influenced when the LRP began to differ on go and no-go trials, and allowed the duration of phonological encoding of a word to be estimated. These results provide electrophysiological evidence for early semantic activation and later phonological encoding.

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Speaking is a central skill of the human species. An essential component of this complex human capacity is to transform a mental concept into a sequence of spoken sounds. If, for instance, people want to name an object in their environment, the visual recognition of the object allows them to activate an associated concept. This concept is used to retrieve from the mental lexicon all the information required for pronouncing the name of the object. The lexical information concerns semantic and syntactic specifications of the object name, as well as its sound pattern. The process of mapping a conceptual structure onto lexical representations is referred to as lexical access. To date, most speech production research has been dedicated to the study of lexical access.

At a general level, lexical access can be fractionated into semantic and phonological processing. It is generally acknowledged that these two are distinct, and that they exploit different kinds of knowledge (Butterworth, 1989; Dell, 1986; Garrett, 1975, 1976, 1988; Kempen & Huijbers, 1983; Levelt, 1989). There is less agreement, however, on the interplay over time between semantic activation and phonological encoding. Evidence on the time-course of semantic activation and phonological encoding has come from analyzing word-order preferences (e.g., Bock, 1986), speech error analyses (e.g., Dell, 1986) and from reaction-time research (e.g., Levelt et al., 1991; Schriefers, Meyer, & Levelt, 1990). In the present study, we introduce a new technique into the field of language production: the registration of event-related brain potentials (ERPs). One of the useful characteristics of ERPs is their millisecond-to-millisecond temporal resolution. They have been successfully used to study the nature and the temporal properties of several cognitive processes, such as language comprehension (e.g., Hagoort, Brown, & Groothusen, 1993; Kutas & Hillyard, 1980; Kutas & Van Petten, 1988; Osterhout & Holcomb, 1992), attention (e.g., Hillyard, Mangun, Woldorff, & Luck, 1995; Hillyard & Münte, 1984; Näätänen, 1990), memory (reviewed in Rugg, 1995), and perceptual-motor information transmission (e.g., Coles, 1989; De Jong, Wierda, Mulder, & Mulder, 1988; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988; Miller, 1991). However, there is no report in the literature of ERP studies focusing on cognitive processes underlying speaking. The present study is the first that uses ERPs to measure the time course of semantic activation and phonological encoding in speech production.[1]

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*[1] There are some reports of ERP studies on speech production, but these studies focused on motor mechanisms underlying speaking (e.g., Deecke et al., 1986; McAdam & Whitaker, 1971; Grözinger, Kornhuber, & Kriebel, 1977; Wohlert, 1993).*

## GENERAL MODEL OF SPEECH PRODUCTION

The various cognitive processes involved in speaking are usually partitioned into three types (Bock, 1982; Dell, 1986; Garrett, 1975, 1988; Kempen, 1977; Kempen & Hoenkamp, 1987; Levelt, 1989). The generation of an utterance starts with *conceptualization.* This process specifies the content of the utterance and generates a prelinguistic representation of the intended speech. The result is a conceptual structure that serves as input for formulation. In this process, the linguistic representation that best matches the conceptual structure is retrieved from the mental lexicon. The formulation process involves *grammatical* and *phonological encoding*. During grammatical encoding, lexical items are selected on the basis of their meaning and syntactic specifications, and a syntactic frame of the utterance is generated. During phonological encoding, the sound form of the utterance is created: the word forms of the lexical items are retrieved, and the metrical structure and the intonation pattern of the utterance are specified. The final product of phonological encoding is a phonetic program that serves as input for *articulation.* The articulation process translates the phonetic program into an articulatory motor program and guides the execution of the motor commands. (See Levelt, 1989, for a detailed description of the cognitive processes involved in speaking.)

## TWO-STAGE APPROACHES TO LEXICAL ACCESS

Lexical access is part of the formulation process and is assumed to proceed in two steps (Butterworth, 1980; Dell, 1986; Garrett, 1976; Kempen & Huijbers, 1983; Levelt, 1983, 1989). In the first step, *lemma retrieval*, a set of l*emmas* is activated by the conceptual input. Lemmas are representations of the meaning and the syntactic characteristics of the lexical items (Kempen & Huijbers, 1983; Levelt, 1989). They get activated if some of their semantic properties match the conceptual input. The activation of a lemma makes available the syntactic characteristics of the lexical item, needed for grammatical encoding (such as word-class and gender; see Kempen & Huijbers, 1983; Levelt, 1989). After some time, the highest activated lemma is selected (for a computational model of lemma retrieval, see Roelofs, 1992). In the second step of lexical access, phonological encoding, the phonological form of the item is accessed, and a phonetic representation of the word is constructed (for models of phonological encoding, see Dell, 1986, 1988; Shattuck-Huffnagel, 1979, 1983, 1987; see Meyer, 1992, for a discussion of different approaches to phonological encoding).

The distinctiveness of the semantic and phonological processing stages has been demonstrated by various kinds of behavioral data, including speech errors (e.g., Garrett, 1976), the tip-of-the-tongue phenomenon (see Brown, 1991, for an overview), and reaction-time data (e.g., Levelt et al.,1991; Schriefers et al., 1990). Also, neuropsychological data provide evidence for two distinct stages (e.g., Butterworth, 1989; Howard & Franklin, 1989; Kay & Ellis, 1987). In addition, recent brain-imaging research suggests the involvement of different brain areas in semantic and phonological processes (e.g., Petersen & Fiez, 1993).

Although there is agreement in the literature on the distinction between a semantic and a phonological processing stage, the temporal properties of the two stages are still a matter of debate. Modular theories claim that the stages of semantic and phonological activation are strictly separated in time (e.g., Garrett, 1975; Levelt, 1989; Levelt et al., 1991). This means that lemma selection does not only precede phonological encoding, but has to be completed before phonological encoding can start. Therefore, the phonological form will only be constructed for the selected lemma. According to this view, then, phonological activation can not affect lemma selection. A contrasting view is held by interactive models (e.g., Dell, 1986; Dell & Reich, 1981; Harley, 1984; Stemberger, 1985). Although these models do not dispute that lexical items are initially activated on the basis of their meaning, they allow for a continuous spread of activation between the stages of semantic and phonological activation. All semantic activation feeds forward into the phonological processing stage, and activation spreads back from the phonological level to the semantic level. Furthermore, word-form encoding is not restricted to one lemma, but can occur for several activated lemmas. Therefore, in interactive models, the final selection of a particular lexical item is dependent on the activational dynamics at both the lemma and the lexeme level.

Evidence for the modular view of lexical access initially came from analyses of speech-error data. These analyses showed, for instance, that a distinction can be made between meaning-based and form-based errors. These two error types were argued to occur independently of each other, suggesting that they originate from two separate processing levels (e.g., Fromkin, 1971; Garrett, 1975, 1988; see Butterworth, 1989, for a review).

More recently, evidence for a modular account of lexical access has been provided by reaction-time studies. In a study using a picture-naming task, Schriefers et al. (1990) asked participants to name a picture while hearing an interfering word. The interfering word could be phonologically or semantically related to the picture name and was presented at different moments in time. The results of this study show that semantically related words interfere with picture naming in an early phase of the naming process, whereas phonologically related words affect the naming process only in a later phase. In another reaction-time study, using a different experimental paradigm, Levelt et al. (1991) found no evidence for phonological activation of semantic alternatives of the target word. Only phonological activation of the target lemma was observed. This indicates that a lemma has to be selected before its lexeme is activated. Although these results are interpreted as providing evidence for a modular approach, this interpretation is controversial, and remains a matter of dispute (see Dell & O'Seaghdha, 1991, 1992, and Harley, 1993).

The modular view of lexical access has also been challenged on the basis of speech-error analyses (e.g., Dell & Reich, 1981; Martin, Weisberg, & Saffran, 1989; Martin, Gagnon, Schwartz, Dell, & Saffran, 1995). Speech error analyses show that there is a tendency for sound errors to result in real words, which has been called the *lexical bias* effect (cf. Baars, Motley, & MacKay, 1975). Related to this is the observation that semantic errors tend to occur between words that share phonological features (e.g., *rat* is said instead of *cat*). These errors are usually referred to as *mixed errors.* The probability of their occurrence appears to be higher than would be predicted from the independent contributions of semantic and phonological similarity. The lexical bias effect and the occurrence of mixed errors suggest that semantic and phonological information interactively affect lexical selection. In a serial approach to lexical access, it is hard to account for mixed errors and the lexical bias effect, because activation at the word-form level is not allowed to influence lexical selection. Interactive models, on the other hand, predict the occurrence of these error types. In these models, activation at the word-form level spreads back into the lemma level, which allows semantic and phonological processes to interact.

A major reason for the continuing debate lies in the fact that the claims of the competing models with respect to the time course of the ongoing processes have become more and more fine grained. As a consequence, a definitive test by means of reaction time measures alone is increasingly unlikely. To increase our insight into the on-line process of lexical access, we need to incorporate new research techniques that can - in principle - provide a more detailed picture of the temporal dynamics of lexical access in production.

The goal of the present study is twofold. First, we want to validate a new experimental paradigm that uses ERPs to study the temporal properties of semantic and phonological processes in speech production. Second, we want to obtain converging evidence regarding the temporal separation between semantic and phonological processing stages. This study does not provide conclusive evidence for either a modular or an interactive approach, but is a first attempt to create new possibilities for testing this and other central issues in language production research. The ERP component we use is the lateralized readiness potential. First we describe the characteristics of this ERP measure. Then we explain how we used it in the present study and describe the experimental paradigm.

## THE LATERALIZED READINESS POTENTIAL

The lateralized readiness potential (LRP) is derived from the readiness potential, or Bereitschaftspotential. The readiness potential was first described by Kornhuber and Deecke (1965). It is a slow, negative-going potential that starts to develop some time prior to the execution of a voluntary hand movement and reaches its maximum just after movement onset. The readiness potential is largest in amplitude at scalp sites overlying the motor cortex contralateral to the responding hand (cf. Kutas & Donchin, 1974, 1977, 1980; Vaughan, Costa, & Ritter, 1968). Several researchers showed that if, in a choice reaction-time task, information about the side of the response is given in advance, the readiness potential starts to lateralize in the period between the appearance of the informative signal and the appearance of the signal to respond (Kutas & Donchin, 1980; Rohrbaugh, Syndulko, & Lindsley, 1976). Therefore, Kutas and Donchin (1980) suggested that the lateralization of the readiness potential can be used as an index for specific response preparation. This idea has been elaborated by numerous researchers (Coles, Gratton, & Donchin, 1988; De Jong et al., 1988; Gratton et al., 1988; Smid, Mulder, & Mulder, 1987) and has led to what is now known as the LRP, which has been shown to be a specific index for response preparation. The LRP can be derived as follows: [2]

LRP = right hand [C3' - C4'] - left hand [C3' - C4']

First, on each trial a waveform representing the difference between potentials recorded from electrode sites C3' and C4' is obtained. The electrode sites C3' and C4' are located above the left and the right motor cortices, where the readiness potential during hand movements has been found to be largest in previous research (Kutas & Donchin, 1980). Second, these waveforms are averaged separately for trials in which the left hand is cued and for trials in which the right hand is cued. Third, the average waveform obtained for the left-hand trials is subtracted from the average waveform obtained for right-hand trials. This subtraction cancels out lateralized potentials that are not specifically related to response preparation. The resulting LRP reflects the average amount of lateralization occurring as a result of response preparation (see, e.g., Coles, 1989; De Jong et al., 1988). The LRP has a negative polarity if response preparation for the cued response hand occurs and has a positive polarity if preparation for the incorrect response occurs.

The LRP has been used in a number of elegant studies to assess aspects of human information processing (e.g., Coles, 1989; Coles et al., 1988; De Jong et al., 1988; Gratton et al., 1988; Miller & Hackley, 1992; Osman, Bashore, Coles, Donchin, & Meyer, 1992; Smid, Mulder, Mulder, & Brands, 1992). In particular, the LRP has been used to detect the transmission of partial information between perceptual and motor processes. The results of these studies have established that an LRP can develop on the basis of partial stimulus evaluation, and in the absence of an overt response. This indicates that partial information about a stimulus can be used to select and prepare responses before the stimulus has been fully identified. Whether partial information is used to select responses can be influenced by the particular task conditions. For example, it has been shown that in some experimental conditions, participants are able to strategically control the transmission of

[2] *This measure is equivalent to what de Jong et al. (1988) called the corrected motor asymmetry. This derivation of the LRP is also equivalent to that of Coles (1989) and Gratton et al. (1988) [left hand (C4' - C3') + right hand (C3' - C4') / 2] except that it has twice the amplitude.*

partial information (e.g., Gratton, Coles, & Donchin, 1992; Smid et al., 1992; see Coles, Smid, Scheffers, & Otten, 1995, for an overview). This means that partial information might be available, but not used for response preparation. As a consequence, the development of an LRP does not indicate precisely when information becomes available, but indicates that information is used to activate responses. This implies that relevant partial information is available at least at LRP onset but that it may have been available earlier as well.

When these studies are considered together, we can conclude that the LRP is a real-time measure of response preparation and that it can be used to detect the relative moments in time at which different kinds of information influence response preparation. The onset of the LRP can be interpreted as an estimate for the moment at which information was used for response preparation. Let us now turn to the use of the LRP in the study of semantic and phonological processing in speech production.

The evidence for the transmission of partial information on the one hand, and the evidence for the distinctiveness of semantic and phonological processing on the other hand, make it plausible to assume that the output of the semantic and phonological processing stages can be transmitted separately to the response processes. We hypothesize that if semantic activation precedes phonological encoding, the results of the semantic activation process will be transmitted to the response system earlier in time than the results of the phonological encoding process. This implies that if a response is related to a combined semantic and phonological stimulus evaluation, response preparation will first be based on semantic information alone (partial evaluation), followed by the response preparation based on both semantic and phonological information (complete evaluation).

To use the LRP in the study of speech production, an experimental situation is required in which semantic and phonological processing during speech production are related to response preparation. The response conditions have to be chosen in such a way that the influence of semantic information on response preparation can be distinguished from the influence of phonological information on response preparation. A procedure meeting this requirement is the two-choice reaction go/no-go paradigm (Miller & Hackley, 1992; Osman et al., 1992; Smid et al., 1992), which is the procedure we used here.

## EXPERIMENTAL PARADIGM

Picture naming is an experimental task that is often used to investigate the time course of speech production (reviewed in Glaser, 1992). In the present study, we used a picture naming task to initiate the speech process. On 50% of the trials, a frame appeared around the picture, 150 ms after picture onset. The frame served as a cue to perform a secondary task before picture naming.

The secondary task was the critical experimental task and involved a two choice go/ no-go task. Participants were asked to classify the picture along a semantic dimension and along a phonological dimension. Depending on the outcome of the semantic and phonological classifications, a left-hand response or a right-hand response, or neither response was given. The semantic classification involved an animate-inanimate decision. There is a sizable literature on the mechanisms underlying picture categorization in relation to picture naming and word categorization. An extensive review of these studies is given by Glaser (1992). On the basis of this literature, we assume that the animate-inanimate categorization taps into the stage of semantic activation.

The phonological classification involved a word-final phoneme decision (Experiment 1 and Experiment 2) or a word-initial phoneme decision (Experiment 3). We assume that the phoneme decision task taps into the stage of phonological encoding. To make this decision the phonological segments of the word have to be available, which requires that the segments of the word have been spelled out. A study by Wheeldon and Levelt (1995) showed that phoneme monitoring in a language production task is sensitive to the time course of phonological encoding, which supports the assumption that the phoneme decision task taps into a phonological processing stage.

In Experiment 1, we attempted to detect response preparation based on semantic information alone. In this experiment, the semantic classification determined the response side (e.g., in the case of an animal, a right-hand response has to be made, and in the case of an object, a left-hand response has to be made). The phonological classification determined whether the response should be executed or not (for example, a response had to be executed if the picture name ended with the phoneme /n/ but it had to be withheld if the picture name ended with the phoneme /s/).

The logic behind the paradigm is as follows. At the moment of appearance of the task cue (150 ms after picture onset), participants are in an early phase of the naming process. We assume that if, in speech production, semantic activation precedes phonological encoding, semantic information about the picture will be available earlier than phonological information about the picture name. This assumption is illustrated in Figure 2.1. In this figure, period *a-b* represents the period during which semantic information becomes available for response preparation, and period *c-d* represents the period during which information about the word form becomes available. The critical test involves the presence or absence of an LRP on no-go trials. On the basis of the previously described LRP studies, we assume that information is transmitted to the response system as soon as it becomes available. With reference to Figure 2.1, this means that the preparation of the correct response hand can start during period *a-b* whereas the go/no-go distinction can be made only during period *c-d*. Therefore, in the case that semantic information is available earlier in time than phonological information, we expect an LRP to develop on both go and no-go trials at about the same latency. After some time, response preparation on no-go trials will decrease because of the completion of the phonological decision, and the LRP will return to the baseline, without producing an ERP profile that is associated with an overt response.

To validate the logic behind the paradigm, a second experiment was carried out. In this experiment the task instruction was reversed. That is, the result of the phonological analysis determined the response hand, and the result of the semantic analysis determined the go/no-go decision. This means that selective response preparation could start only if the phonological analysis had been completed. Under the hypothesis that the semantic analysis is completed before the phonological analysis, we expected that the go/no-go decision could be made before information about the response hand became available (see Figure 2.1). Therefore, the presence of an LRP was only expected for go trials.

In a third experiment, we used the same task instruction as in Experiment 1, with one difference: the phonological go/no-go decision was based on the word-initial phoneme instead of the word-final phoneme of the target word. Apart from validating the pattern of results obtained in Experiment 1, this manipulation allowed us to determine whether the LRP is sensitive to the temporal properties of phonological encoding. If word-initial phonological information is available earlier in time than word-final phonological information, the go/no-go distinction can be made faster in Experiment 3 than in Experiment 1. As a result, in Experiment 3 the go and no-go LRPs should start to diverge from each other at an earlier point than in Experiment 1.

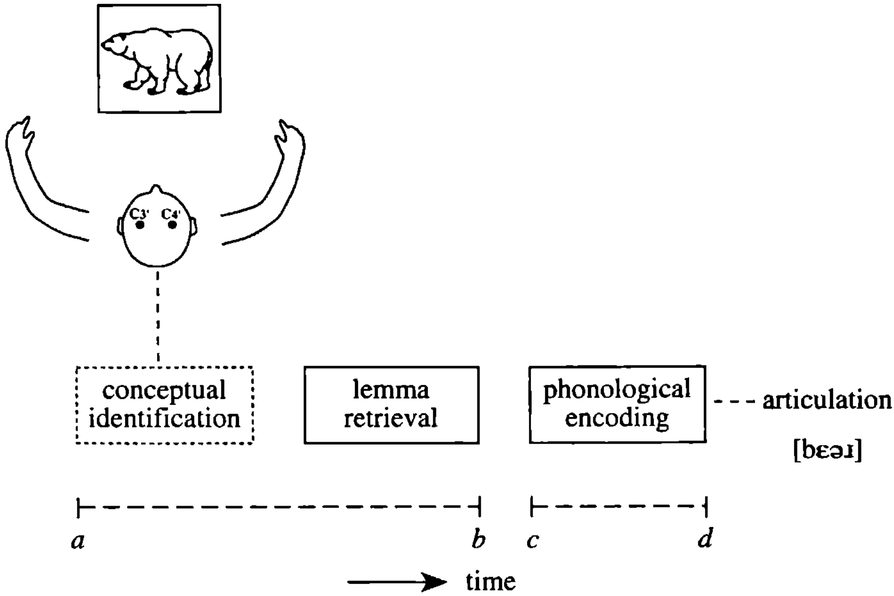


**Figure 2.1** *Processing stages in picture naming using the LRP paradigm. Semantic information about the picture becomes available for response preparation during conceptual identification and lemma retrieval. Phonological information about the picture name becomes available for response preparation during phonological encoding. Under the hypothesis that conceptual identification and lemma retrieval precede phonological encoding, response preparation is first based on semantic information (period a-b), and phonological information affects response preparation at a later moment (period c-d). C3' and C4' are electrode sites.*

In addition to recording LRPs, the EEG is recorded from midline frontal (Fz), central (Cz), and parietal sites (Pz), to validate the LRP measurements. Because the results were as expected in all three experiments, we present a composite report of the midline data in the discussion of Experiment 3.

## EXPERIMENT 1

### Method

*Participants*

Sixteen undergraduate students (2 male) between 20 and 25 years of age from the subject pool of the Max Planck Institute for Psycholinguistics participated in the experiment, all native speakers of Dutch. They were all right-handed according to their response on an abridged and adapted Dutch version of the Oldfield Handedness Inventory (Oldfield, 1971). Except for 1 participant, no left-handedness occurred among the direct relatives of the participants. All participants had normal or corrected-to-normal vision. None of them had any neurological impairment or had experienced any neurological trauma according to their responses on a questionnaire. They were paid for their participation.

*Materials*

A set of pictures was selected according to the following criteria. The first criterion was that the pictures had to be unambiguous. That is, they had to be labeled in an identical way by most of the participants in a naming task. This should guarantee that for the selected pictures, the intended lexical items were retrieved by the participants. The second criterion was that the selected set of pictures had to be fairly homogeneous with respect to perceptual processing time. That is, times to recognize a picture as depicting a particular object or animal should be roughly the same for all pictures. Because the present study focuses on the moments at which semantic and phonological information become available during the naming process, we had to minimize the variability in recognition times for the individual pictures by selecting as homogeneous a set as possible.

To establish a set of pictures meeting the two criteria, we pretested a large set of pictures in a picture-naming experiment and a picture-recognition experiment. The selection of the set of experimental pictures was based on the results of these two pretests.

**Picture naming pretest.** In this pretest, 57 pictures of animals and 98 pictures of objects were successively presented for 600 ms each, with an intertrial interval of 2400 ms. Twenty participants took part in the pretest and were paid for their participation. They were instructed to name the pictures as quickly as possible. Four random presentation orders were constructed and balanced among the 20 participants. Pictures were presented on a NEC-Multisync 3D computer screen. Naming responses were recorded with a Sony 300 ES DAT-recorder. Naming latencies were measured from picture onset by a voice-key. A picture was said to elicit a consistent naming response if it was given an identical name by at least 80% of the participants. Thirty-five pictures of animals and 86 pictures of objects met this criterion. These pictures were used as target pictures in the picture-recognition pretest.

**Picture recognition pretest.** The pretest was administered to 14 paid participants who did not take part in the previous test. Pictures were presented in the same way as in the picture-naming pretest. To determine the recognition times for these pictures, participants were given an old-new judgment task. In this task, participants were initially presented with a set of 50 filler pictures, which they were asked to remember. Subsequently, they were presented with another series of pictures, consisting of the 50 filler pictures shown in the initial phase and 121 new pictures. The pictures were presented in a random order. The participants' task was to indicate whether the picture was *old* (i.e., presented before) or *new*, by pressing one of two buttons. The *new* button was assigned to the participants' dominant hand. Response latencies were measured from picture onset. The critical pictures were the non-repeated pictures, which had to be indicated as *new*. The assumption was that to give a correct *new* response, a picture had to be recognized, but did not need to be lexicalized. Therefore, differences in reaction times would reflect differences in the duration of perceptual identification. Mean reaction times and error percentages were calculated for the 121 target pictures. The overall error percentage was 2.4%.

**The resulting set of pictures.** A set of 32 pictures was selected for the main experiments. The selection of the pictures was based on the results of the pretests. To minimize the differences in perceptual features between the animal and object pictures, we were careful to select pictures that were as similar as possible in terms of curves, straight lines, edges, and so forth. The mean naming latencies and the mean recognition times of the selected items are listed in Appendix A. In addition, 16 pictures were selected as filler items. In the complete experimental picture set, 24 pictures depicted animals, and the remaining 24 pictures represented objects. The names of these pictures included four different word-final phonemes, namely /l/, /s/, /n/, and /r/. Each of these word-final phonemes was represented equally often in the picture set.

The combination of the two semantic categories and the four phonological categories resulted in the following 8 sets of pictures: animal, word-final /l/ (e.g., *uil* [owl]); animal, word-final /s/ (e.g., *muis* [mouse]); animal, word-final /r/ (e.g., *beer* [bear]); animal word-final /n/ (e.g., *spin* [spider]); object, word-final /l/ (e.g., *bal* [ball]); object, word-final /s/ (e.g., *muts* [cap]); object, word-final /r/ (e.g., *deur* [door]); object, word-final /n/ (e.g., *schoen* [shoe]). In addition, a set of practice pictures was selected. This set consisted of 8 animals and 8 objects. The picture names had the phoneme /p/ or the phoneme /t/ at word-final position.

### *Procedure*

Participants were tested individually. They were seated in a soundproof booth in front of a computer screen. A trial started with the presentation of a fixation point in the middle of the screen. After 750 ms, the fixation point disappeared, and the screen stayed blank for 750 ms. Then a picture was presented for 2500ms. Participants were instructed to name the picture as quickly as possible. At 150 ms after picture onset, a frame was superimposed around the picture in half of the trials. The appearance of the frame signaled that the semantic-phonological judgment task had to be carried out before picture naming. Participants were instructed to rest their arms and hands on the elbow rest of the chair and to hold their index fingers on the left and the right response button. For go trials participants responded by pressing one of the two buttons as quickly as possible. For no-go trials participants did not press any of the buttons. The frame remained on the screen for 1500 ms, during which a response had to be made. Participants were instructed not to speak during this period. After the frame had disappeared, participants named the picture. Participants were asked not to blink or to move their eyes during the period in which the picture was on the screen.

