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