At the beginning of a session, the practice set was presented to familiarize participants with the task. Practice trials were presented until the participants performed the task accurately. Electrodes for measuring electrophysiological activity were applied after the training session. Before the experimental blocks were presented, participants were given a booklet containing all experimental pictures and their names. They were asked to carefully look at the pictures and to use the given names in the experiment. When a participant indicated that he or she had looked at all pictures and their names, the actual experiment started.

The actual experiment consisted of two series of six experimental blocks. One series contained all word-final /l/ and word-final /s/ items, and the other

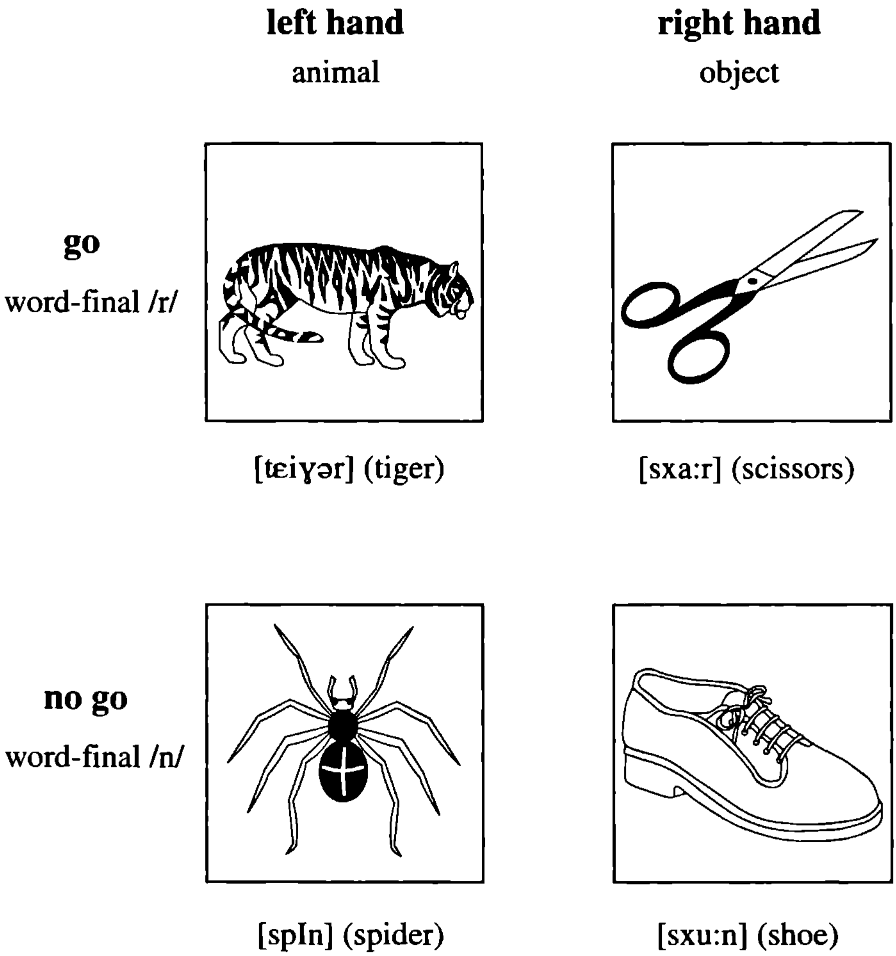


**Figure 2.2** *Examples of the pictures used in the combined semantic - phonological categorization task in Experiment 1. In the figure, the Dutch picture names (in the International Phonetic Alphabet (International Phonetic Association, 1967)) are shown below the pictures. The four pictures depicted here represent separate trials for the four experimental conditions. An animal cues a left-hand response, and an object cues a right-hand response. The response has to be executed if the picture name ends with an /r/ (go trials), but is withheld if it ends with an /n/ (no-go trials).*

series contained all word-final /n/ and word-final /r/ items. The order in which the two series were presented was balanced across participants. Each of the series started with a practice block containing all pictures that would be presented during that series. In each of the series, pictures were repeated 10 times. Test pictures were presented 6 times in critical judgment trials and 4 times in naming trials. Filler pictures were presented 3 times in filler judgment trials and 7 times in naming trials. As a result, 50% of the trials were naming-only trials, and 50% of the trials had the judgment task in addition.

A block of experimental trials was composed as follows. There were 16 critical judgment trials in which the test pictures were presented. In addition, there were 4 filler judgment trials and 20 naming trials in which test pictures and filler pictures were presented. The items were presented in a pseudorandomized order: repeated items were always separated by at least 8 other items and there were never more than three successive naming trials or more than three successive judgment trials. Each block lasted 4 minutes and there was a short break between the blocks. Between the first series of six blocks and the second series of six blocks participants were given a 10-15 min break.

Examples of the stimuli are shown in Figure 2.2. In these, an animal cues a left-hand response and an object cues a right-hand response. A response has to be executed if the picture-name ends with the phoneme /r/ but is withheld if the picture name ends with an /n/. To control for material-specific effects, four experimental versions were constructed. The versions were presented to separate groups of 4 participants. Across versions, the assignment of the four response types (left-hand go, left-hand no-go, right-hand go, right-hand no-go) to the four picture sets in each of two blocks was rotated in such a way that each picture contributed equally to each of the four response types. For example, the picture of a tiger would cue a right-hand response in Version 1, a left-hand response in Version 2, and it would cue no response in Version 3 and Version 4.

*Apparatus*

The pictures were presented in the center of a high resolution NEC/Multisync 3 computer screen, in white on a black background. The presentation of the stimuli and the acquisition of the reaction-time data were controlled by NESU, a system developed at the Max Planck Institute for Psycholinguistics, using a Hermac AT computer. Naming latencies were measured from picture onset by a Sennheiser voice key. Push buttons were attached to the left and the right arm of the chair. Hand responses were made by pressing either the button on the left side or the button on the right side of the chair with the index finger. Pushbutton latencies were measured from frame onset. The time-out period (the moment in time after which responses were registered as missing) was set at 2500 ms for the naming response and at 1500 ms for the push-button response. Participants' naming responses were recorded by a Sony 300 ES DAT-recorder.

### *Electrophysiological recordings*

The EEG was recorded monopolarly from midline frontal (Fz), central (Cz), and parietal (Pz) sites as defined by the International 10-20 system (Jasper, 1958). These electrodes were referenced to the left mastoid. The difference in activity between C3' and C4' (approximately 3.5 cm lateral and 1 cm anterior to Cz) was recorded via a bipolar montage of the two electrodes. A ground electrode was placed on the forehead. Vertical and horizontal eye movements were recorded bipolarly by electrodes placed above and below the right eye, and external to the outer canthus of each eye. Bipolar recordings of the EMG were made by placing pairs of electrodes above the responding muscles of each arm (M. flexor digitorum superficialis and the M. flexor digitorum profundus). For all recordings Beckmann biopotential Ag/AgCl electrodes were used. Electrode impedance was kept below 3 kOhm for the EEG recording, below 10 kOhm for the EOG recording and below 20 kOhm for the EMG recording. The EEG, EOG and EMG signals were amplified by Nihon Kohden AB-601G bioelectric amplifiers and filtered with a high frequency cut-off point of 30 Hz for the EEG and EOG, and a high frequency cut-off point of 100 Hz for the EMG. A time-constant of 8 seconds was used. The signals were digitized on-line with a sampling frequency of 200 Hz. Sampling started 200 ms before picture onset on a critical trial, with a total sampling epoch of 2700 ms. The EMG signal was rectified off-line.

### *Data Analysis*

Data from critical trials were analyzed as described below. Filler trials were not further analyzed.

**Overt responses.** First, the naming data and the pushbutton data were inspected for errors. A trial was classified as erroneous if the following occurred: a) Naming started before the button press was given, or started earlier than 1500 ms after frame onset. These trials were removed to avoid articulatory artifacts in the EEG signal; b) The picture was named incorrectly; c) An incorrect hand response was given.

Second, each trial was visually inspected for the occurrence of EMG activity. From other studies (e.g., Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; Eriksen, Coles, Morris, & O'Hara, 1985), it is known that response activation can occur without a response being executed. In trials where only one response is given, response activation can be concurrently present in both EMG channels. To make sure that the development of the LRP would not be biased by trials in which the incorrect response was activated earlier than, or simultaneously with the correct response, all go trials in which EMG activity was detected in the incorrect channel were classified as error trials. In no-go trials, the presence of EMG activity could have been the result of erroneous or incomplete go/no-go analyses. To avoid the possibility that the presence of an LRP on no-go trials could be attributed to incomplete or incorrect go/no-go decisions, all no-go trials in which EMG activity occurred were classified as error trials. All error trials were eliminated from the dataset.

**Event-related potentials.** All single trial waveforms containing eye movement artifacts, amplifier blocking or electrode drifting, in the time window from 200 ms before picture onset to 1500 ms after picture onset, were removed from the data set. From each single trial waveform the average voltage in the 200 ms period preceding picture onset was subtracted.

LRPs were derived separately for the go and no-go conditions. To test for the presence of an LRP and to estimate its onset, analyses were performed at 50 ms intervals, starting at frame onset and continuing in sequential steps of 10 ms (e.g., 150-200 ms, 160-210 ms etc.). For each window a one-tailed $t$ test with a 95% confidence interval was performed to test whether the mean voltage within the window exceeded the mean voltage within the baseline interval. An LRP was defined to be present if 5 or more consecutive windows resulted in a significant $t$ value. The onset of the first of these consecutive significant windows determines the LRP onset latency.

To determine the point of divergence between the go and no-go LRPs, the average voltage at each individual time point of the no-go waveform was subtracted from the average voltage at the corresponding time points of the go waveform. One-tailed $t$ tests were performed to test whether the mean go/no-go difference scores differed significantly from zero, using the same procedure as described for the individual LRP waveforms. The point of divergence was defined as the beginning of the earliest of 5 or more consecutive time windows that resulted in significant $t$ values.

To date, all of the published work on language and ERPs has been based on subject analyses. Item analyses have not been incorporated in the analytic procedures for ERP data, and such analyses were not performed on the current data set.

## Results

### *Overt responses*

The mean pushbutton latency, measured from frame onset, for the correct go trials was 818 ms (standard deviation (*SD*) = 255; mean response latencies for animals and objects were 799 ms (*SD* = 268) and 838 ms (*SD* = 249) respectively). The mean error rate for the go trials was 4.7%. For the no-go trials the mean error rate was 2.5%. These errors included all trials on which EMG-errors, as specified above, were detected. Because the error rates were small, they were not further analyzed.

The mean naming latency for the experimental pictures in the naming-only trials was 762 ms (*SD* = 152), measured from picture onset.

### *Lateralized readiness potentials*

In total, 19% of the trials were rejected because of errors and EEG artifacts. The rejected trials were equally distributed across conditions and participants. Per participant, the minimum number of trials left for averaging was 35 per condition.

Figure 2.3 presents the averaged LRP waveforms for the go trials and the no-go trials.[3] This figure shows that a negative LRP developed on both go trials and no-go trials. Thus, on both go and no-go trials a greater negative potential was observed contralateral to the cued response hand. This enhanced negativity indicates the presence of preparation for the cued response hand. The go and the no-go LRPs started to develop at approximately the same moment in time. On go trials, the LRP started to deviate significantly from zero at 370 ms after picture onset ($t\,(15) = -1.89$, $SD = 0.95$, $p = 0.05$), which corresponds to 220 ms after frame onset. On no-go trials the LRP became

[3] *For presentation purposes, the waveforms in this and all other figures have been low pass filtered (cf. Ruchkin & Glaser, 1978) using a 50 ms time frame. The unfiltered data were used in all statistical analyses.*

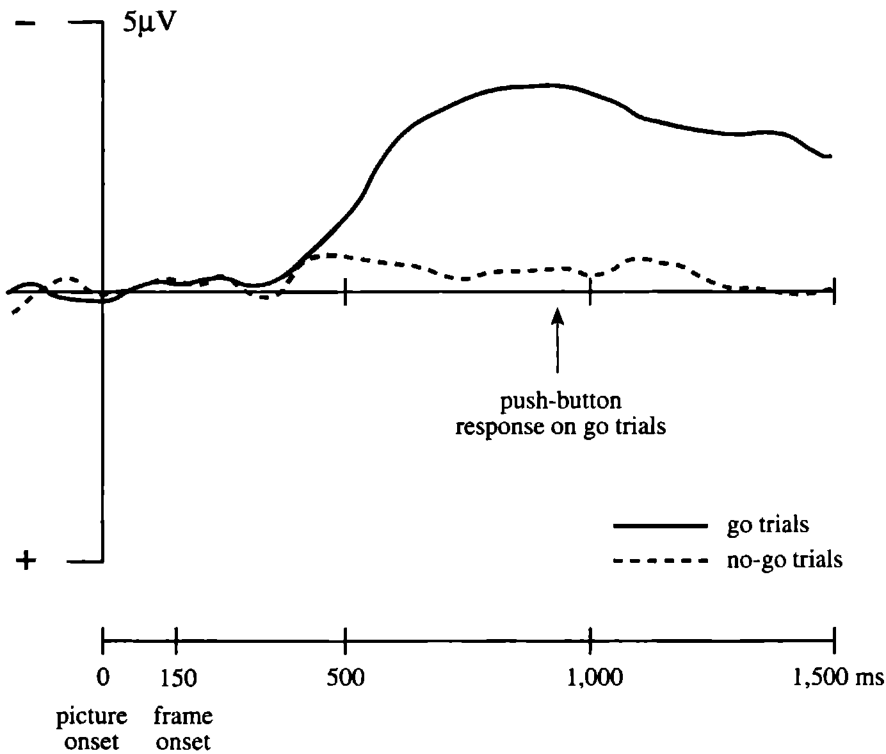


**Figure 2.3** *Grand average (N = 16 participants) lateralized readiness potentials on go and no-go trials of Experiment 1. The semantic decision determined response hand; the word-final phoneme decision determined whether a trial was a go or a no-go trial. Significant lateralization of the readiness potential was obtained both on go and on no-go trials. The shaded area shows the time interval in which the go and the no-go LRPs were significantly different from the baseline but not from each other.*

significant at 380 ms after picture onset ($t$ (15) = -2.09, $SD$ = 0.90, $p$ < 0.05), which corresponds to 230 ms after frame onset. The LRP kept on developing on go trials, reaching its maximum value around 840 ms after picture onset.

The no-go LRP slowly returned to the baseline after its initial development. At 590 ms after picture onset the $t$ value for the mean LRP amplitude was no longer significant ($t$ (15) = -1.68, $SD$ = 0.81, $p$ = 0.1). To provide information about the variation between subjects, plots of individual go and no-go LRP waveforms are shown in Figure 2.4. In this figure it can be seen that for the majority of subjects a lateralization of the readiness potential was obtained on both go and no-go trials. The difference between the go and the no-go waveform became significant at 490 ms after picture onset ($t$ (15) = -1.99, $SD$ = 1.26, $p$ < 0.05). This means that, after their initial onset, the go and the no-go LRP developed at the same rate for about 120 ms.

### Discussion

The main findings of Experiment 1 concern the development of the LRP on no-go trials. In parallel with the development of an LRP on go trials, an LRP developed on no-go trials, for a short period of time. This means that the cued response hand was activated even when the phonological evaluation cued no response. The onset latency of the LRP was about the same in go and no-go trials, indicating that response preparation started in the same time range on both kinds of trials. This suggests that semantic information was used to activate the response hand before phonological information could be used to make the go/no-go distinction. The go and no-go LRP developed at the same rate for 120 ms, after which they started to diverge. Thus, after 120 ms the phonologically based go/no-go distinction influenced the development of the LRP. On go trials, the LRP kept on growing, but on no-go trials the LRP returned to the baseline without any EMG activity being produced.

The LRP results obtained in Experiment 1 suggest a temporal advantage of semantic information over phonological information. The early available semantic information serves as partial information, and therefore response preparation can start before sufficient phonological information is available to complete the go/no-go analysis. To validate this interpretation, Experiment 2 was carried out. In this experiment, we reversed the assignment of the semantic and phonological evaluation to the left-right and the go/no-go dimensions. This manipulation allowed us to determine whether the no-go LRP

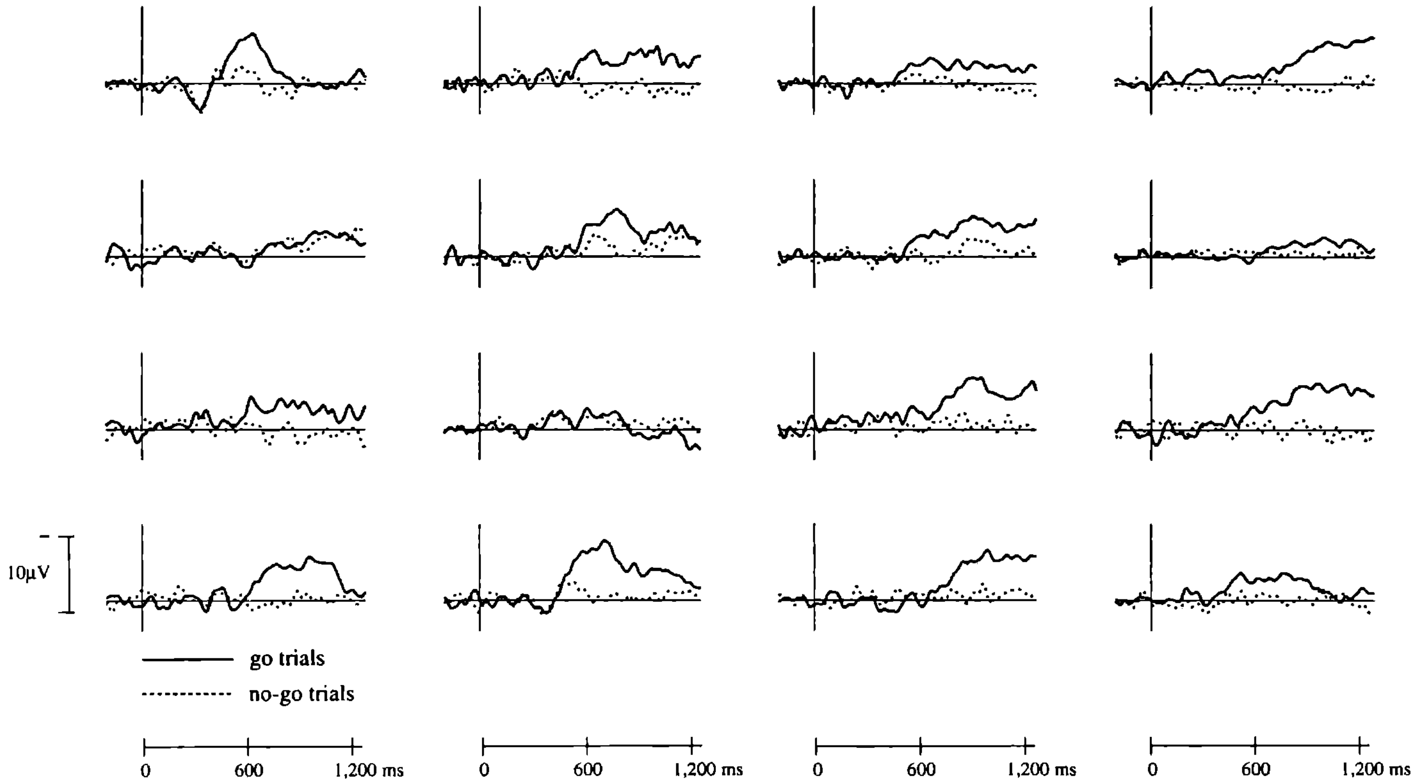


**Figure 2.4** *Lateralized readiness potentials on go and no-go trials for each of the participants in Experiment 1. The first nine plots, depicted from left to right, show data from the individuals who participated in both Experiments 1 and 2.*

observed in Experiment 1 reflected a temporal difference between semantic and phonological processing, or whether it was due to mechanisms that are independent of the time course of the two distinct types of processes.

## EXPERIMENT 2

Just as in the first experiment, target pictures were presented to participants, and in addition to naming the picture, participants had to perform a two-choice reaction go/no-go task on 50% of the trials. However, in Experiment 2, the assignment of the semantic and phonological dimensions to the go/no-go and response hand decisions was the mirror image of that in Experiment 1: In Experiment 2, the go/no-go distinction was determined by the animate-inanimate decision, and the response hand was determined by the word-final phoneme decision. Assuming that semantic information precedes phonological information, no selective response activation should be present on no-go trials in Experiment 2, since the go/no-go decision on the basis of semantic information can be completed before the response hand can be prepared on the basis of phonological information.

### Method

Sixteen undergraduate students (2 male) between 20 and 26 years of age from the subject pool of the Max Planck Institute for Psycholinguistics took part in the experiment were paid for their participation. Nine of them had already participated in Experiment 1. They were all native speakers of Dutch and had normal or corrected-to-normal vision. All participants were right-handed according to their response on an abridged adapted Dutch version of the Oldfield Handedness Inventory (Oldfield, 1971). No left-handedness occurred among the direct relatives of the participants. None of the participants had any neurological impairment or had experienced any neurological trauma.

Materials, procedure, apparatus, electrophysiological recordings, and data analysis were the same as those described for Experiment 1.

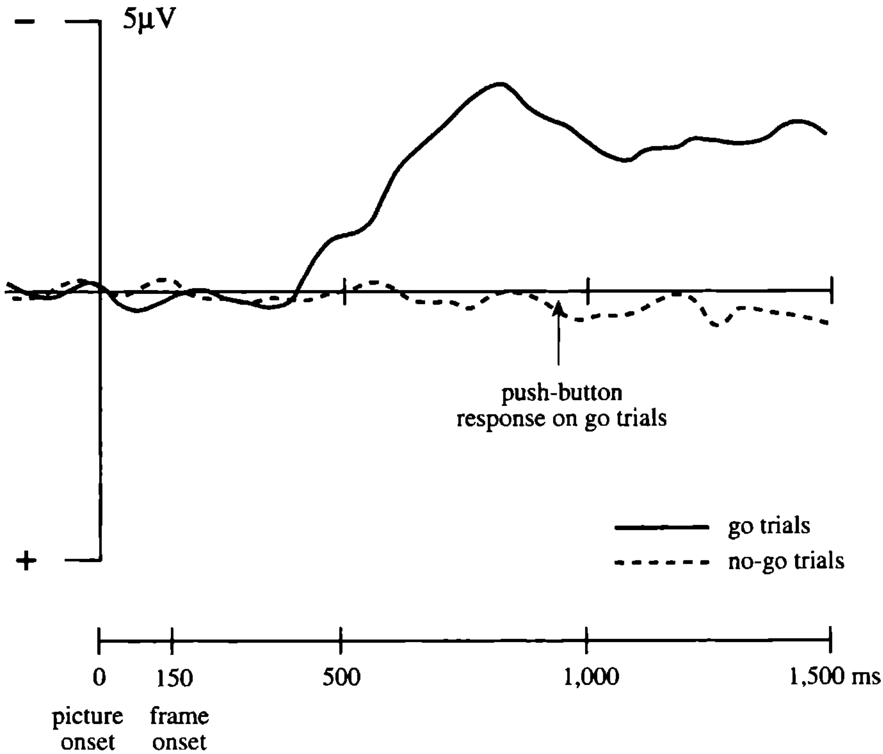


**Figure 2.5** *Grand average (N = 16 participants) lateralized readiness potentials on go and no-go trials of Experiment 2. The semantic decision determined whether a trial was a go or a no-go trial; the word-final phoneme decision determined the response hand. No significant lateralization of the readiness potential was obtained on no-go trials.*

## Results

### *Overt Responses*

The mean response time for the correct go trials was 816 ms (*SD* = 230) after frame onset (mean response latencies for the word-final phonemes /n/, /r/, /l/, and /s/ were 824 ms (*SD* = 246), 811 ms (*SD* = 226), 815 (*SD* = 234), and 816 (*SD* = 240) respectively). The error rate for the go trials was 4.2%. For the no-go trials the error rate was 2.2%. As in Experiment 1, the error rates were not further analyzed. The mean naming latency for the experimental pictures in the naming-only trials was 719 ms, measured from picture onset.

### *Lateralized readiness potentials*

The overall rejection rate was 18%. The rejected trials included all trials on which response errors or EEG artifacts were observed. The rejected trials were equally distributed across the conditions and participants. Per subject, the minimum number of trials left for averaging was 35 per condition.

The averaged LRP waveforms for go trials and no-go trials are presented in Figure 2.5. In this figure we can see a negative LRP developing on go trials. The go waveform started to deviate from zero at 410 ms after picture onset ($t(15) = -2.13$, $SD = 0.85$, $p = 0.03$). It kept on developing and reached its maximum value around 820 ms after picture onset. The no-go waveform fluctuated around the baseline during the epoch, without producing a significant deviation in either a positive or negative direction. Thus, for no-go trials, no significant development of the LRP was observed, indicating that no response preparation occurred on these trials.

Analyses of the go/no-go difference scores showed that the go and no-go waveforms started to diverge at 410 ms after picture onset ($t(15) = -2.27$, $SD = 1.05$, $p < 0.05$). This point of divergence corresponds to the onset of the LRP on go trials, and confirms the absence of significant differential activity on no-go trials.

To provide information about the variation between subjects, plots of individual go and no-go LRP waveforms are shown in Figure 2.6. The first nine plots in Figure 2.4 and Figure 2.6 show the data of subjects who participated in both Experiment 1 and Experiment 2. In these figures it can be seen that, in contrast to Experiment 1, in Experiment 2 basically no lateralization of the readiness potential was observed on no-go trials.

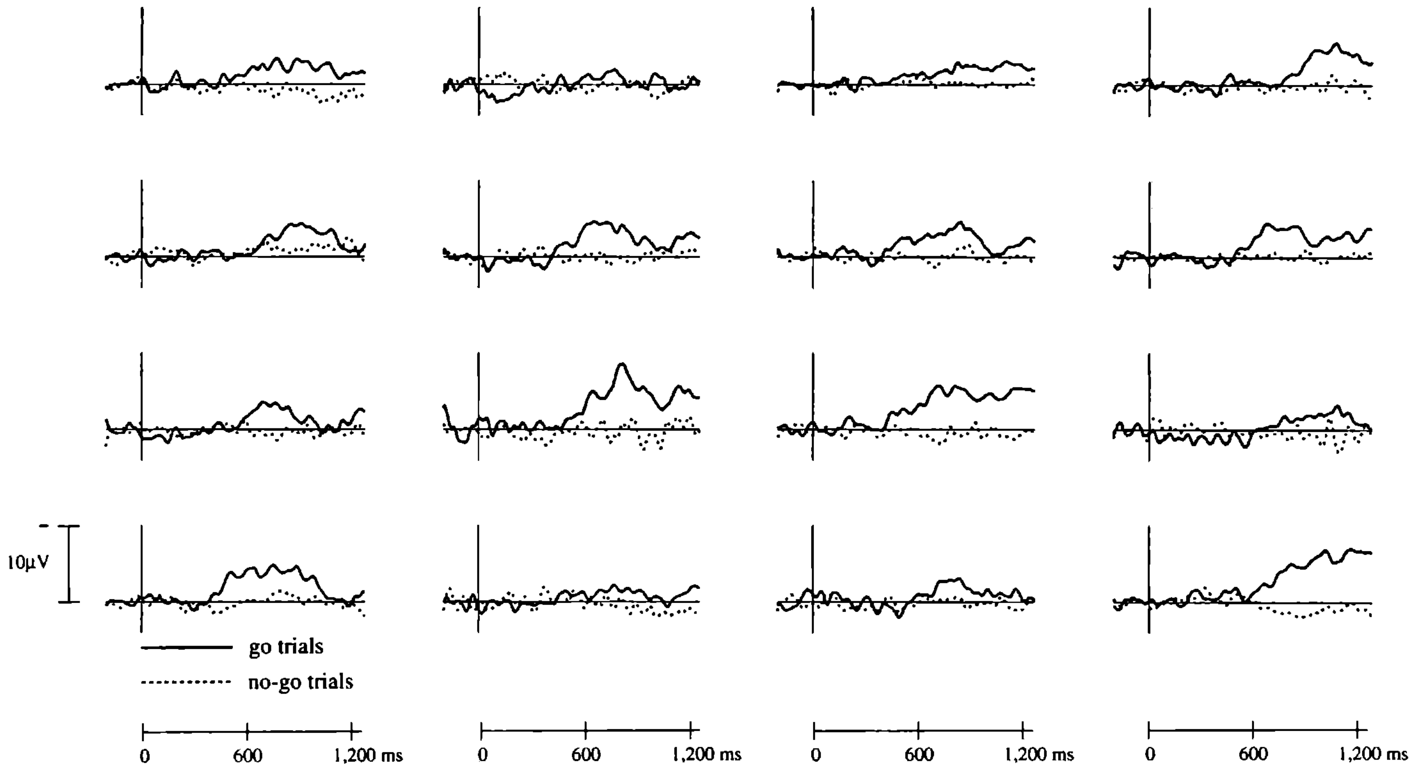


**Figure 2.6** *Lateralized readiness potentials on go and no-go trials for each of the participants in Experiment 2. As in Figure 2.4, the first nine plots, depicted from left-to-right, show data from the individuals who participated in both Experiments 1 and 2.*

In order to make a within-subjects comparison of the results of the two experiments, separate analyses were performed on the LRP data of the nine subjects who participated in both Experiment 1 and Experiment 2. These analyses showed that in Experiment 1 an LRP was present on both go and no-go trials. The LRP onset latency was 370 ms after picture onset for the go trials ($t(8) = -1.97$, $SD = 0.68$, $p < 0.05$), and 390 ms after picture onset for the no-go trials ($t(8) = -1.943$, $SD = 0.84$, $p < 0.05$). In Experiment 2, a significant LRP started to develop at 400 ms after picture onset on go trials ($t(8) = -1.91$, $SD = 0.53$, $p < 0.05$). However, no LRP was present on no-go trials for these participants.

## Discussion

The reaction time data showed that the mean response time in Experiment 2 was almost identical to the mean response latency obtained in Experiment 1. Although some care needs to be taken in comparing the mean RTs of two separate subject groups, this result suggests that the specific task conditions in the two experiments did not affect the total amount of time required to give a response. The LRP data showed that whereas an LRP was present on go trials, no significant LRP was observed on no-go trials. The absence of an LRP on no-go trials in Experiment 2 indicates that, on these trials, phonological information did not affect response preparation. Phonological information started to activate response hands only after the semantically based go/no-go distinction had been made. These findings support the claim that semantic information influences response preparation at an earlier moment in time than phonological information.

The results of Experiment 2 rule out two alternative explanations for the no-go LRP obtained in Experiment 1. The first alternative explanation is that the no-go LRP in Experiment 1 could have resulted from the automatic activation of response hands after *both* the semantic *and* the phonological analysis had been completed. If this were the case, then one could claim that the LRP observed on no-go trials did not result from the transmission of early available semantic information, but instead reflected that participants automatically first activated the response hand, and then either withheld or executed the response. This explanation, however, is shown to be incorrect by the present data. If participants always first automatically activated the correct response hand, an LRP should have been present on no-go trials in both experiments. This is not in agreement with the results obtained in Experiment 2, and therefore this possibility can be ruled out.

A second alternative interpretation of the no-go LRP observed in Experiment 1 is that the experimental task induced participants to use a response selection strategy. As was already mentioned in the introduction, there is some evidence indicating that participants have strategic control over the use of partial information (cf. Coles, De Jong, Gehring, & Gratton, 1991; Smid et al., 1992). Applying a response selection strategy means that the information discriminating between response hands is made available earlier than the go/no-go information. That is, in the special circumstances of the task in Experiment 1, participants would first complete the semantic analysis to select the response hand, and then complete the phonological analysis to make the go/no-go decision. As a consequence, the presence of an LRP on no-go trials would not be a reflection of the early availability of semantic information during picture naming, but just be the result of strategic use of information during the experimental task. This explanation, however, does not hold. If the effect would indeed have been due to strategic control, we should have observed an LRP on no-go trials independent of whether the response hand was determined by the phonological analysis or the semantic analysis. In contrast to this prediction, our results show that the occurrence of an LRP on no-go trials is dependent on how the semantic and phonological dimensions are assigned to the response hand and go/no-go distinctions. The results show that in Experiment 2, phonological information did not serve as partial information to selectively activate response hands before the semantically based go/no-go distinction had been made. Therefore it seems unlikely that the no-go LRP in Experiment 1 can be explained as a strategy effect.

The only remaining option for a strategy account of our results would be one that attributes differential strategic effects to the different subject groups. Since there were different participants in the two experiments, the null-effect in Experiment 2 might reflect that participants in Experiment 1 used such a strategy while participants in Experiment 2 did not. However, analyses performed on the data of the nine participants who participated in both experiments revealed that for these nine participants a significant no-go LRP occurred in Experiment 1, whereas in Experiment 2 no LRP developed on no-go trials. This clearly shows that the possibility that the no-go LRP observed in Experiment 1 is the result of a response selection strategy can be excluded.

Together, the results of Experiment 1 and Experiment 2 show that the LRP is differentially sensitive to the separate moments in time at which semantic information and word-form information become available in a semantic-phonological judgment task about pictures and their names. However, these results do not provide decisive evidence that semantic activation precedes phonological encoding in speech production. Instead of demonstrating a temporal separation between semantic activation and phonological encoding, the results might be a reflection of the temporal properties of phonological encoding itself. Although the precise nature and the timing of the sub-processes involved in phonological encoding are still a matter of investigation, current models of speech production agree that phonological word forms cannot be retrieved from the mental lexicon as entities, but rather are constructed out of segments or sequences of segments (Dell, 1988; Levelt, 1989; Meyer, 1990, 1991; Shattuck-Huffnagel, 1979). The phonological form of a word does not become available at once; time is required to make available the word's constituent phonemes and to assign them to the prosodic frame of the word. Recent reaction time studies on the time course of phonological encoding suggest that the process of constructing the phonological form of a word operates in a left-to-right manner, with the beginning of a word being encoded before its end (Meyer & Schriefers, 1991; Wheeldon & Levelt, 1995). These findings have the following implication for the present data. The phonological analysis we used in the experiments involved the classification of the word's final phoneme. Because there is evidence that word-form encoding proceeds from left to right, the consequence of using a word-final phoneme categorization task is that correct response selection could occur only *after* the main part of the phonological form of the word had already been constructed. The amount of time needed to complete this relatively extensive phonological analysis might have contributed to the temporal advantage we observed for the semantic analysis. This means that in the present data it is unclear to what extent the no-go LRP in Experiment 1 reflected a temporal separation between semantic and phonological processing, and to what extent the no-go LRP developed as a result of the time required for constructing the word form. Therefore we decided to run a third experiment in which we tried to minimize the time required for completing the phonological analysis.

## EXPERIMENT 3

In this experiment participants had to perform the same task as in Experiment 1, with one difference: Instead of the word-final phoneme, the word-initial phoneme determined whether a response should be executed. Thus, in Experiment 3, the selection of response hand was based on the animate-inanimate decision, and the go/no-go distinction was made on the basis of the word-initial phoneme.

The main purpose of this experiment was to determine whether semantic information would still be available before phonological information if the time required for phonological processing was minimized. According to the claim that semantic activation precedes phonological encoding, manipulating the duration of phonological processing should not affect the initial development of an LRP on no-go trials. Therefore, the presence of a no-go LRP would provide additional support for a temporal separation of semantic and phonological processing in speech production. If no lateralization were observed on no-go trials, then, strictly speaking, we would no longer be able to make this claim on the basis of the data from Experiments 1 and 2. The LRP obtained on no-go trials in Experiment 1 could then be explained as reflecting the additional amount of time required for the phonological encoding of the full word form relative to the phonological encoding of its onset.

Another objective of Experiment 3 was to explore the LRP's sensitivity to the temporal properties of phonological encoding itself. In Experiment 3, as in Experiment 1, the time required to complete the phonological analysis was expected to affect the time at which response preparation starts to decrease on a no-go trial. If word-form information is available later than semantic information, the offset of response preparation on no-go trials might be affected by the position of the critical phoneme in the word. If word-initial information becomes available earlier in time than word-final information, we expect that in Experiment 3 less time would be needed to make the go/no-go distinction. Therefore, in Experiment 3, participants might be able to decrease response preparation earlier than in Experiment 1, and as a result the interval during which the go and the no-go waveform develop simultaneously will be reduced.

## Method

### *Participants*

Sixteen undergraduate students (five male) between 20 and 27 years of age from the participant pool of the Max Planck Institute for Psycholinguistics took part in the experiment and were paid for their participation in the experiment. They were all native speakers of Dutch, were all right-handed and had normal or corrected-to-normal vision. For 5 of the participants, left-handedness occurred among the direct relatives. None of the participants had any neurological impairment or had experienced any neurological trauma.

### *Materials*

The materials consisted of 32 target pictures and 20 filler pictures. The criteria for the selection of the target pictures were identical to the criteria described for Experiment 1 and Experiment 2: the pictures had to be unambiguous and they had to be as homogeneous as possible with respect to their recognition times. On the basis of these criteria we selected a set of 27 target pictures from the larger set of pictures for which naming responses and recognition times had been collected in the pretests described above. An additional 5 target pictures were selected on the basis of results of other picture naming studies carried out at the Max Planck Institute in which these pictures were used as targets. Although we could not directly compare the results of these experiments with the results of our pretests, the correspondence in reaction times between these 5 pictures and the set of 27 pictures was sufficiently good to include them in the experiment. The selected target pictures are listed in Appendix B.

Half of the pictures depicted animals and the other half depicted objects. The names of the target pictures had the phonemes /k/, /s/, /v/, or /h/ at wordonset position. The combination of the two semantic and the four phonological categories resulted in eight sets of pictures: animal, word-initial /k/ (e.g., *kameel* [camel]); animal, word-initial /s/ (e.g., *spin* [spider]); animal, word-initial /v/ (e.g., *vlinder* [butterfly]); animal, word-initial /h/ (e.g., *hond* [dog]); object, word-initial /k/ (e.g., *kanon* [cannon]); object, word-initial /s/ (e.g., *sleutel* [key]); object, word-initial /v/ (e.g., *vlag* [flag]); object, word-initial /h/ (e.g., *hamer* [hammer]). Each of these sets consisted of 4 target pictures and 1 filler picture. The remaining 12 filler pictures had different word-initial phonemes and were only presented in the naming trials. These fillers were included to disrupt the sequence of the critical word-initial phonemes. In addition, a set of 16 pictures was selected to serve as practice

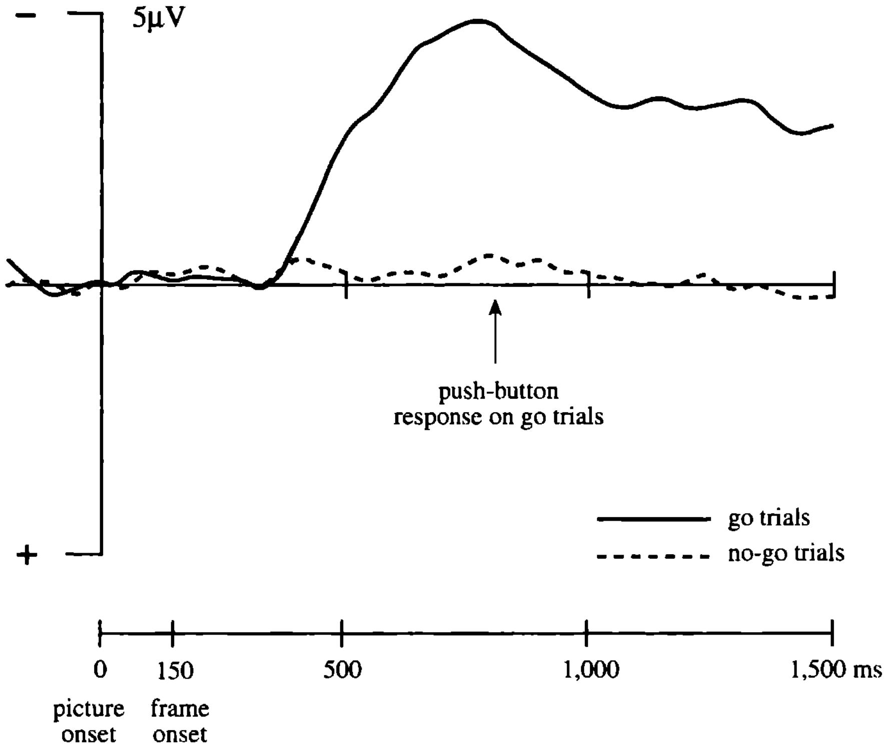


**Figure 2.7** *Grand average (N =16 participants) lateralized readiness potentials on go and no-go trials of Experiment 3. The semantic decision determined response hand; the word-initial phoneme decision determined whether a trial was a go or a no-go trial. As in Experiment 1, a significant lateralization of the readiness potential was obtained on no-go trials. The shaded area shows the time interval in which the go and the no-go LRPs were significantly different from the baseline but not from each other.*

items. The set of practice pictures included 8 animals and 8 objects. There were 6 picture names starting with an /m/, and 6 picture names starting with a /p/. The other 4 picture names had different wordonsets, and were presented only in naming trials.

*Procedure*

The procedure was identical to the procedure used in Experiment 1 and Experiment 2, with the following exceptions. The actual experiment consisted of two series of four experimental blocks. One series contained all word-initial /k/ and /s/ items, the other series contained all word-initial /v/ and /h/ items. The order in which the two series were presented was counterbalanced across subjects. Each of the series was preceded by a naming block in which all pictures of that series were presented once. This block served as a practice block to familiarize participants with the pictures. In each of the series, target pictures were presented six times in critical judgment trials and four times in naming trials. The 8 filler pictures that had critical phonemes at the word-onset position were presented four times in filler judgment trials and 6 times in naming trials. The other filler pictures were presented four times in naming trials. As a result, as in the previous experiments, half of the trials were naming-only trials, and the other half had the judgment task in addition.

An experimental block included 24 critical judgment trials, 4 filler judgment trials, and 28 naming trials. Each block lasted 6 minutes.

Apparatus, electrophysiological recordings, and data analysis were the same as those described for Experiment 1.

## Results

*Overt responses*

The mean pushbutton latency for the correct go trials was 669 ms ($SD$ = 213), measured from frame onset (the mean response latencies for animals and objects were 640 ms ($SD$ = 199) and 697 ms ($SD$ = 221) respectively). The error rate for was 7.2% for the go trials, and 2.2% for the no-go trials. These error trials included all trials in which EMG errors occurred. As in Experiment 1 and Experiment 2, the errors were not further analyzed.

The mean naming latency for the experimental pictures in the naming-only trials was 720 ms, measured from picture onset.

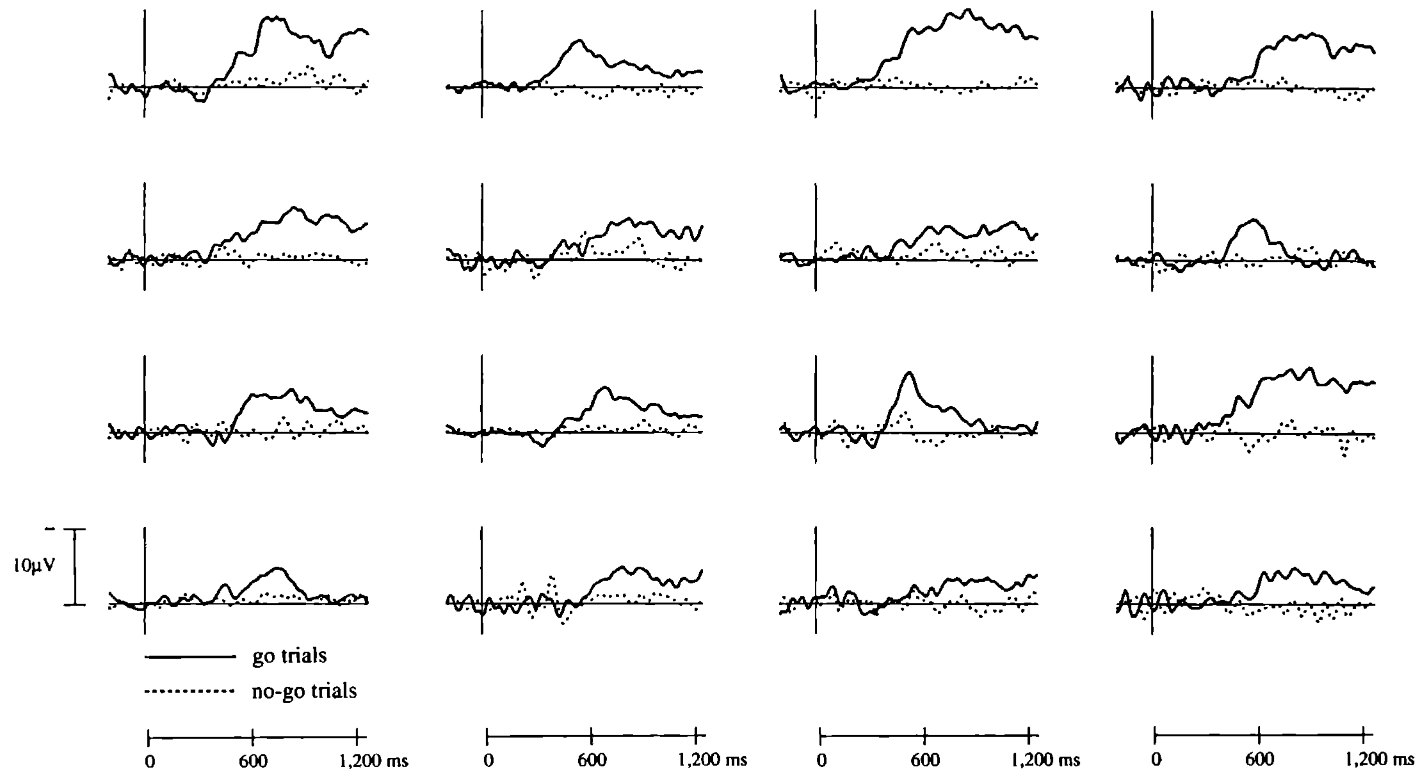


**Figure 2.8** *Lateralized readiness potentials on go and no-go trials for each of the participants in Experiment 3.*

### *Lateralized Readiness Potentials*

In total 19% of the trials were excluded from the data set because of naming errors, EMG errors, and EEG artifacts. The rejected trials were equally distributed across conditions and participants. Per participant, the minimum number of trials left for averaging was 35 per condition.

Figure 2.7 shows the averaged LRP waveforms for the go and the no-go trials. In this figure it can be seen that a negative LRP developed on both go and no-go trials. This indicates that response preparation for the cued response hand occurred on both go and no-go trials. On go trials the LRP started to deviate significantly from zero at 360 ms after picture onset ($t(15) = -1.89$, $SD = 1.09$, $p = 0.05$). The LRP kept on developing and reached its maximum around 780 ms. On no-go trials the LRP became significant at 350 ms after picture onset ($t(15) = -1.88$, $SD = 0.62$, $p = 0.05$). For a short period of time the no-go LRP developed at the same rate as the LRP for go trials.

To provide information about the variation between subjects, plots of individual go and no-go LRP waveforms are shown in Figure 2.8. In this figure it can be seen that for most of the participants a lateralization of the readiness potential was observed on both go and no-go trials.

At 400 ms after picture onset the no-go waveform started to diverge significantly from the go waveform ($t(15) = -2.24$, $SD = 1.41$ $p = 0.03$). Whereas the LRP kept on developing for go trials, the no-go waveform returned to the baseline.[4]

## Discussion

Experiment 3 yielded two important results. First, we replicated the finding of an LRP on no-go trials. We found that for a short period of time, an LRP developed at the same rate on both go and no-go trials. This means that as in Experiment 1, initial response preparation occurred independently of the

[4] *As can be seen in Figure 2.7, after returning to the baseline, the no-go LRP started to develop again around 720 ms after picture onset. In some of the LRP studies reported in the literature, a similar reappearance of an LRP on no-go trials can be observed (cf. Osman et al., 1992; Smid et al., 1992), although it is unclear whether these LRPs are significantly different from the baseline. We do not have an explanation for this effect. However, because the no-go LRP returned to the baseline after its initial development and appeared again at the latency that a response was actually given on go trials, it is reasonable to assume that this effect has no implications for the early processes we are interested in.*

outcome of the go/no-go distinction. These findings show that semantic information was used for response preparation earlier than phonological information, independent of whether the phonological analysis involved the word-initial or word-final phoneme. Therefore, they support the claim that semantic information about a picture is available earlier in time than word-form information.

The other important finding concerns the point of divergence between the go and the no-go waveforms. The results showed that the LRP developed at the same rate on go and no-go trials from 360 ms to 400 ms after picture onset. At 400 ms after picture onset the no-go waveform started to return to the baseline while the LRP kept on developing on go trials. This indicates that already at 40 ms after LRP onset, sufficient phonological information was available to make the go/no-go distinction. When we compare this period with the 120 ms period in which the go and no-go LRP developed simultaneously in Experiment 1, it is evident that wordonset information was available for response preparation at an earlier moment than word-final information was. In addition to providing a new source of evidence for the idea that the word form is constructed in a left-to-right manner, these results show that the LRP is sensitive to the time course of processes involved in phonological encoding. We further elaborate on these results in the General Discussion.

In addition to the LRP measurements, for each of the go and no-go conditions, average waveforms were computed for the electrode sites Fz, Cz, and Pz. In Figure 2.9 the averaged waveforms for the electrode site Pz in Experiments 1, 2, and 3 are shown. We expected no differences to occur in the waveforms for the separate conditions, except for a difference in the amplitude of the P300 in the go and the no-go conditions. The P300 is a component of the ERP signal that is characterized by a positive going deflection that peaks around 300 ms after the onset of the stimulus that elicited it. The amplitude of the P300 is known to be influenced by the extent to which information about a stimulus is extracted by the participant (cf. Fabiani, Gratton, Karis, & Donchin, 1987; Johnson, 1988). Therefore, if we observed a difference in P300 amplitude between go and no-go trials, this would indicate that more extensive stimulus processing was going on when an actual two-choice response is required than when no choice response was required. The P300 component varies not only in amplitude but can also vary in its latency. The latency of the P300 is assumed to depend on the time required for stimulus evaluation (cf. Donchin & Coles, 1988; Fabiani et al., 1987). For our study, we did not expect P300

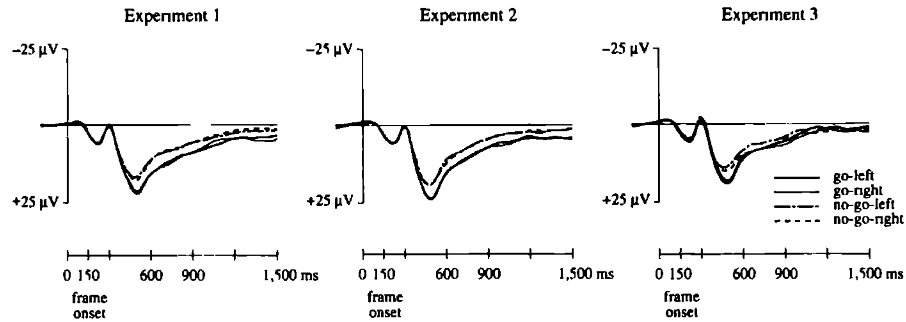


**Figure 2.9** *Grand average (N =16 participants) event-related potentials from the Electrode Site Pz for go and no-go trials of Experiments 1, 2, and 3 in which either the left or the right hand was cued.*

latencies to differ across the separate conditions because the stimuli we use were matched in terms of complexity, and the experiment was designed in such a way that each stimulus contributed equally to each of the conditions.

As can been seen in Figure 2.9, in all three experiments the P300 amplitude was larger in the go conditions than in the no-go conditions. To further analyze this difference, for each of the conditions, mean amplitudes were computed in the latency range of 250-450 ms after frame onset. In addition, mean positive peak latencies were determined for each of the conditions. On both the mean amplitudes and the mean peak latencies, a repeated measures analysis of variance was performed with Participants, Electrode Site (Fz, Cz, and Pz), Response Side (left or right) and Response (go or no-go) as completely crossed variables. In addition to these overall analyses, similar analyses were performed for each electrode site separately. The mean amplitude difference (averaged over the electrode sites Fz, Cz, and Pz) between the go and the no-go trials in the 250-450 ms range after frame onset latency were 3.7 μV, 3.1 μV, and 2.9 μV in Experiment 1, 2, and 3 respectively. In an analysis of variance this difference was statistically significant for each of the experiments (Exp. 1: $F(1,15) = 65.37$, $MSE = 144.52$, $p < 0.01$; Exp. 2: $F(1,15) = 21.5$, $MSE = 327.19$, $p < 0.01$; Exp. 3: $F(1,15) = 32.4$, $MSE = 188.34$, $p < 0.001$). There was no effect of response side ($F < 1$) in any of the experiments, and there were no significant interactions. For all three experiments, the mean peak latencies of the P300 did not significantly differ for go and no-go trials ($F < 1$).

Thus, as predicted, we found that a larger P300 was elicited in go trials than in no-go trials, but that no P300 latency differences emerged across the conditions. This indicates that although more processing was required on trials in which a push button response had to be executed, the time needed to evaluate the target pictures was equal across conditions. In summary, the results of these midline recordings do not bear directly on the experimental questions, but serve as an indirect validation of the materials used in the experiments, and as an indication of the reliability of the LRP recordings.

## GENERAL DISCUSSION

In the present study we have developed a new experimental paradigm in which we used the LRP to investigate the time course of semantic activation and phonological encoding in speech production.

In Experiment 1 an LRP was observed on no-go trials, indicating that semantic information was used to activate the response hand, independent of whether the word-final phoneme decision cued a response or not. In Experiment 2, we found that a word-final phoneme decision resulted in an LRP *only* on trials in which the semantic decision cued a response. In Experiment 3, we demonstrated that when the phonological decision involved the word-initial phoneme instead of the word-final phoneme, again a no-go LRP developed on the basis of semantic information.

The presence of an LRP on no-go trials in both Experiment 1 and Experiment 3 indicates that semantic information about a picture affects response preparation before sufficient phonological information about the picture-name is available. The absence of a no-go LRP in Experiment 2 substantiates this claim of temporal priority for semantic information over phonological information. Also, it rules out the possibilities that the early response preparation observed on no-go trials in Experiment 1 and Experiment 3 was either generated automatically following the simultaneous availability of both types of information, or was due to strategic control over the use of partial information.

Before turning to the implications of the present results, two issues related to the experimental procedure need to be discussed. The first concerns the possible effects of picture repetition. Could the multiple presentation of each picture have affected the nature of the naming process? In unpublished picture-word interference experiments, carried out at our institute, it has been shown that repeating pictures speeds up naming latencies, but does not interact with semantic or phonological relatedness effects. This indicates that each time a picture is named the same production processes are involved, independent of the number of repetitions. Another effect of repeating pictures could be that after having given the same response to a picture a couple of times, a response might be given on the basis of the visual recognition of the picture alone. However, such an effect could not have contributed to the development of a no-go LRP. On the contrary, one would expect a no-go LRP to disappear if such a stimulus-response coupling had been made.

The second issue related to the experimental procedure concerns the possibility of strategic effects due to (putative) differences in difficulty of the phonological decision task compared with the animacy decision task. It could be claimed that the animacy decision task is somehow intrinsically simpler than the phonological decision task, and that individuals use the strategy of always performing the easier task first. This strategy could lead to the pattern of effects we obtained. According to this account, the observed initial development of the LRP on no-go trials would have resulted from a strategic choice to perform the animacy decision first, and then the phonological task, because the phonological task is more difficult. However, recent evidence from our laboratory indicates that the intuitively supposed differences in complexity of the decision tasks do not determine the order in which different kinds of information are used for response selection. In an experimental paradigm similar to the one reported here, the word-initial phoneme decision task was combined with a grammatical gender decision task. Although the conscious retrieval of the grammatical gender of a picture name is intuitively more complex than the retrieval of a word's initial phoneme, the data show that gender information affected response preparation earlier than word onset information. This finding allows us to argue against the position that the present LRP data were mainly caused by strategy effects induced by differences in task difficulty.

In summary, the present results demonstrate that the LRP is differentially sensitive to the moments in time at which semantic and phonological properties of pictures and their names become available for response preparation. Under the plausible assumption that the availability of semantic and phonological properties of a picture name are a reflection of the time course of speech production, we can conclude that the LRP paradigm provides insight into the relative timing of semantic activation and phonological encoding in speech production. What, then, do the present results reveal about speech production?

One of the aims of this study was to show that during speech production, semantic activation *precedes* phonological encoding. The following findings provide evidence for early semantic activation in speech production.

In Experiment 1 and Experiment 3, we found that for a short period of time an LRP developed not only on go but also on no-go trials. The go and no-go LRPs had approximately the same onset latencies and they developed at the same rate. From these results we can conclude that semantic properties of a picture are used to selectively activate response hands before either the word-final phoneme (Experiment 1) or the word-initial phoneme (Experiment 3) of the picture name is available to suppress the response preparation. The absence of a no-go LRP in Experiment 2 shows that the semantic properties of the picture were available to make the go/no-go distinction before word-final phoneme information was used to prepare response hands.

Other evidence for the early availability of semantic information comes from a comparison of the results obtained for go trials in the three experiments. As mentioned earlier, we have to be careful in interpreting the outcomes of direct comparisons of response- or LRP onset latencies obtained in the separate experiments. Because different subject groups contributed to the experiments, these comparisons do not provide exact quantitative estimations of the semantic and phonological processing times. Rather, these comparisons can provide more insight into whether differences in the time course of semantic and phonological processing were at all present.

First, when comparing the results obtained for go trials in Experiment 1 and Experiment 2, we see that whereas the mean response latencies were almost identical in both experiments, the go LRPs tended to start at an earlier moment in time in Experiment 1 than in Experiment 2. In both experiments, a correct go response could only be given when *both* the semantic and the word-final phoneme analyses had been completed. The difference, however, was that in Experiment 1 the selection of the response hand could be made during the stage of semantic activation, whereas in Experiment 2 this selection could be made only after the word form had been constructed. The reaction time data suggest that this manipulation did not affect the moment at which the response was carried out. However, the observed difference in LRP onset latencies suggests that response preparation started earlier in Experiment 1 than in Experiment 2.

Second, the go trials in Experiment 1 resulted in substantially longer reaction times than the go trials in Experiment 3, in the absence of such a difference for the LRP onset latencies. This finding suggests that in both experiments, semantic information was used to selectively prepare response hands at about the same moment. Manipulating the position of the critical phoneme in the word thus did not influence the onset of response preparation but did affect the time required to complete the go/no-go decision.

Taken together, these findings are consistent with the claim that in the initial phase of speech production, the semantic properties of the to-be-pronounced word are activated, whereas the phonological form of the word has not yet been encoded. We cannot conclude from these data whether the stages of semantic activation and phonological encoding are discrete. Although we have demonstrated that semantic activation precedes phonological encoding, there might still be some overlap between the final part of the semantic stage and the start of phonological encoding. Now that the LRP paradigm has been shown to be sensitive to the time course of lexical access in speech production, this issue of the exact temporal profile can be addressed in future research.

In addition to the relative timing of semantic and phonological processing, the LRP results also provide more insight into the time course of phonological encoding itself. As we have argued, in Experiments 1 and 3 the point of divergence between the go and the no-go waveforms was determined by the moment at which the word's critical phoneme was available. The idea that the point of divergence between the go and the no-go waveforms can be used as an estimate of the time course of phonological encoding is validated by the following. For Experiment 1, we subtracted the no-go waveform from the go waveform. The resulting go/no-go difference waveform is shown in Figure 2.10. This difference waveform reflects the impact of the go/no-go decision on response preparation. Its onset provides an estimate of when word-final phoneme information decreased response preparation on no-go trials in Experiment 1. Also shown in this figure is the LRP for go trials, obtained in Experiment 2, where the word-final phoneme decision determined the response hand. The onset of this go waveform reveals when word-final phoneme information affected the LRP. The observed correspondence between the difference waveform in Experiment 1 and the go LRP in Experiment 2 suggests that the phonological information affected the development of the LRP at roughly the same moment in time, independent of whether the phonological decision was assigned to the response hand or to the go/no-go dimension. From this we infer that the period during which the go and the no-go LRP develop simultaneously provides an estimate of the additional time needed for phonological encoding, after the picture's semantic properties have

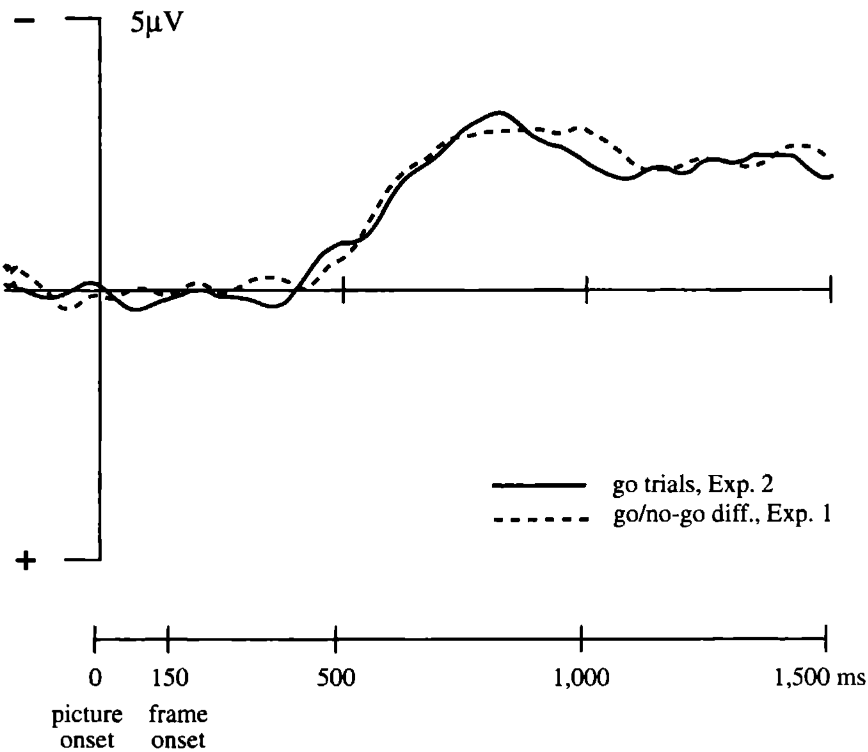


**Figure 2.10** *Grand average (N =16 participants) waveforms from Experiments 1 and Experiment 2. The solid waveform shows the lateralized readiness potential on go trials in Experiment 2, where the go/no-go decision was based on the meaning of the words, and the word-final phoneme decision determined which hand to use. The dashed waveform represents the go/no-go difference waveform obtained in Experiment 1, where the go/no-go decison was based on the word-final phoneme, and the meaning of the word determined which response hand to use. The moment at which the go/no-go difference waveform diverges from the baseline provides an estimate of when the phonological information decreased response preparation on no-go trials.*

been retrieved. Thus, the duration of the no-go LRP can be used as an estimate for the extra time needed to retrieve the critical phoneme of the picture name. Since this period is measured within-subjects, a straightforward comparison is possible.

With these findings in hand we return to the difference we observed between the duration of the no-go LRP in Experiment 1 and Experiment 3. In Experiment 1 the word-final phoneme was critical for making the go/no-go distinction, and here we found that 120 ms after LRP onset response preparation was decreased on no-go trials. In Experiment 3, where the word-initial phoneme was critical for making this distinction, only 40 ms were required to decrease the response. This 80 ms difference in the duration of response preparation on no-go trials is most likely related to the time course of the phonological encoding from the beginning of the target word to its end. It supports the idea that phonological encoding proceeds in a left-to-right manner, with the onset of a word being encoded before its end.[5] On the basis of this finding we estimate that for words consisting of on average 1.5 syllables and 4.5 phonemes, it takes about 80 ms longer to encode the end of a word than to encode its beginning.

This estimation is consistent with the data from phoneme monitoring experiments reported by Wheeldon and Levelt (1995). In their study, Wheeldon and Levelt asked Dutch participants to detect a given phoneme in an internally produced Dutch translation word from an English target word. They found that, for disyllabic words, the difference between monitoring latencies for phonemes at the first and the last position of a syllable was on average 55 ms, and the difference between monitoring the first and the last phoneme of a word was approximately 124 ms. Taking into account that the words in our study were shorter than the words used by Wheeldon and Levelt (our words had an average length of 1.5 syllables, Wheeldon and Levelt's words were all disyllabic), these findings correspond nicely to the 80 ms estimate we made for the duration of phonological encoding from wordonset to wordoffset.

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[5] *However, one problem that arises when drawing inferences from the LRP data about the temporal properties of phonological encoding concerns the nature of the phoneme decision task. Are the word's constituent phonemes transmitted to the response processes as soon as they are spelled out, or do they become available in a later phase of phonological processing? The present experiments were not designed to distinguish between separate levels of phonological encoding, and therefore further research is required to examine the precise locus of the phonological effects obtained in this study.*

Now we go back to the overall results in Experiment 1. As already mentioned above, the time between the onset of the LRPs and the onset of the go/no-go difference waveform, was 120 ms. What does this tell us about the length of phonological encoding? According to a strict two-stage model of speech production, phonological encoding can start only after a lemma has been selected. If we assume that at LRP onset the lemma has been selected, we can interpret the period in between the onset of the LRPs and the onset of the go/no-go difference waveform, as an estimation of the time required to make available the critical phoneme. According to this view, the period of 120 ms found in Experiment 1 can be taken as an estimation of the time required to construct a word form from its beginning to its end, for words that on average consist of 1.5 syllables and 4.5 phonemes. Following the same line of reasoning, the period of 40 ms observed in Experiment 3 can be interpreted as an estimation of the time required to encode the onset of a word.

However, perhaps the assumptions we are making are too strong. On the basis of our data we cannot claim that phonological encoding started after lemma selection. Moreover, given the nature of our semantic task, it is not clear whether the semantic decision involved lemma selection. It could be that the semantic property animacy became available during an earlier phase of conceptual identification. Irrespective of which assumptions apply, what we can infer from the data is that once a semantic candidate has been retrieved, it takes an additional 120 ms to encode its word form.

In conclusion, we have demonstrated that the LRP can be used to track the time course of processes involved in speech production, and we have provided evidence for the claim that in speech production there is an initial phase of semantic activation, followed by a stage of phonological encoding. Furthermore, on the basis of the LRP data, we estimate that, for words consisting of an average of 1.5 syllables and 4.5 phonemes, it takes 80 ms longer to retrieve a word's final phoneme than to retrieve its beginning. Finally, we observed that it takes 120 ms longer to retrieve the final phoneme of a word than to retrieve its semantic category. This 120 ms interval can be interpreted as the additional amount of time needed to phonologically encode a word once the semantic candidate has been retrieved.

By introducing the LRP go/no-go paradigm into the field of speech production research, we have been able to show that ERPs can be used to observe the rapid mental processes that underlie speaking. This novel finding opens the way for a more fine-grained real-time analysis of speech production than has hitherto been possible.

# THE TIME COURSE OF GRAMMATICAL AND PHONOLOGICAL PROCESSING DURING SPEAKING: EVIDENCE FROM EVENT-RELATED BRAIN POTENTIALS

CHAPTER 3


## ABSTRACT

Motor-related brain potentials were used to examine the time course of grammatical and phonological processes during noun phrase production in Dutch. In the experiments, participants named coloured pictures using a no-determiner noun phrase. On half of the trials a syntactic-phonological classification task had to be performed before naming. Depending on the outcome of the classifications, a left or a right push-button response was given (go trials), or no push-button response was given (no-go trials). Lateralized readiness potentials (LRPs) were derived to test whether syntactic and phonological information affected the motor system at separate moments in time. The results showed that when syntactic information determined the response-hand decision, an LRP developed on nogo trials. However, no such effect was observed when phonological information determined response hand. On the basis of the data it can be estimated that an additional period of at least 40 msec is needed to retrieve a word's initial phoneme once its lemma has been retrieved. These results provide evidence for the view that during speaking, grammatical processing precedes phonological processing in time.

Speaking involves the translation of an idea into a linear sequence of sounds. Whereas an idea, or thought, is verbally unspecified, speech consists of strings of words with a clear temporal order. The present study is concerned with the temporal parameters of the processes that underlie speaking. The main focus is on the time course of grammatical and phonological encoding in noun phrase production. Two experiments were designed to examine whether grammatical processing precedes phonological processing in time. We use event-related brain potentials (ERPs) to tap into grammatical and phonological processing as it proceeds in real-time.

## PROCESSING LEVELS IN SPEECH PRODUCTION

In describing the processing mechanisms underlying the transformation of a thought into speech, theories of speech production usually distinguish between conceptual, grammatical, and phonological processing levels (Bock, 1982; Bock & Levelt, 1994; Butterworth, 1989; Dell, 1986; Garrett, 1975, 1976, 1980; Kempen & Huijbers, 1983; Levelt, 1989). At the conceptual level a conceptual structure, often called the message (e.g., Garrett, 1975; Levelt, 1989), is abstracted from the many aspects of an idea. The message represents the speaker's intention, and specifies the content of the utterance. During grammatical processing, the conceptual structure is translated into a linguistic representation. The conceptual structure drives the activation and selection of the appropriate word representations in the mental lexicon. These representations are often called *lemmas* (Kempen & Huijbers, 1983), and can be thought of as entries in the mental lexicon specifying a word's syntactic properties. Lemma activation makes available the syntactic characteristics of a lexical item that are needed for grammatical encoding (such as word-class and grammatical gender; see Kempen & Huijbers, 1983; Levelt, 1989; Roelofs, 1992). Grammatical procedures are initiated to assign syntactic relations between the lexical items, and to determine their serial order in the utterance (see for a detailed description of grammatical encoding Bock & Levelt, 1994; Levelt, 1989). During phonological processing the sound form of the utterance is created. This involves the retrieval from the mental lexicon of the phonological properties of the words (e.g., the phonological segments of a word, its stress pattern, and its number of syllables), and the construction of larger phonological units (e.g., phonological words and phrases). The end-product of phonological encoding is a phonetic plan of the utterance to be executed by the articulators (for details see, for example, Dell, 1986, 1988; Levelt, 1989; Levelt & Wheeldon, 1994; Meyer, 1992; Meyer & Schriefers, 1991; Shattuck-Huffnagel, 1979, 1983). In the present study we focus on the separation between the grammatical and phonological processing level.

Empirical support for the distinction between a grammatical and a phonological processing level originates from the analysis of speech errors observed in natural speech (Garrett, 1975, 1980, 1988). A by now classical outcome of such speech error analyses concerns the contrast observed between word exchange errors and sound exchange errors. Word exchange errors, such as "I left the briefcase in my cigar" (in which *briefcase* and *cigar* are exchanged; Garrett, 1980), predominantly occur between phrases, in some cases even between clauses, and they typically are exchanges between words of the same syntactic category. Sound exchange errors, such as "heft lemisphere" (in which the segments /h/ and /l/ are exchanged; Fromkin, 1973), usually occur within phrases, and they are strictly clause- bounded. Sound exchanges are not constrained by syntactic category, and they tend to be influenced by phonological similarity (cf. MacKay, 1970). This contrast between the properties of sound and word exchanges has been interpreted as evidence for a separation between a processing level at which lexical items are retrieved and assembled in a syntactic frame, and a level at which the phonological form of the utterance is constructed (cf. Bock, 1982; Dell, 1986; Garrett, 1975, 1988; Kempen & Huijbers, 1983; Levelt, 1989). Moreover, studies in which speech errors are elicited under experimental control show that the occurrence of syntactic errors such as subject-verb agreement errors is not affected by phonological factors (see, for example, Bock & Eberhard, 1993). These results support the view that syntactic processes operate independently of phonological processes.

Corresponding to the distinction between grammatical and phonological encoding, models of speech production distinguish between two types of word information that are stored in the mental lexicon: lemmas, which represent a word's syntactic properties, and word forms, which include a word's morpho-phonological characteristics. Lemmas are activated and selected during grammatical processing, whereas word forms are retrieved during phonological processing. Clear evidence for a distinction between lemmas and word forms comes from the tip-of-the-tongue phenomenon. In tip-of-the-tongue states speakers claim to know the word, and they often can successfully report the grammatical gender of the word. At the same time, however, they are not able to retrieve the complete sound form of the word. This dissociation between retrieving a word's semantic and syntactic properties, and retrieving its sound form suggests that the different types of information are represented and accessed separately (Brown & MacNeill, 1966; Brown, 1991; Vigglioco, Antonini, & Garrett, 1996). Also, data from studies of language impairment suggest a dissociation between lemma retrieval and word-form encoding (Butterworth, 1989; see Garrett (1992) for an overview). Finally, experimental studies provide evidence for a separation of lemma retrieval and word-form encoding during lexical access in speech production (Kempen & Huijbers, 1983; Levelt, Schriefers, Vorberg, Meyer, Pechmann, & Havinga, 1991; Levelt & Maassen, 1981; Schriefers, Meyer, & Levelt, 1990).

## TEMPORAL PARAMETERS OF SPEECH PRODUCTION

As was described above, there is ample evidence for the existence of separate conceptual-semantic, syntactic, and phonological processing levels in speech production. However, much less is known about the temporal parameters under which these processes operate. The temporal coordination of the separate processing levels is of crucial importance for the production of fluent speech. This becomes apparent when one considers the fast speech rate (on average speakers produce 2 to 3 words per second, cf. Maclay & Osgood, 1959; Levelt, 1989), and the high level of fluency that speakers are able to achieve. In order to produce such fluent speech the processing components of the production system need to be simultaneously active (Dell, 1986; Kempen & Hoenkamp, 1987; Levelt 1989). This means that a sentence does not need to be fully specified at one level before processing at the next level can start. For example, as soon as a sentence fragment has been specified at the conceptual level, it can be translated into a linguistic structure, while at the same time other fragments are being conceptually specified. In stage-theories of speech production, the parallel activity at the conceptual, syntactic, and phonological levels is combined with seriality. This means that although the different processing components are simultaneously active, each of the components is assumed to work on a different part of the sentence (Dell, 1986; Garrett, 1976; Kempen & Hoenkamp, 1987; Levelt, 1989). According to these theories, the processing of a fragment at one level is guided by the level directly above it. With respect to the temporal parameters of grammatical and phonological encoding this implies that the phonological form of a particular sentence fragment can be constructed only after the syntactic frame of that fragment has been built-up.[1]

The claim that during speaking grammatical processing precedes phonological processing in time has mainly been based on speech error data (Garrett, 1980, 1988; Dell, 1986). Some indirect support for this claim has been provided by studies examining word order preferences. In a sentence priming experiment, Bock (1986) showed that the assignment of syntactic functions could be influenced by semantic priming, but not by phonological priming (but see Bock, 1987). In a series of sentence recall experiments, McDonald, Bock, and Kelly (1993) found an influence of conceptual factors on the assignment of grammatical roles to words in the recalled sentences. At the same time, no significant influences from word length and prosody were found, suggesting that phonological factors did not have an impact on the order in which words appear in a sentence.

These findings suggest that phonological factors do not influence the syntactic structure of a sentence. In this respect, these data are consistent with the idea that the syntactic frame of a fragment is built-up before its phonological form is constructed. However, these studies did not focus on time course questions, and the measures they used did not tap into the speech production process as it proceeds in time. Therefore, these data do not provide real-time evidence on the temporal parameters of grammatical and phonological encoding.

An experimental paradigm that has been used to track the time course of processes involved in speaking is the picture-word interference paradigm. In this paradigm, participants are asked to name pictures while hearing, or seeing, interfering words. The interfering word is either related or unrelated to the picture name, and is presented at different moments in time. The critical measure involves the difference in response latencies between the related and the unrelated conditions. The results of these studies show that during the production of single words, semantically related words interfere with picture naming in an early phase of the naming process, while phonologically related words affect picture naming only in a later phase (Schriefers et al., 1990).

[1] *Although it is generally agreed upon that the size of these sentence fragments should be small, and different between the levels, the exact size and the nature of the processing units at the separate levels are still unclear. See for relevant evidence and discussions on this topic, for example, Bock, (1982), Dell and O'Seagdha, (1992), Ferreira, (1991), Ford and Holmes, (1978), Kempen and Huijbers, (1987), Levelt, (1989), Levelt and Maassen, (1981), Meyer, (1996), Schriefers, (1992).*

Using a similar experimental paradigm, Dell and O'Seaghdha (1992) and Meyer (1996) investigated the time course of word retrieval during the planning of short sentences. They showed that during the planning of short sentences, semantic effects were not influenced by the position of the target word in the sentence, while phonological relatedness effects differed when comparing early and late words in a sentence. These data suggest that planning at the lemma level exceeds that at the phonological level.

Together, these reaction-time data support the view that during speech production, semantic processing precedes phonological processing in time. To what extent the semantic effects provide evidence on the time course of grammatical processing is unclear. In the studies described above, it was claimed that the semantic effect arises at the level of lemma retrieval. This claim has been substantiated by control experiments carried out by Schriefers et al. (1990), and Levelt et al., 1991) showing that the semantic relatedness effect disappeared when subjects performed a picture recognition rather than a picture naming task. However, it can be argued that the memory representations used in picture recognition are not identical to the conceptual representations used in picture naming. The fact that the studies described above did not explicitly address the retrieval of syntactic properties makes it hard to disentangle effects arising at a conceptual and a grammatical processing level. Therefore, these data do not provide clear-cut evidence on the temporal relation between the levels of grammatical and phonological processing.

In the present study we used noun phrase production as the primary experimental task because it involves both grammatical and phonological encoding. Schriefers (1993) used the picture-word interference paradigm to investigate grammatical processing during noun phrase production and details of his findings will be described below. We created an experimental paradigm in which we tapped into grammatical and phonological encoding by the registration of event-related brain potentials (ERPs).

In Chapter 2, the use of ERPs was introduced into the field of speech production research and we obtained real-time information on the temporal dynamics of the separate processes involved in speaking. One of the useful characteristics of ERPs is their high temporal resolution. Moreover, based on the morphology and scalp distributions of the potentials, ERPs provide the possibility to distinguish between different cognitive processes (see, for example, Rugg and Coles (1995) for an overview of the characteristics of different ERP components, and their relation to cognitive processes). ERPs have been successfully used to study the nature and the temporal characteristics of processes involved in language comprehension (e.g., Hagoort, Brown, & Groothusen, 1993; Kutas & Hillyard, 1980; Kutas & Van Petten, 1988; Osterhout & Holcomb, 1992). The findings reported by Van Turennout et al. (1997) showed that ERPs can also be used to investigate the cognitive processes underlying language production. They showed that ERPs provide a sensitive measure of the different moments in time at which semantic and phonological information become available during picture naming.

## AIM OF THE STUDY

The aim of the present research is to provide electrophysiological evidence on the temporal parameters of grammatical and phonological encoding. We attempt to find evidence for a stage of syntactic processing that precedes phonological encoding in time during the production of noun phrases. We apply the ERP technique to tap into grammatical and phonological processing as they proceed in real-time. The ERP component we use is the Lateralized Readiness Potential (LRP). First we will describe the characteristics of the LRP, and then explain how this measure is used to provide insight into the time course of grammatical and phonological processing.

## THE LATERALIZED READINESS POTENTIAL

The LRP is derived from the readiness- or Bereitschafts-potential (Kornhuber & Deecke, 1965). The readiness potential (RP) is a movement-related brain potential that occurs before a movement is executed. For hand movements, the RP is largest in amplitude at scalp sites overlying the motor cortex contralateral to the moving hand. The lateralized part of the RP has been shown to be related to the preparation for the execution of a specific movement (cf. Kutas & Donchin, 1974, 1977, 1980; Vaughan, Costa, & Ritter, 1968; Rohrbaugh, Syndulko, & Lindsey, 1976). To be able to use the lateralized motor potentials as a measure for specific response preparation, they have to be isolated from all other lateralized brain activity occurring at the scalp. To achieve this, the following two-step subtraction procedure has been used in experimental situations in which either a left-hand or a right-hand movement is executed in response to a stimulus (Coles, Gratton, & Donchin, 1988; De Jong, Wierda, Mulder, & Mulder, 1988). First, for each trial, the amount of lateralized activity is obtained by subtracting potentials recorded from above the left motor cortex from potentials recorded from above the right motor cortex. These differences are averaged separately for left- and right-hand trials. In the second step, the average lateralization obtained for the left-hand trials is subtracted from the average lateralization obtained for the right-hand trials. Lateralized activity that is not specifically related to response preparation will be the same on both left- and right-hand trials, and will therefore be eliminated by the second subtraction. The resulting measure is the LRP, reflecting the average amount of lateralization occurring as a result of specific motor preparation (see for detailed description Coles, 1989; De Jong et al., 1988).

The LRP has been used in a variety of studies to assess aspects of human information processing (see Coles, Smid, Scheffers, & Otten, 1995 for an overview). In particular, the LRP has been used to detect transmission of partial information between perceptual and motor processes (e.g., Coles, 1989; De Jong et al., 1988; Miller & Hackley, 1992; Osman, Bashore, Coles, Donchin, & Meyer, 1992; Smid, Mulder, Mulder, & Brands, 1992). An experimental paradigm in which it has been established that an LRP can develop on the basis of partial stimulus evaluation, is the two-choice reaction go/no-go paradigm (e.g., Smid et al., 1992; Osman et al., 1992; Miller & Hackley, 1992). In this paradigm, one attribute of a stimulus indicates a left- or right-hand response, while another attribute of the same stimulus indicates whether or not the response has to be given. The results obtained in this paradigm consistently show that partial stimulus information can be used to select response hands before the stimulus has been fully identified. This means that an LRP can develop on the basis of partial information. As soon as perceptual and cognitive information relevant for response-hand selection is transmitted to the motor system, an LRP starts to develop, even if on the basis of complete information no overt response is given. As such, the LRP can be used to detect the relative moments at which distinct kinds of information become available for response preparation. However, some care has to be taken with interpreting the initial development of an LRP as an indication of the moment in time that information becomes available. Some evidence exists that in certain experimental conditions, the use of partial information for response selection can be strategically modulated (Gratton, Coles, & Donchin, 1992; Smid et al., 1992; De Jong, Liang, & Laubert, 1994). This flexibility in transmission processes needs to be kept in mind when applying the LRP paradigm to investigations of time-course differences in cognitive processes.

The LRP go/no-go paradigm was recently used by us to study the time course of speech production (Van Turennout et al., 1997). In the Van Turennout et al. study, the LRP was used to detect a separation in time between the availability of semantic and phonological information during picture naming. In addition to picture naming, a semantic-phonological classification of the picture had to be performed. Individuals were asked to respond with one hand for animate, and with the other hand for inanimate picture referents, a decision requiring the retrieval of semantic information. The decision whether or not to execute the response was determined by the word-initial phoneme, necessitating the retrieval of the phonological form of the picture name. During the performance of this task, ERPs were recorded from electrode sites located above the left and the right motor cortices, and LRPs were derived. The rationale behind the study was as follows. If, during picture naming, semantic activation precedes the retrieval of the sound pattern, the results of the semantic process will be transmitted to the response system earlier than the results of the phonological retrieval. In this case, preparation of the response hand can start before phonological information informs the individual about whether or not to respond. Exactly this pattern of results was observed. An LRP developed not only for go trials, but initially also for no-go trials, in the absence of an overt response. The early availability of semantic information enabled response preparation, but when information about the word's sound pattern became available, this then overruled further response preparation on the no-go trials. These results show that the LRP can be used to track the time course of processes involved in speech production, and they provide evidence for the claim that during picture naming there is an initial stage of semantic activation, followed by a stage of phonological encoding.

In the present study a similar paradigm will be used to investigate whether syntactic processing precedes phonological processing in time. The evidence for the distinctiveness of syntactic and phonological processing makes it plausible to assume that the output of these two stages can be transmitted separately to the response processes. On the basis of the results of the studies described above, we hypothesize that if the syntactic and phonological stages are not only distinct but also have a different time course, the output of these processes should be available for response preparation at separate moments in time. To initiate syntactic and phonological processing in speech production, we instruct individuals to produce noun phrases in response to coloured pictures. In addition to the production task, a two-choice reaction go/no-go procedure is applied to distinguish between the moments at which syntactic and phonological information become available for response preparation. Before we turn to the details of the experimental paradigm we will describe the syntactic processes involved in noun phrase production that are relevant for the present study.

## NOUN PHRASE PRODUCTION

In Dutch noun phrases that contain an adjective, the adjective has to precede the noun. Dutch nouns usually have either one of two grammatical genders: common gender or neuter gender.[2] When produced with a definite article, a noun phrase is gender marked by the definite article of the noun, *de* for nouns of common gender, and *het* for nouns of neuter gender (e.g., *de rode bank*, the red couch; *het rode bed*, the red bed). When a noun phrase is produced without a definite article, gender is marked by the adjectival inflection. For common gender the adjective-stem carries the suffix *e*, whereas for neuter gender only the adjective-stem is used (e.g., *rode bank*, red couch vs. *rood bed*, red bed). The syntactic processes in noun phrase production involve the retrieval of the grammatical gender of the noun, and on the basis of this information, the determination of the corresponding definite article, or adjectival inflection. In a recent series of picture naming experiments, Schriefers (1993) investigated syntactic processing during the production of Dutch noun phrases. In these experiments, coloured pictures were presented together with distractor words, and participants were instructed to name the pictures using a definite-determiner noun phrase in one experiment and a no-determiner noun phrase in another. The distractor words were bare-nouns that had either the same or a different grammatical gender than the picture name.[3] The results showed that

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[2] *The Dutch gender system is arbitrary in the sense that the grammatical gender of a noun is not determined by natural gender, and there are hardly any rules on the basis of which the gender of a noun can be determined (see Van Berkum (1996) for a comprehensive overview of the linguistics of the Dutch gender system).*

[3] *Schriefers (1993) included four additional distractor conditions in which the semantic relation between the adjective and the distractor, or the target noun and the distractor was manipulated. These results will not be discussed here.*

a gender incongruency effect occurred for both definite-determiner noun phrases and for no-determiner noun phrases. Naming latencies were longer when the target word and the distractor word had a different grammatical gender than when they had the same grammatical gender, even though gender information of the distractor was not explicitly presented (see Van Berkum (1996) for similar findings). Schriefers (1993) accounted for these results in terms of Roelofs' (1992) spreading activation model of lexical processing, that was developed within Levelt's (1989, 1992) framework of speech production. Figure 3.1 shows a simplification of the Levelt/Roelofs' model. In this model, lemmas and their syntactic properties are conceived of as linked nodes on the grammatical level of a lexical network. Each lemma is linked to a lexical concept node on the conceptual level, and also to a word-form node on the phonological level. Semantic properties are specified by labelled links between the concept nodes, word-form nodes point to the segments that make up a word's phonological form (see Figure 3.1). In the network, activation spreads from a concept node to its corresponding lemma node. As soon as a lemma is activated, activation spreads to the syntactic property nodes that are linked to it (e.g., Gender: neuter). A lemma is selected if its activational level exceeds the activational level of other lemmas by a critical value (see Roelofs, 1992 for details). Once a lemma has been selected, activation spreads to its word-form node, and the phonological properties of the word can be retrieved.

Extrapolating from this model of lexical retrieval, Schriefers (1993) suggested that the observed gender incongruency effect arises at the level of syntactic processing. During noun phrase production, activation spreads from the noun's lemma node to its gender node. The selection of the gender node makes available the correct definite article, or the correct adjectival inflection, required for filling the corresponding slots in the syntactic frame of the utterance. If during noun phrase production a distractor word is presented, the gender node of both the target lemma and the distractor lemma gets activated automatically. When the distractor and the target have the same gender, the activation of the distractor's gender node does not interfere with the selection of the target's gender node. However, when the distractor's gender is different from the noun's gender, competition will occur between the two gender nodes. Due to this competition, the selection of the target noun's gender node will be delayed. As a consequence, the correct definite article or adjectival inflection needed to produce a correct noun phrase will be retrieved later in time, and naming latencies will be delayed.

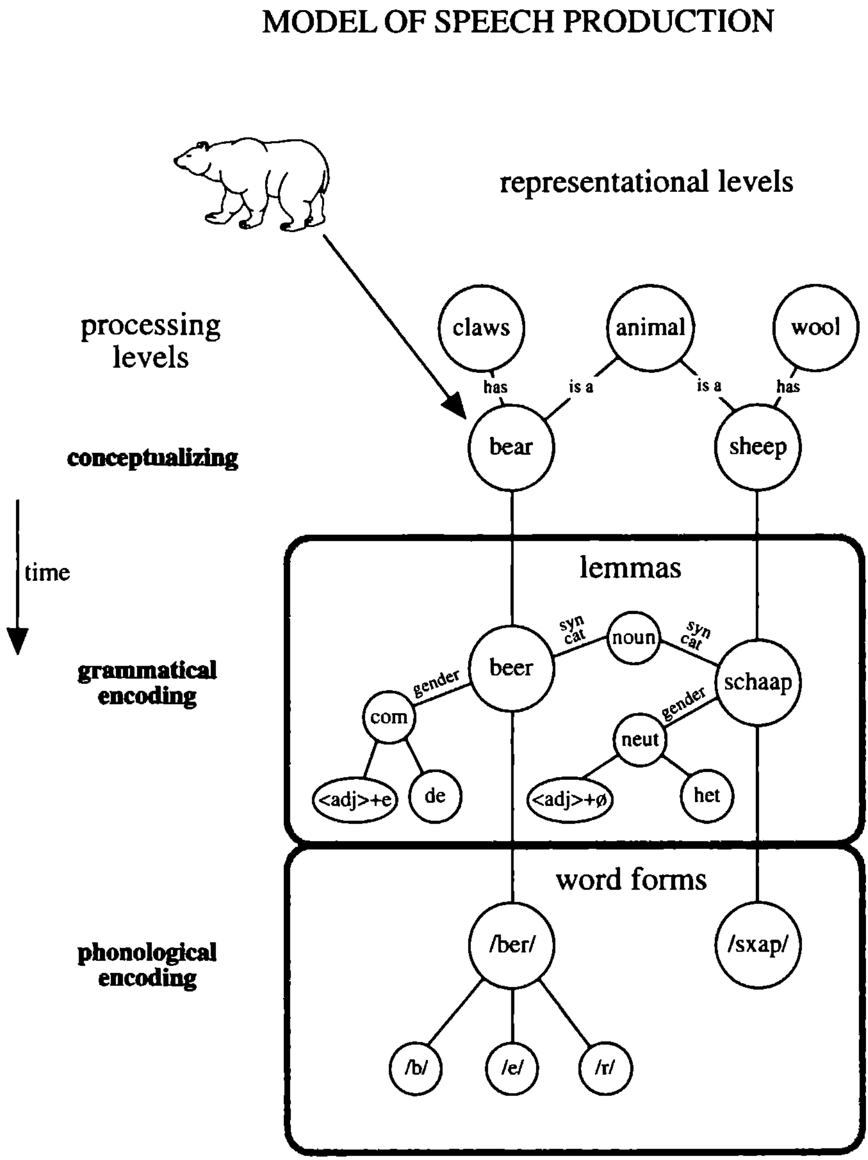


**Figure 3.1** *A simplified model of the separate processing and representational levels of speech production. (After Levelt, 1989, 1992; Roelofs, 1992)*

What conclusions follow for the present study? The findings by Schriefers (1993) make it plausible to assume that in noun phrase production the definite article and the inflectional suffix are retrieved during syntactic processing. The result that the presence of a gender incongruency effect was independent of the syntactic format of the utterance suggests that during noun phrase production the definite article and the adjectival inflection are not directly activated by conceptual input, but are determined after the noun's grammatical gender has been retrieved (see also Levelt, 1989). We hypothesize that if lexical access proceeds from the lemma to the word-form level, information about the grammatical gender of a noun will be activated earlier in time than its phonological segments. If we extend this to the time course of syntactic and phonological processing in noun phrase production, we hypothesize that determining a noun's definite article or inflectional suffix precedes the retrieval of the word's phonological segments. To test this hypothesis we constructed an experimental task in which both syntactic and phonological processes were related to motor responses. We used a two-choice reaction go/no-go paradigm to distinguish between the moments in time at which information obtained during syntactic and phonological processing affected the preparation of a motor response.

## EXPERIMENTAL PARADIGM

The main task was noun phrase production. Participants were presented with coloured pictures and were instructed to name the pictures using a no-determiner noun phrase. That is, their naming response included a colour adjective, the correct adjectival inflection, and the noun (for example, *rood bed*-red bed, or *rode tafel*-red table). On half of the trials a frame appeared around the picture at 150 ms after picture onset, indicating that a secondary task had to be performed before noun phrase production. The secondary task was the critical experimental task. It involved a syntactic-phonological classification task consisting of the conjunction of a go/no-go decision and a left or right-hand response. The syntactic classification involved the determination of the definite article of the noun. Participants were asked to decide whether the picture represented a *de* or a *het* word. The phonological classification involved the categorization of the noun's initial phoneme. Participants were asked to decide whether the name of the picture started with, for example, a /b/ or an /s/. After the syntactic/phonological classification task had been carried out, participants named the picture using a no-determiner noun phrase.

In the first experiment we attempted to detect response preparation based on syntactic information alone. In this experiment, the syntactic classification determined the response side. For example, a right-hand response had to be made if the noun had the definite article *de*, and a left-hand response had to be made if the noun had the definite article *het*. The phonological classification determined whether the response should be executed or not. For example, a response had to be executed if the picture name, i.e. the noun, began with a /b/, but it had to be withheld if it began with an /s/.

The logic behind the paradigm is as follows. At the moment of the appearance of the task cue (150 ms after picture onset), participants are in an early phase of noun phrase production. Since the main task is noun phrase production, on each trial the speech production process will be initiated directly after picture onset. The assumption underlying the syntactic-phonological classification task is that the critical information becomes available via the speech production process. That is, the retrieval of the noun's definite article follows the same processing route as the retrieval of the adjectival inflection, and therefore the noun's definite article becomes available during grammatical encoding. To retrieve the word's initial phoneme, the individual segments of a word have to be spelled-out, and therefore a word's initial phoneme becomes available during phonological encoding (see, for example, Van Turennout et al., 1997; Wheeldon & Levelt, 1995). If grammatical encoding precedes phonological encoding in time, then information about the noun's definite article should be available earlier in time than information about the word's initial phoneme. The critical test of this hypothesis involves the presence or absence of response activation on trials in which the phonological information instructs not to respond. From the LRP studies described earlier (e.g., Coles, 1989; Miller & Hackley, 1992; Smid et al., 1992; Osman et al., 1992; Van Turennout et al., 1997), we know that information can be transmitted to the response system as soon as it becomes available. Moreover, these studies showed that the LRP can be used as a continuous measure of response preparation, and that the LRP is sensitive to low levels of response activation that do not result in an overt response. Therefore, if a noun's definite article is available earlier in time than its initial phoneme, we expect to observe an LRP on both go and no-go trials. After some time, the retrieval of the word's initial phoneme will decrease response preparation on no-go trials, and the LRP will return to the baseline. On go trials, response preparation will continue, resulting in an overt response.

A second experiment was carried out to validate the results of the first experiment. From studies that were mentioned earlier, it is known that subjects are able to strategically control the use of partial information. To test whether strategic effects played a major role in the first experiment, in the second experiment the task instruction was reversed. Here, the syntactic classification determined whether or not to respond, and the phonological classification determined which hand to use. For example, in the case of a *de* word, a right-hand response had to be made for a word-initial /b/, and a left-hand response for a word-initial /s/. In the case of a *het* word, no response had to be given. Thus, in this experiment, a response could only be activated once the word-initial phoneme was available. The decision whether or not to respond could be made as soon as the gender information was available. Following the same logic as in Experiment 1, we expect that if gender information is available earlier in time than phonological information, the go/no-go decision can be made before information about the response hand becomes available. Therefore, the presence of an LRP is only expected for go trials.

In addition to the LRP measurements, for each of the go and no-go conditions, average waveforms were computed for the midline frontal (Fz), central (Cz), and parietal (Pz) electrode sites. The results of these midline recordings do not bear directly on the experimental questions, but serve as an indirect validation of the materials used in the experiments, and as an indication of the reliability of the LRP recordings. Because the results from the midline recordings were as expected in both experiments, they will not be presented.

## EXPERIMENT 1

### Method

#### *Participants*

Sixteen undergraduate students (7 male) between 21 and 29 years of age from the participant pool of the Max Planck Institute for Psycholinguistics took part in the experiment. They were all native speakers of Dutch and had normal or corrected-to-normal vision. All participants were right-handed according to their response on an abridged and adapted Dutch version of the Oldfield Handedness Inventory (Oldfield, 1971). Familial left-handedness was reported

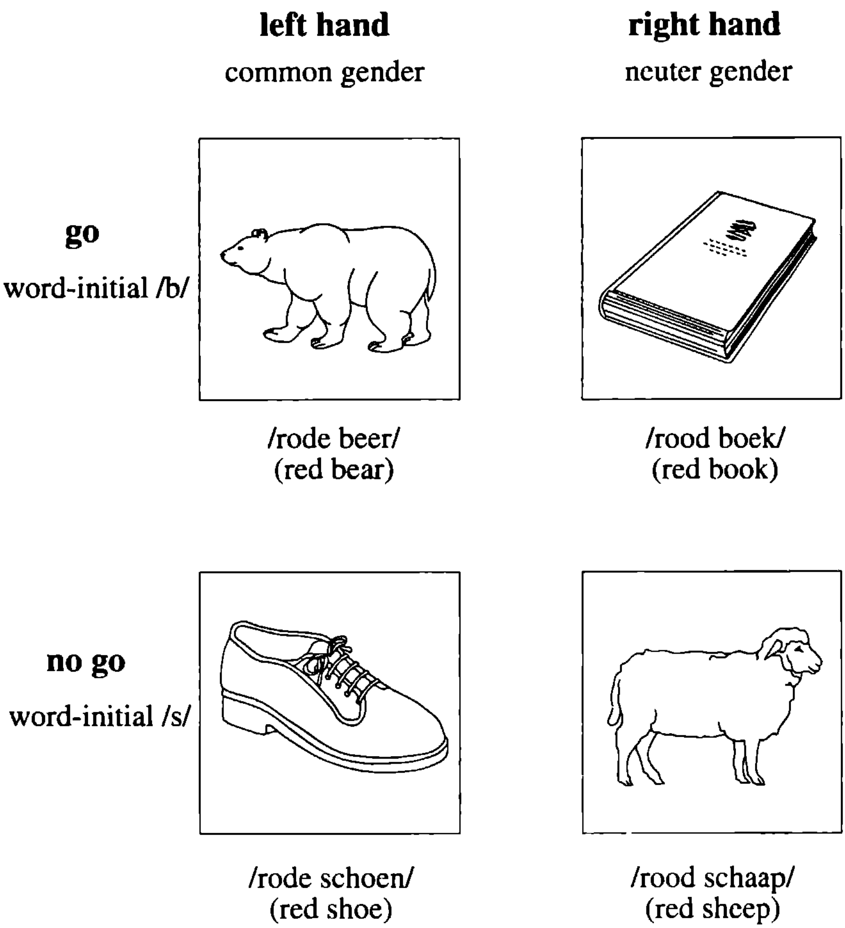


**Figure 3.2** *Examples of the pictures used in the syntactic - phonological categorization task in Experiment 1. In the figure, the Dutch picture names are shown below the pictures. In the experiment, pictures were presented in colour, and naming responses included the colour adjective, the correct adjectival inflection, and the picture name. The four pictures depicted here represent separate trials for the four experimental conditions. In this figure, a* DE *word cues a left-hand response, and a* HET *word cues a right-hand response. The response is executed if the picture name starts with a /b/ (go trials), and it is withheld if the picture name starts with an /s/ (no-go trials).*

by five of the participants. None of the participants had any neurological impairment or had experienced any neurological trauma according to their response on a questionnaire. They were paid for their participation.

### *Materials*

The materials consisted of 48 coloured line drawings with morphologically simple names. Half of the picture names were *de* words, which were the experimental items. They were all high frequent words (their mean token frequency was 2700 in 42 million words). The words consisted of one or two syllables and had an average length of 4.3 segments. The other 24 pictures were *het* words and were used as filler items. The decision to use only *de* words as experimental items was made in order to reduce the between-item variability in the experiments. The *het* words were matched to the *de* words for word frequency, number of syllables, and word length. There were no clear semantic differences between the set of *de* and *het* words. The experimental pictures were selected according to the following criteria: a) Pictures had to be unambiguous. That is, a picture had to elicit a consistent naming response between subjects. To establish this, a pretest was run in which ten undergraduate students were asked to name 122 pictures. The pictures were successively presented for 600 ms on a NEC/Multisync 3D computer screen, with an inter-stimulus-interval of 3 s. A picture was said to be unambiguous if it was given an identical name by at least nine of the ten participants. b) The grammatical gender of the picture names had to be clear, and relatively fast to retrieve. To determine the accuracy and speed of gender decisions another pretest was run. The same 122 pictures that were used in the naming pretest were presented to ten undergraduates. Pictures were presented in the same way as was done in the naming pretest. Participants were instructed to indicate as quickly as possible whether the name of the picture was a *de* or *het* word by pressing either the left or the right button of a button box. Response latencies were measured from picture onset. Median reaction times and errors were calculated for the 122 pictures. To be selected, a picture had to be classified correctly by all participants and the median reaction time had to be less than 850 ms. The set of experimental pictures is listed in Appendix A.

The names of the pictures included four different word-initial phonemes, namely /b/, /s/, /v/, and /k/. Each of these word-initial phonemes was represented equally often in the picture set. The combination of the two syntactic categories and the four phonological categories resulted in four sets of experimental pictures: de - word-initial /b/ (e.g., bloem [flower]), de - word-initial /s/ (e.g., schoen [shoe]), de - word-initial /v/ (e.g., voet [foot]), de - word-initial /k/ (e.g., kast [cupboard]), and four sets of filler pictures: het - word-initial /b/ (e.g., brood [bread]), het - word-initial /s/ (e.g., schaap [sheep]), het - word-initial /v/ (e.g., vuur [fire]), het - word-initial /k/ (e.g., kasteel [castle]). These materials were divided into two series. One series contained all word-initial /b/ and word-initial /s/ items, the other series contained all word-initial /v/ and word-initial /k/ items. The order in which the two series were presented was balanced across participants. The assignment of the four response types (left-hand go, right-hand go, left-hand no-go, right-hand no-go) to the separate picture sets was rotated across participants in such a way that each picture contributed equally to each of the responses. This was done to control for material-specific effects in the separate conditions. Examples of the stimuli are shown in Figure 3.2. In this figure, a *de* word cues a left-hand response, and a *het* word cues a right-hand response. The response has to be executed if the picture name starts with a /b/ (go trials), and it has to be withheld if the picture name starts with an /s/ (no-go trials). To be able to derive LRPs for each individual subject by averaging over *de* words only, *de* words were assigned to the right hand in one series, and to the left hand in the other series. The order in which these assignments were given was balanced across subjects.

In addition to the pictures used in the judgment trials, twenty-four pictures were included that were used for filler-naming trials, in which subjects only named the pictures. Half of these fillers were *de* words and the other half were *het* words. Their word-initial phonemes differed from the word-initial phonemes of the targets. Also, a set of practice items was included. This set consisted of ten pictures representing a *de* word and ten pictures representing a *het* word. Half of the picture names started with a /p/, the other half started with an /h/.

### *Procedure*

Participants were tested individually in a dimly lit sound-attenuating booth. They were seated in a comfortable chair in front of a high resolution NEC/Multisync 3D computer screen. A trial started with the presentation of a fixation cross in the middle of the screen for 750 ms. The screen turned blank for 750 ms and then a picture was presented for 2500 ms. Participants were asked not to blink or to move their eyes during the period that the picture was on the screen. The pictures were presented in either the colour yellow or red. Subjects were instructed to name the coloured picture as quickly as possible using a no-determiner noun phrase. Naming latencies were measured from picture onset by a voicekey. The naming responses were recorded by a Sony 300 ES DAT-recorder. On half of the trials a frame appeared around the picture at 150 ms after picture onset. The appearance of the frame signalled that the judgment task had to be carried out before picture naming. Push-buttons were attached to the left and the right arm of the chair. For go trials, participants made a hand response by pressing with their index finger either the button on the left side or the button on the right side of the chair. Push-button latencies were measured from frame onset. For no-go trials participants did not press any of the buttons. The frame remained on the screen for 1500 ms. Participants were instructed not to speak during this period. After the frame had disappeared participants named the picture. The presentation of the stimuli and the acquisition of the reaction time data was controlled by NESU, a system developed at the Max Planck Institute for Psycholinguistics, using a Hermac AT computer.

A session started with training on the task, using the set of practice pictures. Practice trials were presented until the participants performed the task accurately. After the training, electrodes for measuring electrophysiological activity were applied. The actual experiment consisted of two series of six blocks. In one series the /b/ and /s/ items were presented, and in the other series the /v/ and /k/ items were presented. The order in which the series were presented was balanced across subjects. Each of the series started with a block in which subjects were familiarized with the pictures and their names. The second block was a practice block containing all pictures that would be presented during that series. After the practice block four experimental blocks were presented. An experimental block was composed as follows. The 12 experimental *de* word pictures and the 12 filler *het* word pictures were presented twice in a judgment trial, and once in naming-only trials. The filler-naming pictures were presented twice in naming-only trials. As a result, in each of the experimental blocks there were 48 naming-only trials, and 48 trials that in addition had the critical judgment task. In half of the trials a picture was presented in red, in the other half a picture was presented in yellow. The items were presented in pseudo-randomized order. Repeated items were always separated by at least 8 other items, there were never more than two successive trials in the same condition, and there were never more than three successive naming-only trials or more than three successive judgment trials. Each block lasted eight minutes, with a short break between the blocks. Between the first series and the second series participants were given a ten to fifteen minutes break. In the second series, the assignment of *de* and *het* words to either a left- or right-hand response was reversed. At the beginning of the second series, participants got an additional training session using the set of practice pictures to familiarize them with the new instruction.

### *Electrophysiological recordings*

The EEG was recorded from electrodes placed at midline frontal (Fz), central (Cz), and parietal (Pz) sites according to the International 10-20 system (Jasper, 1958), each referred to the left mastoid, and from C3' and C4' (approximately 3.5 cm lateral and 1 cm anterior to Cz). The difference in activity between C3' and C4' was recorded via a bipolar montage of the two electrodes. LRPs were derived according to the following formula:

LRP = right hand [C3'- C4'] - left hand [C3' - C4'].[4]

Vertical and horizontal eye movements were monitored via a sub- to supra-orbital bipolar montage, and a right to left canthal bipolar montage, respectively. A ground electrode was placed on the forehead, 10% from the nasion-inion distance above the nasion. Recordings of the EMG were made by placing pairs of electrodes above the M. flexor digitorum superficialis and the M. flexor digitorum profundus of each arm. For all recordings Beckmann biopotential Ag/AgCl electrodes were used. Electrode impedance was kept below 5 kOhm for the EEG recording, and below 10 kOhm for the EOG and EMG recording. The EEG, EOG, and EMG signals were amplified by Nihon Kohden AB-601G bioelectric amplifiers and filtered with a high frequency cut-off point of 30 Hz for the EEG and EOG, and a high frequency cut-off point of 100 Hz for the EMG. A time constant of 8 seconds was used. The signals were digitized on-line with a sampling frequency of 200 Hz. Sampling started 200 ms before picture onset, with a total sampling epoch of 2700 ms. The EMG signal was rectified off-line.

### *Data analysis*

Data from critical trials were analyzed as described below. Filler trials were not further analysed.

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[4] *This derivation of the LRP is equivalent to that of Coles (1989) and Gratton et al. (1988) [left hand (C4' - C3' + right hand (C3' - C4')/2], except that it has twice the amplitude.*

**Overt responses.** Trials on which participants produced other utterances than the expected ones, started speaking while the frame was still on the screen, gave an incorrect hand response, or did not respond on go trials within 2000 msec after frame onset, were eliminated from the data set. Moreover, each trial was visually inspected for the occurrence of EMG activity. All go trials in which EMG activity was detected on the incorrect response side were excluded from further analyses, as were all no-go trials in which EMG activity occurred. This was done to make sure that the development of the LRP on go trials would not be biased by trials in which both response hands were activated, and to avoid the possibility that the presence of an LRP on no-go trials could be attributed to incomplete or incorrect go/no-go analyses.

**Event-related potentials.** All single trial waveforms containing eye movement artifacts, amplifier blocking or electrode drifting, in the time window of 200 ms before picture onset to 1500 ms after picture onset, were removed from the dataset. Per subject, the minimum number of trials left for averaging was 35 per condition. From each single trial waveform the average voltage in the 200 ms period preceding picture onset was subtracted.

LRPs were derived separately for the go and no-go conditions. To test for the presence of an LRP and to estimate its onset, analyses were performed on 50 ms intervals, starting from frame onset in sequential steps of 10 ms (e.g., 150-200 ms, 160-210 ms etc.). For each window a one-tailed t-test with a 95% confidence interval was performed to test whether the mean voltage within the window exceeded the mean voltage within the baseline interval. An LRP was defined to be present if 5 or more consecutive windows resulted in a significant t-value. The onset of the first of these consecutively significant windows determines the LRP onset latency.

To determine the point of divergence between the go and no-go LRPs, the average voltage at each individual time point of the no-go waveform was subtracted from the average voltage at the corresponding time points of the go waveform. One-tailed t-tests were performed to test whether the mean go/no-go difference scores differed significantly from zero, using the same procedure as described for the individual LRP waveforms. The point of divergence was defined as the beginning of the earliest of 5 or more consecutive time-windows that resulted in significant t-values.

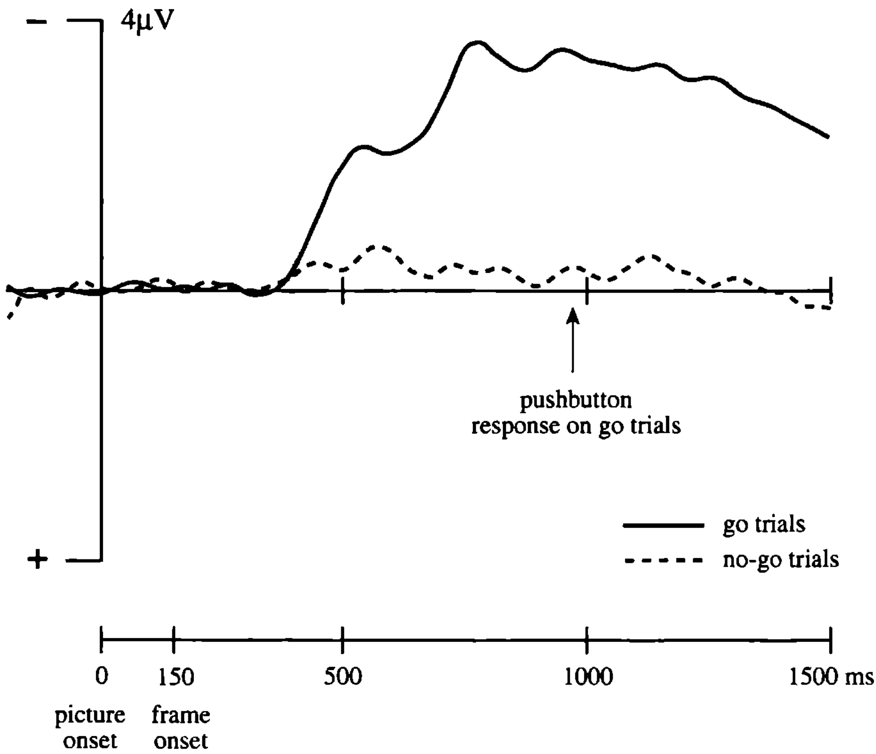


**Figure 3.3** *Grand average (N = 16 participants) lateralized readiness potentials on go trials and no-go trials in Experiment 1. The grammatical gender decision determined response hand; the word-initial phoneme decision determined whether a trial was a go or a no-go trial. Significant lateralization of the readiness potential was obtained both on go and on no-go trials. The shaded area shows the time interval in which the go and the no-go LRPs were significantly different from the baseline, but not from each other.*

## Results

### *Overt responses*

The mean push-button latency, measured from frame onset, for the correct go trials was 822 ms (standard deviation (sd) = 264). The mean error rate for the go trials was 4.8% (on 1.3% of the go trials an incorrect response was given, on 2.5% of the go trials EMG activity occurred on both response sides). For the no-go trials the mean error rate was 1.5%. Because the error rates were low, they were not further analyzed.

### *Lateralized readiness potentials*

In total, 18% of the trials were rejected due to errors and EEG artifacts. The rejected trials were equally distributed across participants and conditions. Per condition, the minimum number of trials left for averaging was 35 for each particpant.

The grand average LRP waveforms for the go trials and the no-go trials are presented in Figure 3.3. As this figure shows, a negative LRP developed on both the go trials *and* the no-go trials. That is, on both go and no-go trials, a lateralization of the readiness potential was observed, indicating the presence of response preparation for the cued response hand. On go trials the LRP started to deviate significantly from zero at 390 ms after picture onset ($t(15) = -1.90$, SD = 1.184, $p = 0.05$). On no-go trials the LRP became significant at 370 ms after picture onset ($t(15) = -1.90$, SD = 0.710, $p = 0.05$). Initially, the no-go LRP developed at the same rate as the go LRP. However, at 410 ms after picture onset, the two waveforms started to diverge ($t(15) = -1.78$, SD = 1.161, $p = 0.05$). While the go LRP kept on developing, reaching its maximum value around 760 ms after picture onset, the no-go LRP slowly returned to the baseline. From 620 ms after picture onset, the no-go LRP no longer differed significantly from zero ($t(15) = -1.438$, SD = 0.710, $p > 0.05$).

## Discussion

The main finding of Experiment 1 concerns the presence of an LRP on no-go trials. We found that at 370 ms after picture onset, an LRP started to develop on no-go trials, in the absence of concomitant EMG activity. This observation of an LRP on trials in which participants refrained from responding implies that the response hand was selected earlier in time than the go/no-go decision was made. In the present experiment, response selection was based on the definite article of the noun. Therefore, the results indicate that at 370 ms after picture onset gender information was sufficiently available to preliminary activate a lateral response. The go and the no-go LRP initially developed at the same rate, but at 410 ms after picture onset the two waveforms started to diverge. On go trials the LRP kept on developing, but on no-go trials the LRP returned to the baseline without any EMG activity being produced. Since the go/no-go distinction was based on the word's initial phoneme, the go/no-go divergence point provides information about when phonological information started to influence motor processes. We found that at 410 ms after picture onset a sufficient amount of phonological information of the word was available to either decrease (on no-go trials) or further develop (on go trials) response preparation.

It is tempting to conclude from these findings that during noun phrase production gender information is retrieved earlier than phonological information. However, before we can attribute these findings to differences in the time course of grammatical and phonological processing, we need to rule out an alternative explanation for the obtained pattern of results.

This alternative explanation concerns the possibility that individuals can have strategic control over the temporal order in which distinct types of information are used for response preparation. Gratton et al. (1992) provided data that suggested that in a visual attention task participants can modulate the use of partial information. They showed that the influence of partial information on response preparation was dependent on its usefulness for giving fast and correct responses. Moreover, a study by Smid et al. (1992) showed that participants can control which of two visual stimulus attributes is made available for response preparation first. Smid et al. (1992) observed that in a two-choice go/no-go task, subjects were able to use either one of two separate stimulus attributes for early response preparation, depending on which of the attributes determined response hands. The importance of these findings for the present study concerns the possibility that information is available, but not used for response preparation. This could mean that the initial response preparation we observed on no-go trials might have resulted from a strategy to always first use the gender information to select response hands, and to then use the phonological information to complete the go/no-go decision. Thus, a noun's syntactic and phonological properties might have been activated in parallel during the speech production process, but due to strategic control of the available information, these properties were used for response preparation at different moments in time. Experiment 2 was designed to exclude this possible explanation of the results. In this experiment we reversed the assignment of the syntactic and phonological evaluation to the left-right and go/no-go dimensions. The reversal allows us to determine whether the response preparation observed on no-go trials can be attributed to early availability of gender information, or just to strategic use of this information.

## EXPERIMENT 2

In Experiment 2 the same experimental paradigm was used as in the first experiment. Participants were presented with coloured pictures and were instructed to name the picture as quickly as possible using a no-determiner noun phrase. On half of the trials a frame appeared around the picture at 150 ms after picture onset. The frame served as a cue to perform the syntactic/phonological decision task. In Experiment 2 the assignment of the syntactic and phonological decision to the left-right and go/no-go dimensions was the reverse of the one used in Experiment 1. The word-initial phoneme decision determined with which hand to respond, and the gender decision determined whether or not to execute the response. Again we assume that if during noun phrase production syntactic processing precedes phonological processing, then the grammatical gender of a word will be available earlier in time than a word's initial phoneme. As a consequence, the gender based go/no-go distinction can be made *before* response hand can be selected on the basis of the word's initial phoneme. Therefore, in Experiment 2 we expect no response preparation to occur on no-go trials.

### Method

*Participants*

Sixteen undergraduate students (4 male) between 19 and 29 years of age from the participant pool of the Max Planck Institute for Psycholinguistics were paid for their participation in the experiment. Eight of them had already participated in Experiment 1. All participants were native speakers of Dutch and had normal or corrected-to-normal vision. They were all right-handed according to their response on an abridged and adapted Dutch version of the Oldfield Handedness Inventory (Oldfield, 1971). Familial left-handedness was reported by four of the participants. None of the participants had any neurological impairment or had experienced any neurological trauma according to their response on a questionnaire.

### *Procedure*

As in the first experiment, the participants were presented with two series of six blocks. In one of the series *de* words instructed to execute the response (go trials), in the other series *de* words instructed not to respond (no-go trials). The assignment of *de* and *het* words to either a go or a no-go response was reversed between the series, to be able to derive both go and no-go LRPs for each of the participants averaging over *de* words only. At the beginning of the second series, the participants were familiarized with the new instruction during a short training session. The order in which the assignments were given was balanced over subjects. The rest of the procedure was the same as described for Experiment 1.

Materials, apparatus, electrophysiological recordings, and data analysis were the same as described for Experiment 1.

## Results

### *Overt responses*

The mean response time for the correct go trials was 717 ms (SD = 261.82), measured from frame onset. The mean error-rate for the go trials was 4.9% (on 1.6% of the go trials an incorrect response was given and on 0.7% of the trials no response was given, on 2.6% of the go trials EMG activity occurred for both response sides). For the no-go trials the mean error rate was 3.1%. Because error rates were small, they were not further analyzed.

### *Lateralized readiness potentials*

In total, 18% of the trials were rejected due to errors and EEG artifacts. The rejected trials were equally distributed across participants and conditions. Per condition, the minimum number of trials left for averaging was 35 for each participant.

The grand average LRP waveforms for go trials and no-go trials are presented in Figure 3.4. In this figure, we can see a negative LRP developing on go trials. The LRP started to deviate from zero at 380 ms after picture onset ($t\,(15) = -2.42$, SD = 1.05, $p = 0.03$) and reached its maximum around 615 ms after picture onset. On no-go trials, no development of an LRP was observed.

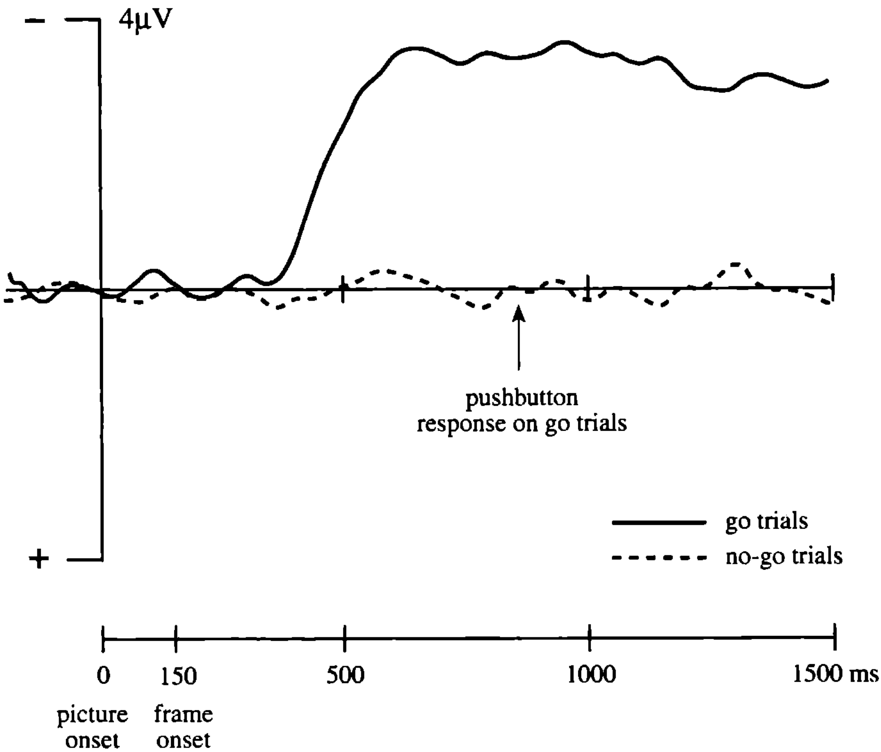


**Figure 3.4** *Grand average (N = 16 participants) lateralized readiness potentials on go and no-go trials of Experiment 2. The grammatical gender decision determined whether a trial was a go or a no-go trial; the word-initial phoneme decision determined the response hand. No significant lateralization of the readiness potential was obtained on no-go trials.*

The no-go waveform did not significantly deviate from zero during the epoch, indicating that no response preparation occurred on no-go trials.

In addition to the overall analyses, separate analyses were performed on the LRP data of the eight subjects who participated both in Experiment 1 and Experiment 2. These analyses showed that for these eight participants an LRP was obtained on go and no-go trials in Experiment 1. The no-go LRP started to significantly deviate from zero at 360 ms after picture onset ($t(7) = -1.90$, $SD = 0.78$, $p = 0.05$), and the go LRP reached significance at 400 ms after picture onset ($t(7) = -2.87$, $SD = 0.72$, $p = 0.03$).[5] In Experiment 2, a significant LRP started to develop on go trials at 380 ms after picture onset ($t(7) = -2.06$, $SD = 1.12$, $p = 0.05$). However, no significant LRP was observed on no-go trials for these participants.

### Discussion

The results of Experiment 2 showed that whereas on go trials an LRP started to develop at 380 ms after picture onset, no development of an LRP was observed on no-go trials. The absence of an LRP on no-go trials indicates that on these trials phonological information did not affect response preparation. Gender information was already available to make the go/no-go distinction before phonological information could be used to select response hands.

The results of Experiment 2 rule out the possibility that the no-go LRP observed in Experiment 1 was due to a selective use of information. If the no-go LRP had resulted from the strategy to always select response hands first, an LRP should have developed on no-go trials independent of whether response hand was determined by syntactic or phonological information. This is not what we observed. In Experiment 2 we found that phonological information did *not* serve as partial information to selectively activate response hands before the syntactically based go/no-go distinction had been made. However, since different subjects participated in the two experiments, the absence of a no-go LRP in Experiment 2 might reflect that subjects in Experiment 1 used a response selection strategy, whereas subjects in Experiment 2 did not.

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5 *In addition, analyses were performed on the data from the eight participants who only participated in Experiment 1. These analyses showed that also for this group participants a significant no-go LRP was obtained, starting at 410 ms after picture onset ($t(7) = -2.18$, $sd = 0.68$, $p = 0.05$).*

Analyses of the data from the eight subjects who participated in both experiments show that for this group of subjects a no-go LRP was obtained in the first, but not in the second experiment. This rules out that the disappearance of the no-go LRP in Experiment 2 was due to a difference in the use of strategies between participants.

The overall response latency in Experiment 2 was faster than in Experiment 1. The reason for this is unclear. However, the difference in mean response latencies between the experiments has no implications for our interpretation of the no-go LRP obtained in Experiment 1. As we mentioned earlier, evidence has been provided that shows that the use of partial information to select response hand leads to a reduction in reaction time and error rate (e.g., Gratton et al., 1992; Smid et al., 1992). We found that the mean RT in Experiment 1 was *slower* than the mean RT in Experiment 2. Under a strategy account of the present LRP results, RTs in Experiment 1 should have been faster than RTs in Experiment 2.

## GENERAL DISCUSSION

In the present study we aimed to find evidence on the time course of grammatical and phonological processing during speech production. To accomplish this, we applied the lateralized readiness potential to the study of lexical access in noun phrase production. An experimental paradigm was constructed in which a syntactic-phonological classification task had to be carried out prior to noun phrase production. The classification task consisted of the conjunction of a go/no-go decision and a push-button response with the left or the right hand. LRPs were measured during the performance of the task. In an earlier study, the LRP had already proven to be a good tool to investigate the time course of semantic and phonological processing during picture naming (Van Turennout et al., 1997). In the present study we showed that the LRP is also differentially sensitive to the moments in time at which syntactic and phonological information become available during noun phrase production. The following findings provide evidence for this.

In Experiment 1, we found that initially an LRP developed on both go and no-go trials, indicating that syntactic information was used to select response hand before phonological information was used to make the go/no-go distinction. In Experiment 2, the phonologically- based response hand decision only resulted in an LRP on trials in which syntactic information cued a

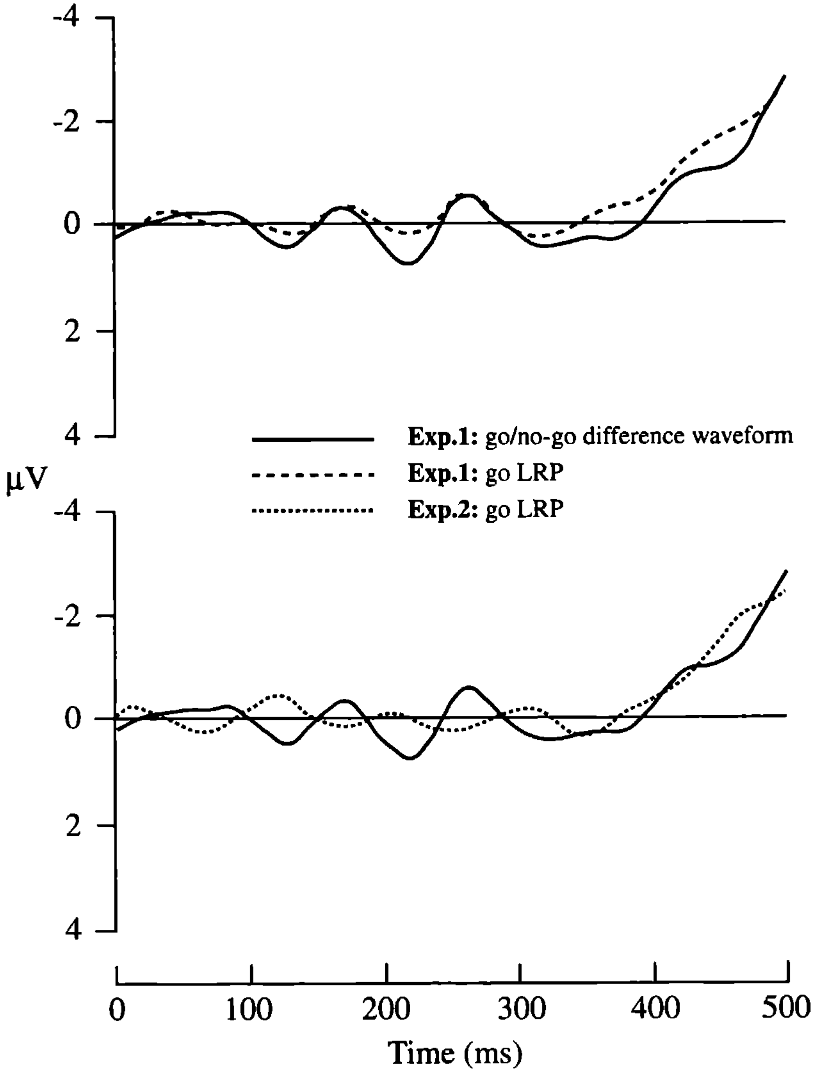


**Figure 3.5** *a) Grand average LRP on go trials, and the go/no-go difference waveform for eight participants in Experiment 1 whose mean reaction times were between 600 and 800 ms. Visual inspection of the waveforms shows that the go LRP started to develop earlier in time than the go/no-go difference waveform. b) Grand average LRP on go trials for eight participants in Experiment 2 whose mean reaction times were between 600 and 800 ms, together with the go/no-go difference waveform for the selected participants in Experiment 1. Visual inspection of the waveforms shows that the go LRP in Experiment 2 started to develop at about the same moment in time as the go/nogo difference waveform in Experiment 1.*

response. Thus, the observation that syntactic information was available and used for response preparation earlier in time than phonological information proved to be independent of whether the syntactic decision was assigned to response hand or to the go/no-go decision. The data of Experiment 2 therefore rule out the possibility that the early response preparation observed on no-go trials in Experiment 1 can be explained by the strategy to always use information about response hand first. The findings support the claim that syntactic information influences response preparation at an earlier moment in time than phonological information.

The LRP's sensitivity to the moments at which syntactic and phonological properties of a word become available is also illustrated by the following. We derived the go/no-go difference waveform for Experiment 1. This difference waveform is obtained by subtracting the LRP on no-go trials from the LRP observed on go trials. The onset of this waveform represents the moment at which phonological information affected the LRP. We compared the onset of the go/no-go difference waveform with the LRP onsets obtained on the go trials in Experiment 1 and in Experiment 2. In Experiment 1, the onset of the LRP depended on the influence of syntactic information, whereas in Experiment 2 it depended on when phonological information affected the LRP. To reduce the variability in LRP onsets due to subject-related reaction time differences between the experiments, for each experiment we selected eight participants whose mean reaction times were between 600 ms and 800 ms (the mean response latency for the two groups was 733 ms for Experiment 1, and 712 ms for Experiment 2). Figure 3.5a presents the go/no-go difference waveform for this subject group in Experiment 1 together with the corresponding go LRP (upper panel). In Figure 3.5b the same go/no-go difference waveform is shown together with the go LRP for the selected subjects in Experiment 2. As can be seen in these figures, the go LRP in Experiment 1 started to develop earlier in time than the go/no-go difference waveform, indicating that syntactic information affected response preparation earlier in time than phonological information. When we compare the go/no-go difference waveform with the go LRP obtained in Experiment 2 (Figure 3.5b), no such difference appears. The similar onset latencies of the go/no-go difference waveform in Experiment 1 and the go LRP in Experiment 2 suggest that in both experiments phonological information started to influence the motor processes around the same moment in time, independent of whether this information determined response hand or the go/no-go distinction.

Together, these results indicate that in the present study the LRP is indeed sensitive to the moments at which the separate types of information are made available to the response system, and that the LRP is not reflecting effects of specific task configurations. Under the plausible assumption that the definite article and the word-initial phoneme become available for response preparation during the speech production process, we can conclude that the LRP paradigm provides insight into the time course of grammatical and phonological processing in noun phrase production. We can now turn to the implications of the results for the temporal parameters of grammatical and phonological encoding.

## The time course of grammatical and phonological processing

In noun phrase production, the closed-class elements (i.e., the definite article, the adjectival inflection) are retrieved during the stage of grammatical encoding (e.g., Bock & Levelt, 1994; Dell, 1986, 1990; Kempen & Hoenkamp, 1987; Levelt, 1989; Schriefers, 1993). The noun lemma activates its grammatical gender, and on the basis of this gender information the correct definite article can be retrieved. In Experiment 1, the onset of the LRP was determined by the noun's definite determiner. Since grammatical encoding is required to retrieve this information, the development of an LRP around 370 ms reveals that by then grammatical processing was well under way. The observation that for a short period of time the LRP developed at the same rate on both go and no-go trials, indicates that at the same moment, the word-initial phoneme was not yet available. From studies on the time course of phonological encoding we know that a word form is constructed from left-to-right (e.g., Meyer, 1990; Meyer & Schriefers, 1991; Van Turennout et al., 1997; Wheeldon & Levelt, 1995). This implies that a word's initial phoneme is retrieved relatively early during phonological encoding. Therefore we conclude that the late effect of wordonset information on response preparation, compared to gender information, provides clear evidence for the idea that in speech production grammatical processing precedes phonological processing in time.

The data support hierarchical theories of sentence production in which lemmas are retrieved and a syntactic frame of the speech fragment is built-up at the grammatical processing level, before at the phonological processing level the sound pattern of the fragment is constructed. Since we focused on the phonological encoding of the noun, on the basis of these data we cannot claim that during noun phrase production syntactic processing has to be completed before phonological encoding can start. Although the noun's gender was required to retrieve the adjectival inflection and to fully encode the word form, it could well have been the case that phonological encoding of the adjective already started before each slot in the syntactic frame had been filled. Schriefers (1992, 1993) found evidence that sometimes speakers start articulating a no-determiner noun phrase as soon as the adjective-stem is available. On the basis of his data, he argued that depending on the speed with which the lemmas in the noun phrase can be retrieved, speakers can vary the size of the fragments that are transmitted from the grammatical level to the phonological level. An important and still open question for research on the discreteness of grammatical and phonological encoding concerns the size of the processing units at each of these levels in various kinds of utterances.

## The time course of lexical retrieval

As was already mentioned above, according to most theories of lexical retrieval the syntactic properties of a lexical item are carried by the lemma (e.g., Bock, 1982; Dell, 1986; Garrett, 1976; Kempen & Huijbers, 1983; Levelt, 1989; Roelofs, 1992). The present study examined the relation in time between grammatical gender retrieval and word-form retrieval. Since the selection of the correct gender information requires that the lemma has been retrieved, the data enable us to speculate about how lemma selection and phonological encoding relate to each other in time. In Experiment 1, we found that the no-go LRP started to develop at 370 ms after picture onset and developed simultaneously with the go LRP until 410 ms after picture onset, after which the no-go LRP slowly returned to baseline. We have to be careful in using either the LRP onset or the onset of the go/no-go difference waveform as a quantitative estimate of the moment in time at which information becomes available during noun phrase production. The onset of these waveforms not only depends on the retrieval of information, but also on when this information is used for response preparation. Therefore, on their own these values do not provide an exact estimation of when information is retrieved. However, the time interval *between* the LRP onset and the onset of the go/no-go difference waveform can be used as an estimate of the length of the period during which lemma information, but *not* phonological information, influenced response preparation. In an earlier study (Van Turennout et al., 1997), in which the LRP go/no-go paradigm was used to track the time course of semantic activation and phonological encoding during picture naming, we found that the go/no-go divergence point could be manipulated by the position of the critical phoneme in the word. When the go/no-go distinction was based on the wordfinal phoneme, the no-go LRP diverged from the go LRP 80 msec later than when the word-initial phoneme distinguished between go/no-go. This finding is consistent with evidence that the phonological form of a word is constructed from left to right, i.e., from its beginning to its end (Meyer & Schriefers, 1991; Wheeldon & Levelt, 1995). It suggests that the length of the interval during which the go and the no-go LRP develop simultaneously is sensitive to the time it takes to retrieve the critical phoneme in the word.

What can be inferred from the current results for the temporal relation between lemma selection and word-form encoding? Most importantly, these data suggest that a word's lemma is retrieved earlier in time than its phonological form. Therefore, together with data from studies on single word production, they provide support for models of lexical retrieval in which lexical access proceeds from a concept via the lemma to the word form. Moreover, in Experiment 1 we observed that response preparation was based solely on lemma information for about 40 ms. Therefore, we speculate that during noun phrase production, it takes at least 40 ms to retrieve a noun's initial phoneme once its lemma has been selected.

## CONCLUSION

This study provides a first step toward studying the temporal parameters of grammatical and phonological processes in speaking by the registration of event-related brain potentials. By using the LRP technique we were able to separately tap into the stages of grammatical and phonological encoding as they proceed in real-time. The data show that during the production of noun phrases, grammatical processing precedes phonological processing in time. Since the grammatical structure of the utterances used in the experiments was relatively simple, further research involving more complex utterances is required to obtain further evidence on the relation between grammatical and phonological processing.

# SUMMARY AND CONCLUSIONS

CHAPTER 4

Speaking is a complex process that is central to human cognitive functioning. Broadly defined, speaking encompasses the three levels of conceptual, grammatical, and phonological processing. To produce fluent speech, these processes have to be very precisely orchestrated in time. In the present study I explored the use of ERPs to assess the temporal organization of the cognitive processes underlying speaking.

In the series of experiments reported in Chapter 2, I investigated the time course of semantic activation and phonological encoding during the production of words in isolation. The participants in the study were presented with pictures, which they had to name. On a subset of the trials a frame around the picture indicated that before naming they had to perform a semantic-phonological classification task, consisting of the conjunction of a go/no-go decision and a pushbutton response with the left or right hand. In one experiment, the decision whether or not to give a response was determined by the first phoneme of the word describing the picture. For go-trials, individuals were asked to respond with one hand for animate, and with the other hand for inanimate picture referents. In another experiment, individuals had to make a go/no-go decision on the basis of the word-final instead of the word-initial phoneme. During the performance of the task, LRPs were recorded. The results showed that in both of the experiments, an LRP developed not only for go-trials, but initially also for no-go trials, in the absence of an overt response. The early availability of semantic information enabled response preparation, but when information about the word's sound pattern became available, this then overruled further response preparation on the no-go trials. For go/no-go decisions based on the word-initial phoneme, the go LRP and the no-go LRP were identical for 40 ms, after which they started to diverge. When the go/no-go decision was based on the final phoneme of words consisting of, on average, 1.5 syllables, and 4.5 phonemes, go and no-go LRPs did not deviate until 120 ms. One further experiment was performed to validate the interpretation of the results. In this experiment the same task components were used, but now it was the semantic information that determined the go/no-go decision, and the word-final phoneme that determined the response hand. The results showed that a word-final phoneme decision resulted in an LRP *only* on trials in which the semantic decision cued a response, substantiating the claim of temporal priority for semantic information over phonological information.

In Chapter 3, I used a similar experimental paradigm to investigate the time course of grammatical and phonological processing during the production of noun phrases. Coloured pictures were presented to individuals to elicit noun phrase production. The experimental task involved the conjunction of a grammatical gender decision and a word-initial phoneme classification task. When the grammatical gender of the noun determined response hand, and the noun's word-initial phoneme distinguished between go/no-go, LRPs were observed on both go and no-go trials. After having developed simultaneously for 40 ms, the no-go LRP slowly returned to the base-line while the go LRP continued to develop, leading to an overt response. In contrast, when the go/no-go distinction depended on the grammatical gender of a noun, and the response hand was determined by the noun's initial phoneme, an LRP was observed only on go trials.

Before I discuss the implications of these results for the time course of the processes underlying speech production, I want to address two issues related to the assumptions that I made at the beginning of this thesis. The first one concerns the assumption that semantic, syntactic, and phonological information is transmitted to the motor system, and mapped onto a response as soon as this information is retrieved during speech production. The second one concerns the assumption that the order in which the different types of word information are used for response preparation reflects the relative timing of the information retrieval during speech production.

The first issue involves the link between the retrieval of word information and response preparation. Of course, at the start of each experiment no natural association exists between a specific property of a picture name (e.g., 'starts with an /s/') and a specific response (e.g., 'press a button with your left-hand'). These stimulus-response mappings are to be established by training. Although at first sight this seems to be an artificial procedure, arbitrary mappings between a stimulus and an appropriate motor action are actually very common in real life. For example, when riding your bicycle you press on the brakes with your left or right hand in response to an approaching car. It, therefore, seems reasonable to assume that by training, direct mappings can be generated between stimulus information and appropriate motor responses. The nature of the processing system that underlies the transformation of a stimulus into a response has been the focus of an extensive research area on human information processing, but it lies beyond the scope of this thesis to give an overview of existing theories on this topic.

For the present purpose, the most important finding that has emerged from this research area is that information transmission between the perceptual system and the motor system does not occur in an all-or-none fashion. Studies using the LRP have repeatedly shown that different attributes of a stimulus are transmitted to the motor system in the order in which their analyses are completed (e.g., Coles, Smid, Scheffers, & Otten, 1995; Miller & Hackley, 1992; Osman, Bashore, Coles, Donchin, & Meyer, 1992). The LRP data that are presented in this thesis indicate that partial information transmission to the motor system is not restricted to the perceptual domain, but extends to the language domain. The data showed that one aspect of a to-be-produced word can serve as partial information for preliminary response activation, before another aspect influences response preparation.

However, it has also been found that information transmission is not fully continuous. An important factor constraining the extent to which partial information can be made available to the motor system seems to be the distinctiveness of the task-relevant stimulus characteristics (e.g., Miller & Hackley, 1992; Smid, 1993). Given the existing evidence from speech production research for the distinction between lemma and word-form representations, I expected that a word's semantic and syntactic properties could be transmitted to the motor system separately from its phonological properties. The results reported in this thesis confirmed this expectation.

In sum, I conclude that the present results substantiate the assumption that semantic, syntactic, and phonological information are distinct types of information that can be made available for response preparation as soon as they are retrieved during speech production.

The second issue is related to the possibility that the order in which the different types of word information were actually *used* for response preparation could have been caused by task-related strategies. As I pointed out previously, an important factor that influences whether partial information is used for response preparation is its utility in task performance (e.g., Gratton, Coles, & Donchin, 1992). Evidence has been provided indicating that the information processing system is flexible and that some of its operations are under strategic control (e.g., Coles et al., 1995; De Jong, Liang, & Lauber, 1994; Gratton et al., 1992; Smid, Mulder, Mulder, & Brands, 1992). This evidence for strategic effects poses a problem for the validity of the LRP as a measure of the temporal order in which separate types of information become available. In the present study I controlled for this problem by including experiments in which task assignments were reversed. As I already argued in the previous chapters, the control experiments clearly show that the data cannot be interpreted in terms of strategic effects. The results show that the occurrence of an LRP on no-go trials is dependent on how the semantic, syntactic, and phonological dimensions are assigned to the response hand and go/no-go distinctions. The finding that in the specific task configurations phonological information could *not* be used to preliminary activate a response hand, makes it unlikely that the use of semantic and syntactic information for early response selection can be explained as a strategic use of information.

Another important factor that could have influenced the temporal order in which information was used for response preparation, involves the qualitative differences between the classification tasks. It could be claimed that the classification tasks were not equally easy to perform, and that therefore the present LRP results merely reflect differences in task difficulty. Participants might either choose the strategy to always perform the easiest task first, or might simply complete a (putatively) easier task earlier in time than a more difficult task.

A strong argument against this claim can be made on the basis of the results that were obtained with the gender decision task. Reaction-time experiments using the gender decision task have shown that it takes relatively long to perform the task, and that it is open to strategic effects (see Van Berkum, 1996). In Chapter 3, I found that when the gender decision determined response hand, the mean response latency for go trials was 822 ms after frame onset. This latency was substantially longer than the mean response latency of 669 ms that was obtained on go trials when animateness determined response hand (Experiment 3, Chapter 2). Because in both experiments the word-initial phoneme distinguished between go/no-go, the 153 ms difference in mean reaction times probably reflects that gender decision is a more difficult task than the animateness decision task. However, when we compare the LRP data that were obtained in these two experiments, we see that no difference is present for the LRP onset latencies: In the gender experiment the LRP started to develop around 370 ms after picture onset, in the semantic experiment the LRP started to develop around 350 ms after picture onset. This indicates that whereas task difficulty did affect the time at which the response was actually given, it did not affect the moment at which information was made available to the response sytem. These results contradict the claim that the present LRP data were caused by strategy effects induced by differences in task difficulty.

When considered together, the results demonstrate that the LRP is differentially sensitive to the moments at which semantic, syntactic, and phonological properties of pictures and their names become available for response preparation. Moreover, they show that the LRP paradigm provides insight into the relative timing of semantic, syntactic, and phonological processing. What, then, do the present data reveal about the temporal organization of semantic activation, lemma retrieval, and phonological encoding in speaking?

I will start with the temporal relation between semantic activation and lemma retrieval. Can we infer from the present data whether semantic and syntactic properties are retrieved at separate moments in time? When we compare the LRP results of the experiments in which either the semantic decision (Experiment 1 and 3, Chapter 2) or the syntactic decision (Experiment 1, Chapter 3) determined response hand, we see that the LRP onset latencies were a little earlier for the semantically determined response hand decision compared to the syntactically determined response hand decision. However, as I have argued previously, we have to be very cautious when comparing LRP onset latencies that were obtained in the different experiments. Because different tasks (picture naming vs. noun phrase production) and different groups of participants were involved, differences between the LRP onsets are difficult to interpret. A more direct estimate can be obtained by comparing the periods during which the no-go LRPs developed simultaneously with the go LRPs on the basis of semantic or syntactic information. This was around 40 ms in the two experiments in which the go/no-go distinction was made on the basis of a word's initial phoneme. This means that semantic and syntactic information were available for an equal amount of time before word-onset information became available. The results suggest, therefore, that conceptual and lemma information were simultaneously active.

A complication for drawing inferences from the presented data about the temporal order of concept and lemma retrieval is the following. From early picture naming studies it has become clear that when participants are asked to name a picture they usually respond at basic level (Potter & Faulconer, 1975; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). That is, a subject's naming response usually includes the word that is most often used in every day life to describe the pictured object (e.g., they say 'chair', 'guitar', 'spider'). When asked to name a picture using the superordinate category (e.g., 'furniture', 'instrument', 'animal') it takes participants much longer to respond (e.g., Irwin & Lupker, 1983; Glaser & Düngelhoff, 1984). This suggests that, in picture naming, the semantic system is entered at basic level (see Rosch, 1975, and Rosch et al., 1976 for a description of different levels of semantic categorization). Moreover, this implies that some time elapses before activation has spread sufficiently through the conceptual network to enable the retrieval of the appropriate semantic category information. During this time, activation has probably also spread from the conceptual level to the lemma level. Therefore, it could well have been the case in my experiments that although conceptual activation preceded lemma activation, the lemma of the picture name had already been accessed at the moment that its semantic category was retrieved. A similar argument can be made for the retrieval of gender information. A certain amount of time is probably required to retrieve a word's definite article on the basis of its lemma activation. Thus, because it is not known how much time it takes to retrieve superordinate or syntactic category information once the concept or the lemma has been activated, it remains unclear on the basis of the present LRP data exactly how concept and lemma retrieval relate to each other in time.

In sum, the results suggest that for some period of time, lemmas and concepts were simultaneously active. However, on the basis of the present results no conclusions can be drawn on the temporal order of their retrieval. The LRP go/no-go paradigm might in fact provide a suitable tool with which to obtain real-time evidence on the temporal relation between conceptual and grammatical processing. By manipulating the type of semantic and syntactic operations involved in the left/right and go/no-go decisions, one can further investigate the distinctiveness of conceptual and grammatical processes, and how they relate to each other in time.

What do the present data reveal about the time course of lemma retrieval and phonological encoding? In the picture naming experiments, I found that semantic information affected the development of the LRP earlier than phonological information. This finding shows that the semantic properties of a word are retrieved *before* its phonological properties. It provides strong support for the idea that during speaking there is an initial stage of semantic activation during which the phonological form of the word has not yet been encoded. In the noun phrase production experiments, I found that an LRP developed on the basis of the grammatical gender of a word *before* its phonological properties affected the LRP. As I pointed out in Chapter 3, it is plausible to assume that a word's gender is retrieved via its lemma: To determine a word's correct definite article both its lemma and its grammatical gender has to be retrieved. Therefore, the early influence of grammatical information on the LRP, relative to the influence of phonological information, indicates that a word's lemma is retrieved before its word form has been constructed.

Together, these findings demonstrate that during speaking both conceptual identification and lemma retrieval occur earlier in time than phonological encoding. They substantiate the idea that lemmas and word forms are retrieved in a specific temporal order. The latter becomes most clear when considering the following pattern of results. The presence of an LRP on no-go trials in the experiments in which the phonological decision determined the go/no-go distinction, revealed that semantic and lemma information can be retrieved without word-form information being available. The results of the experiments in which the phonological decision determined response hand showed that the reverse was not true. The absence of a no-go LRP in these experiments clearly demonstrated that a phonological property of a word cannot be retrieved without having retrieved its lemma as well. That is, the phonological form of a word cannot be constructed before its lemma has been retrieved. This provides support for a serial approach to lexical access, in which word retrieval proceeds from lemma retrieval to word-form encoding.

Let me now turn to the implications of the data for temporal processing assumptions in theories of speech production. The data clearly support hierarchical models in which the levels of conceptualizing, grammatical encoding, and phonological encoding operate in succession (e.g., Dell, 1986; Dell & O'Seaghdha, 1991; Garrett, 1975, 1976, 1980; Levelt, 1989; Roelofs, 1992). A controversial issue in these hierarchical models concerns the information flow between the representational levels that are accessed during grammatical and phonological encoding. In modular theories such as the

Levelt/Roelofs theory, the stages of lemma retrieval and word-form encoding are assumed to be discrete. This means that lemma retrieval and phonological encoding are assumed to proceed in a strictly serial way, and that there is no interaction between the two stages. An alternative view is held by continuous models of speech production (Dell, 1986; Dell & O'Seaghdha, 1991, 1992; Harley, 1993; Stemberger, 1985). In these models there is temporal overlap between the distinct processing stages, and the models assume interaction between the lemma and the word-form level.

The experimental work to distinguish between the models has concentrated on the questions of a) whether lemma retrieval can be affected by phonological factors, and b) whether only selected lemmas become phonologically activated or whether all active lemmas activate their word form. According to the Levelt/Roelofs theory, lemma retrieval has to be finished before phonological encoding can start, which implies that only the selected lemmas will spread activation to their word forms. Moreover, this principle does not allow lemma selection to be affected by phonological information. In continuous models on the other hand, activation spreads continuously from the lemma level to the word-form level, and therefore all active lemmas will activate their word forms. Because information is allowed to spread back from the word-form level to the lemma level, lemma selection can be influenced by phonological information.

The empirical data on these questions do not provide clear-cut evidence that argues against either one of these models. On the one hand, speech error data seem to indicate that phonological information can influence lemma selection. The observation that mixed errors occur at a greater rate than would be expected on the basis of chance (Martin, Gagnon, Schwartz, Dell, & Saffran, 1996) is often interpreted as evidence for an interaction between the lemma and word-form level. However, these effects can also be accounted for in a modular account of lexical access (see for example, Levelt, Schriefers, Vorberg, Meyer, Pechmann, & Havinga, 1991; Levelt, Roelofs, & Meyer, submitted). On the other hand, reaction time data indicate that phonological activation is not observed for multiple lemma candidates. For example, in a picture-word interference study, Levelt et al. (1991) did not find any effect of distractors that were phonologically related to a semantic alternative of the picture name (e.g., for the picture name *sheep*, the distractor would be *goal*, which is phonologically related to goat), compared to an unrelated distractor. Peterson and Savoy (in press) replicated these results. These findings are problematic for a fully continuous account of lexical access. However, Peterson and Savoy also demonstrated that during picture naming, phonological activation could be found for the synonym of the picture name (e.g., they found that during the naming of the picture of a couch, *sofa* became phonologically activated as well), which is problematic for a modular account of lexical access.

What implications do the data reported in the present thesis have for either of the models? As I argued above, the LRP data showed that lexical access proceeds in a fixed temporal order: A lemma is retrieved before its word form is constructed. With respect to the claims on the temporal overlap between the stages, the data fit well with the modular account of lexical access proposed by Levelt and Roelofs. At the same time, however, they do not provide unequivocal evidence against the continuous model proposed by Dell and O'Seaghdha. Because in my experiments I focused only on the retrieval of the word form of the *selected* lemma, the present data do not exclude that initially other lexical candidates were phonologically activated as well. On the other hand, one could argue that if activation does spread continuously from the lemma level to the word-form level, the phonological properties of a word should be available in parallel with its syntactic properties. As has been shown by Smid et al. (1992), when two types of information are available in parallel, subjects can use one type of information to preliminary activate a response hand. My data demonstrate that syntactic but not phonological information was used to activate a response hand before the actual response decision had been made. This might indicate that for a certain period of time a lemma was activated in the absence of any word-form activation. If true, this provides evidence against continuous models of lexical access. However, although Dell and O'Seaghdha claim that when lemma nodes first become activated, these immediately activate their phonological segments, they also assume that the activational level of the phonological segments is initially much lower than that of the lemmas (e.g., Dell and O'Seaghdha, 1992). Therefore, it could be argued that in fact phonological segments were activated immediately after lemma activation, but that the LRP paradigm is insufficiently sensitive to measure the early, low activational level of phonological segments.

In conclusion, the present data support two-stage models of lexical access in which word retrieval proceeds from the lemma to the word-form level. The data, however, do not clearly distinguish between the discrete approach adopted in the Levelt/Roelofs theory, and the continuous approach as presented in Dell's theory (Dell, 1986; Dell & O'Seaghdha, 1991, 1992).

In addition to the relative timing of the separate processing levels in speaking, the data presented in this thesis also provide more insight into the time course of phonological encoding itself. In the Levelt/Roelofs model, phonological encoding is conceived of as a series of cascading processes in which word-forms are constructed from left-to-right. Phonological encoding is assumed to involve the selection of phonological segments and the syllabification of these segments, in order to build-up a phonological representation of a word. In all of the experiments reported in this thesis, the moment at which phonological information affected the LRP was determined by when the first or the last phoneme of a word became available for response preparation. The results showed that word-initial phonemes affected the LRP earlier than word-final phonemes, implying that the beginning of a word is constructed before its end.

In the LRP paradigm it is, however, unclear whether phonemes are transmitted to the response system immediately after they have been activated. Alternatively, this transmission might occur after a phoneme has been selected and positioned in a syllable. Therefore, the present LRP results do not provide information on whether the individual phonemes are spelled-out from left-to-right, or whether seriality occurs only in a later phase of word-form construction. This remains to be determined in further research. By manipulating the phonological processing involved in the left/right and go/no-go decisions, one could use the LRP paradigm to provide detailed information on the time course of the separate operations involved in phonological encoding. For example, one could compare phoneme and syllable categorizations, vary the position of a critical syllable within a word and the position of a critical phoneme within a syllable, or make use of utterances in which the syllabification of the speech output does not correspond to the syllabification of the individual words in the utterance (e.g., as in the generation of 'I read it', where the syllabification becomes 'I-rea-dit').

What do the data reveal about the duration of phonological encoding? Based on the picture naming data, I estimate that for words consisting of on average 1.5 syllables and 4.5 phonemes, it takes about 80 ms longer to encode the end of a word than to encode its beginning. This estimation corresponds well with earlier estimations on the time course of phonological encoding (Wheeldon & Levelt, 1995). Furthermore, based on the noun phrase production data, I estimate that after lemma selection it takes about 40 ms to construct the beginning of a word. The combination of the results enables me to speculate that in the production of words consisting of on average 1.5 syllables, speakers require about 120 ms to construct a word's phonological form once its lemma has been retrieved.

In the beginning of this thesis I mentioned that speakers produce on average 2 to 3 words (or more specifically 5 to 6 syllables) per second. This provides the rough estimate that each disyllabic word requires at least 300 ms processing time. My research shows that the LRP technique is an excellent tool with which to track the time course of the rapid processes that precede articulation. The data that I have presented in this thesis provide detailed insight into the duration and the temporal organization of the mental processes underlying speaking.

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# APPENDICES

## Chapter 2 Appendix A

Dutch Names, and their English Translations, of the Target Pictures in Experiment 1 and Experiment 2, and their Mean Naming and Recognition Latencies as Obtained in the Pretests

| Picture names grouped by word-final phoneme | Reaction time (ms) Naming | Recognition | Picture names grouped by word-final phoneme | Reaction time (ms) Naming | Recognition |
|---|---|---|---|---|---|
| Animals | | | Objects | | |
| /l/ | | | /l/ | | |
| uil [owl] | 788 | 644 | tol [top] | 806 | 549 |
| egel [hedgehog] | 691 | 681 | bal [ball] | 797 | 622 |
| kameel [camel] | 770 | 720 | orgel [organ] | 890 | 610 |
| krokodil [crocodile] | 1059 | 632 | hengel [fishing rod] | 885 | 630 |
| /s/ | | | /s/ | | |
| vos [fox] | 939 | 707 | kaars [candle] | 637 | 583 |
| rups [caterpillar] | 960 | 600 | vaas [vase] | 759 | 567 |
| gans [goose] | 979 | 688 | muts [hat] | 810 | 604 |
| muis [mouse] | 793 | 669 | ananas [pineapple] | 827 | 570 |
| /n/ | | | /n/ | | |
| zwaan [swan] | 797 | 783 | kan [jug] | 740 | 642 |
| haan [cock] | 937 | 666 | maan [moon] | 918 | 624 |
| spin [spider] | 712 | 601 | kussen [pillow] | 898 | 700 |
| konijn [rabbit] | 850 | 607 | ballon [balloon] | 711 | 632 |
| /r/ | | | /r/ | | |
| beer [bear] | 976 | 616 | veer [feather] | 809 | 605 |
| tijger [tiger] | 837 | 680 | deur [door] | 638 | 587 |
| kikker [frog] | 747 | 645 | spijker [nail] | 751 | 554 |
| vlinder [butterfly] | 666 | 632 | motor [motorcycle] | 787 | 551 |

## Chapter 2 Appendix B

Dutch Names, and their English Translations, of the Target Pictures in Experiment 3 and their Mean Naming and Recognition Latencies as Obtained in the Pretests.

| Picture names grouped by wordinitial phoneme | Reaction time (ms) Naming | Recognition | Picture names grouped by wordinitial phoneme | Reaction time (ms) Naming | Recognition |
|---|---|---|---|---|---|
| Animals | | | Objects | | |
| /k/ | | | /k/ | | |
| kameel [camel] | 770 | 720 | kanon [cannon] | 805 | 578 |
| konijn [rabbit] | 850 | 607 | knoop [button] | 876 | 545 |
| kuiken [chicken] | 901 | 614 | kroon [crown] | 918 | 631 |
| kikker [frog] | 747 | 645 | kan [jug] | 740 | 642 |
| /s/ | | | /s/ | | |
| spin [spider] | 713 | 601 | sleutel [key] | 686 | 574 |
| schaap [sheep] | 845 | 697 | schoen [shoe] | 608 | 578 |
| stier [bull] | 1045 | 649 | sigaar [sigar] | 814 | 641 |
| slang [snake] | - | - | schaats [skate] | 674 | 620 |
| /v/ | | | /v/ | | |
| varken [pig] | 892 | 609 | veer [feather] | 809 | 605 |
| vlinder [butterfly] | 666 | 631 | vaas [vase] | 759 | 567 |
| vos [fox] | 938 | 707 | vlag [flag] | - | - |
| vis [fish] | - | - | vork [fork] | - | - |
| /h/ | | | /h/ | | |
| haan [cock] | 936 | 666 | harp [harp] | 751 | 603 |
| hert [deer] | 875 | 660 | hengel [fishing rod] | 885 | 630 |
| hond [dog] | 658 | 696 | hamer [hammer] | 740 | 640 |
| hagedis [lizard] | - | - | hoefijzer [horseshoe] | 846 | 573 |

*Note.* Dashes indicate pictures that were not included in the pretests. These pictures were selected on the basis of naming responses and response latencies obtained in other pretests carried out at the Max Planck Institute

## Chapter 3 Appendix A

Dutch Names and Their English Translations for the Target Pictures in Experiment 1 and Experiment 2, and Their Median Naming Latencies and Gender Decision Latencies as Obtained in the Pretests.

| Picture names grouped by wordinitial phoneme | Reaction time (ms) Naming | Gender decision | Picture names grouped by wordinitial phoneme | Reaction time (ms) Naming | Gender decision |
|---|---|---|---|---|---|
| /b/ | | | /v/ | | |
| bank [couch] | 665 | 762 | vaas [vase] | 801 | 693 |
| bloem [flower] | 660 | 747 | vis [fish] | 673 | 659 |
| boom [tree] | 623 | 776 | vlag [flag] | 696 | 754 |
| bril [glasses | 742 | 700 | voet [foot] | 698 | 782 |
| broek [trousers] | 682 | 769 | vinger [finger] | 767 | 684 |
| baby [baby] | 848 | 801 | vlinder [butterfly] | 642 | 672 |
| /s/ | | | /k/ | | |
| schoen [shoe] | 642 | 688 | kaars [candle] | 570 | 793 |
| spin [spider] | 618 | 680 | klok [clock] | 825 | 784 |
| ster [star] | 639 | 886 | knoop [button] | 789 | 766 |
| stoel [chair] | 608 | 686 | kast [cupboard] | 752 | 843 |
| sleutel [key] | 669 | 701 | kikker [frog] | 642 | 797 |
| spijker [nail] | 734 | 706 | koffer [suitcase] | 725 | 740 |

# SAMENVATTING

In een doorsnee conversatie worden gedachten razendsnel in woorden omgezet. Een spreker produceert gemiddeld twee tot drie woorden per seconde en maakt daarbij meestal niet meer dan één fout per 1000 uitgesproken woorden. Bovendien heeft een spreker kennis van een enorm aantal woorden. Er wordt geschat dat een volwassen spreker informatie over zo'n 40.000 woorden in het geheugen heeft opgeslagen. Deze informatie betreft, onder andere, de betekenis van woorden, hun grammaticale eigenschappen (bv., 'klimmen' is een werkwoord, en 'beer' is een zelfstandig naamwoord), en de fonologie, dat wil zeggen, de klank van de woorden. De grote snelheid en precisie waarmee sprekers de juiste woorden uit het geheugen kunnen ophalen, grammaticale zinnen kunnen construeren, hun fonologische vorm kunnen specificeren en uitspreken is dan ook verbazingwekkend. Het is zeer aannemelijk dat deze processen grotendeels automatisch verlopen, dat wil zeggen, zonder de bewuste aandacht van de spreker.

In psycholinguïstische theorieën wordt het spraakproductieproces meestal onderverdeeld in semantische, grammaticale, en fonologische componenten. Van cruciaal belang voor het genereren van vloeiende spraak is dat deze componenten precies op elkaar zijn afgestemd in de tijd. Tot nu toe is er echter niet veel bekend over het precieze tijdsverloop van de verschillende automatische processen in spraakproductie. In de huidige dissertatie wordt een methode ontwikkeld om de cognitieve processen die verantwoordelijk zijn voor het ophalen van semantische en grammaticale woordinformatie en het specificeren van hun fonologie op het niveau van milliseconden te volgen. Tevens wordt onderzocht hoe de verschillende processen in de tijd aan elkaar zijn gerelateerd.

Het uitgangspunt van het onderzoek vormt de spraakproductie-theorie van Levelt (1989) en de implementatie van deze theorie in een computermodel door Roelofs (1992). De fundamentele aanname in Levelts spraakproductie-theorie is dat het verloop van de verschillende processen serieel is. Volgens de theorie komen tijdens het ophalen van een woord uit het geheugen de verschillende typen woordinformatie (semantisch, grammaticaal, en fonologisch) niet tegelijkertijd, maar stapsgewijs beschikbaar: eerst worden de semantische en grammaticale eigenschappen van een woord opgehaald, en *alleen* als deze beschikbaar zijn, kan de fonologische vorm van een woord gespecificeerd worden. Alhoewel het bestaan van semantische, grammaticale en fonologische stadia in spraakproductie plausibel is gegeven de evidentie vanuit reactietijdonderzoek, versprekingsanalyses, en neuropsychologische data, is hun precieze tijdsverloop nog altijd een openstaande vraag. In deze dissertatie wordt geprobeerd om evidentie te vinden voor een temporele scheiding tussen de verschillende stadia in spraakproductie. Hoofdstuk 2 beschrijft het onderzoek naar een scheiding in de tijd tussen een semantisch en fonologisch stadium, en in hoofdstuk 3 wordt onderzocht hoe grammaticale en fonologische processen zich in de tijd tot elkaar verhouden.

Levelts spraakproductie-theorie veronderstelt niet alleen serialiteit tussen de verschillende stadia, maar ook binnen het fonologische proces zelf. Op basis van onder meer evidentie uit reactietijdonderzoek, wordt verondersteld dat de fonologische woordvorm niet als een kant-en-klare eenheid beschikbaar is, maar serieel moet worden opgebouwd vanaf het begin tot het eind. In het onderzoek beschreven in deze dissertatie is geprobeerd evidentie te vinden voor deze veronderstelling. Bovendien is onderzocht hoeveel tijd dit proces in beslag neemt, dat wil zeggen, hoeveel tijd er nodig is om de fonologische vorm van een woord vanaf het eerste tot en met het laatste segment te specificeren.

Om het tijdsverloop van de semantische, grammaticale, en fonologische processen gedurende het spraakproces te kunnen volgen heb ik een voor dit onderzoeksveld nieuwe methode toegepast. In deze methode worden hersenpotentialen gemeten tijdens een spraakproductietaak. Een van de voordelen van hersenpotentialen is dat zij een continue maat verschaffen voor de electrische activiteit in de hersenen tijdens het uitvoeren van een bepaalde taak. Met behulp van op de schedel geplaatste elektroden kan de variatie in neurale activiteit in het electroencephalogram (EEG) worden gemeten. Als gevolg van een externe gebeurtenis (bijvoorbeeld het horen van een woord, of het zien van een plaatje) kunnen regelmatigheden in het EEG worden geobserveerd die precies in de tijd gekoppeld zijn aan het moment waarop de gebeurtenis zich voordeed. Deze regelmatigheden in het EEG-signaal worden *event-related potentials* (ERPs) genoemd. ERPs geven de neuronale activiteit weer die direct is gerelateerd aan het verwerken van de externe stimulus. Zij kunnen daarom worden gebruikt als index voor de perceptuele en cognitieve processen die zich afspelen ten gevolge van de stimulusverwerking. Het ERP-signaal bestaat uit een serie van positieve en negatieve pieken, meestal componenten genoemd. De componenten in het ERP-signaal worden benoemd ofwel naar hun polariteit (positief of negatief) en hun latentie (het tijdstip waarop de component zijn maximale amplitude bereikt, gemeten in msec vanaf het moment waarop een stimulus wordt aangeboden), ofwel naar het cognitieve proces dat ze worden gedacht te reflecteren. De ERP-methode is succesvol gebleken in het onderzoek naar taalbegrip, maar is tot nu toe nog niet toegepast om de cognitieve processen tijdens spraakproductie te onderzoeken. Dit is onder meer het gevolg van het feit dat articulatorische bewegingen het EEG-signaal verstoren. De spierbewegingen gaan gepaard met elektrische activiteit die door de elektroden op de schedel wordt geregistreerd. Deze activiteit interfereert met het veel zwakkere EEG-signaal, waardoor de ERP metingen ruizig en onbetrouwbaar worden. Om deze onbetrouwbaarheden ten gevolge van articulatie te ontwijken heb ik een experimenteel paradigma gebruikt waarin de *lateralized readiness potential* (LRP) wordt gebruikt om het tijdsverloop van de semantische, grammaticale, en fonologische processen op een indirecte manier te volgen.

De LRP is een motorpotentiaal die direct is gerelateerd aan het voorbereiden van een selectieve handbeweging (een beweging met de rechter-, of de linkerhand). De LRP begint zich te ontwikkelen direct *nadat* de linker- of rechterhand is geselecteerd om te gaan bewegen, maar *voordat* de beweging is ingezet. De LRP bereikt z'n maximale amplitude vlak na het uitvoeren van de beweging. Het onderzoek waarin de LRP tot nu toe voornamelijk werd gebruikt, richtte zich op de wijze van informatieoverdracht tussen perceptuele/cognitieve processen en het motorsysteem (zie Coles et al., 1995 voor een overzicht). De resultaten van dit type onderzoek laten zien dat perceptuele en cognitieve processen gedeeltelijk verwerkte informatie beschikbaar kunnen maken voor motor processen. Het motorsysteem kan deze informatie gebruiken voor vroege responsvoorbereiding. De LRP is gevoelig voor de transmissie van gedeeltelijk verwerkte informatie naar het motorsysteem en kan gebruikt worden als index voor de momenten waarop verschillende typen van cognitieve en perceptuele informatie responsvoorbereiding beïnvloeden.

Om het tijdsverloop van de verschillende processen tijdens spraakproductie te onderzoeken werd aldus het volgende experimentele LRP-paradigma ontwikkeld. Tijdens de experimenten werden verschillende plaatjes een voor een aangeboden op een computerscherm. Aan de deelnemers van de experimenten werd gevraagd om deze plaatjes te benoemen. Plaatjes benoemen is een taak die veel wordt gebruikt in spraakproductie-experimenten omdat tijdens het uitvoeren van deze taak alle stadia van spraakproductie moeten worden doorlopen. Bovendien is de 'output' eenvoudig te controleren (namelijk, de naam van het plaatje, bijvoorbeeld 'beer'). De benoemingstaak was echter niet de enige taak die de deelnemers uit moesten voeren. Op de helft van het aantal 'trials' verscheen na 150 milliseconden een kader rondom het plaatje, wat betekende dat een classificatie- taak moest worden uitgevoerd *voordat* het plaatje werd benoemd. De classificatie-taak bestond uit een combinatie van een linker- of rechterhandrespons en de beslissing om de respons wel of niet uit te voeren (de 'go-nogo' beslissing genoemd).

In Hoofdstuk 2 werd een semantische classificatie (representeert het plaatje een dier of een ding) gecombineerd met een fonologische classificatie (eindigt de naam van het plaatje op een /r/ of een /n/). In het eerste experiment bepaalde de semantische classificatie de keuze tussen links en rechts, terwijl de fonologische classificatie bepaalde of de respons wel of niet werd uitgevoerd. Bijvoorbeeld, voor woorden die eindigden op een /r/ werd een linkerhandrespons gegeven voor een dier (bijvoorbeeld tijger), en een rechterhandrespons voor een ding (bijvoorbeeld schaar), terwijl voor woorden die eindigden op een /n/ (bijvoorbeeld spin en schoen) geen handrespons werd gegeven (zie figuur 2.2 op pagina 51). De logica achter dit paradigma is als volgt. Op het moment dat het kader rond het plaatje verschijnt, zijn deelnemers in een zeer vroege fase van het benoemingsproces. Als de verschillende processen in spraakproductie verschillen in hun tijdsverloop, dan zal de informatie die wordt gegenereerd door deze processen op verschillende momenten in de tijd beschikbaar komen. Dus, bijvoorbeeld, als semantische processen voorafgaan aan fonologische processen, is het te verwachten dat semantische informatie over een woord eerder beschikbaar zal zijn dan de fonologische segmenten van een woord. Op basis van eerder gerapporteerde LRP-onderzoeken is het plausibel om aan te nemen dat verschillende typen informatie naar het motorsysteem worden getransporteerd zodra ze beschikbaar zijn gemaakt door het spraakproductieproces. Voor de boven beschreven taak betekent dit dat, als tijdens het benoemen van een plaatje semantische informatie eerder beschikbaar is dan fonologische informatie, de links-rechts-respons alvast kan worden geselecteerd op basis van de semantische informatie *voordat* op basis van de fonologische informatie kan worden besloten of de respons wel of niet moet worden uitgevoerd. De voorspelling die hier noodzakelijkerwijs uit volgt, is dat de initiële ontwikkeling van de LRP alleen zal worden beïnvloed door semantische informatie, en dat pas op een later moment in de tijd de invloed van fonologische informatie zichtbaar zal worden in de LRP.

Om deze voorspelling te toetsen werden ERPs gemeten gedurende 'go trials' (trials waarin een respons werd gegeven) en gedurende 'nogo trials' (trials waarin geen respons werd gegeven). De resultaten lieten zien dat een LRP niet alleen op go trials maar ook op nogo trials aanwezig was, terwijl op nogo trials geen enkele spieractiviteit werd waargenomen. De go and nogo LRP ontwikkelden zich op identieke wijze gedurende een interval van 120 msec, daarna begon de nogo LRP langzaamaan te verdwijnen, terwijl de go LRP zich verder bleef ontwikkelen, resulterend in een respons (zie figuur 2.3 op pagina 56). De aanwezigheid van een LRP op nogo trials wijst erop dat vroeg beschikbare semantisch informatie werd gebruikt om de juiste responshand te selecteren *voordat* voldoende fonologische informatie beschikbaar was om go trials van nogo trials te onderscheiden.

Een tweede experiment waarin niet het laatste maar het eerste fonologische segment kritisch was voor het onderscheid tussen go en nogo trials leidde tot vergelijkbare resultaten. Opnieuw werd er een nogo LRP waargenomen, maar het interval waarin de go en nogo LRP zich op identieke wijze ontwikkelden was beduidend korter: na 40 milliseconden keerde de nogo LRP alweer terug naar de baseline (zie Figuur 2.7 op pagina 68).

Een vergelijking van de resultaten van deze twee experimenten laat zien dat de positie van het kritische foneem in het woord niet van invloed was op het begin van de LRPs, maar wel bepalend was voor het moment waarop de nogo LRP van de go LRP begon af te wijken. In een controle experiment werd onderzocht of de logica achter het paradigma correct was. In dit experiment werden de taken omgedraaid: de links-rechts beslissing werd nu bepaald door de fonologische classificatie, en de go-nogo beslissing werd bepaald door de semantische classificatie. Als semantische informatie inderdaad eerder beschikbaar is dan fonologische zou in dit experiment geen LRP mogen verschijnen op nogo trials. Dit is precies wat werd waargenomen: een LRP ontwikkelde zich op go trials, maar op nogo trials was geen enkele indicatie te vinden voor de ontwikkeling van een LRP (zie figuur 2.5 op pagina 60). De resultaten van het controle experiment lieten zien dat de LRP inderdaad gevoelig is voor het moment in de tijd waarop informatie beschikbaar komt tijdens spraakproductie.

In hoofdstuk 3 werd een vergelijkbaar experimenteel paradigma gebruikt om het tijdsverloop van grammaticale en fonologische processen te onderzoeken. Gekleurde plaatjes moesten worden benoemd met korte zinnetjes, en in de helft van het aantal trials werd een grammaticale-fonologische classificatie-taak uitgevoerd. De resultaten lieten zien dat de grammaticale en fonologische woordinformatie op verschillende momenten in de tijd beschikbaar komen. In het geval dat een responshand kon worden geselecteerd op basis van grammaticale informatie werd een LRP geobserveerd op zowel go als nogo trials. Echter, in het geval dat grammaticale informatie bepalend was voor het wel of niet uitvoeren van de respons, werd een LRP alleen geobserveerd op go trials.

Uit de resultaten kon geconcludeerd worden dat een spreker toegang heeft tot de semantische en grammaticale eigenschappen van een woord *voordat* de fonologische woordvorm is gespecificeerd. Het omgekeerde is niet het geval: het is niet mogelijk om een woord fonologisch te specificeren zonder dat de semantische *en* de grammaticale eigenschappen van een woord opgehaald zijn uit het geheugen. De resultaten ondersteunen Levelts spraakproductie-theorie in die zin dat ze aantonen dat de verschillende woordeigenschappen in een vaste temporele volgorde worden opgehaald: eerst wordt op basis van semantische activatie een grammaticale woordrepresentatie geselecteerd, daarna wordt de fonologische woordvorm gespecificeerd. Tevens toonden de resultaten aan dat de klank van een woord serieel wordt opgebouwd: de beginklank is eerder beschikbaar dan de laatste klank.

Naast het onderscheiden van verschillende stadia kon op basis van de LRP-data de tijdsduur van het specificeren van een woordvorm worden geschat. Nadat een grammaticale woordrepresentatie is geselecteerd, duurt het ongeveer 40 milliseconden om de beginklank van dat woord op te halen. Vanaf het moment dat de beginklank beschikbaar is, zijn er nog ongeveer 80 milliseconden nodig om de laatste klank van een woord te specificeren (deze schatting geldt voor woorden die gemiddeld uit 1.5 lettergrepen bestaan). Hieruit volgt dat het tenminste 120 milliseconden duurt om de vorm van een woord (bestaande uit gemiddeld anderhalve lettergreep) van het begin tot het eind op te bouwen. Het is uiteraard een empirische vraag of deze schatting ook van toepassing is op spraak met complexere structuur dan de woorden en korte zinnetjes die in de hier gerapporteerde experimenten moesten worden uitgesproken. Deze dissertatie laat zien dat het LRP-paradigma uitstekende mogelijkheden biedt om het tijdsverloop van verschillende stadia in spraakproductie op milliseconden niveau te volgen.

# Curriculum Vitae

Miranda van Turennout studeerde psychologie aan de Rijksuniversiteit Leiden, met als specialisatie functieleer. Tijdens haar studie werkte zij als stagiaire op het Max Planck Instituut voor Psycholinguïstiek te Nijmegen. Na het behalen van haar doctoraaldiploma in 1992 bleef zij als onderzoeksassistent verbonden aan het MPI. In september 1993 werd haar een stipendium toegekend door de Max Planck Gesellschaft zur Förderung der Wissenschaften om promotieonderzoek te verrichten aan het MPI, binnen de onderzoeksgroep 'Neurocognition of language processing'. Vanaf najaar 1997 is zij als postdoctoral fellow verbonden aan het 'Laboratory of Brain and Cognition', van het National Institute of Mental Health te Bethesda, USA.

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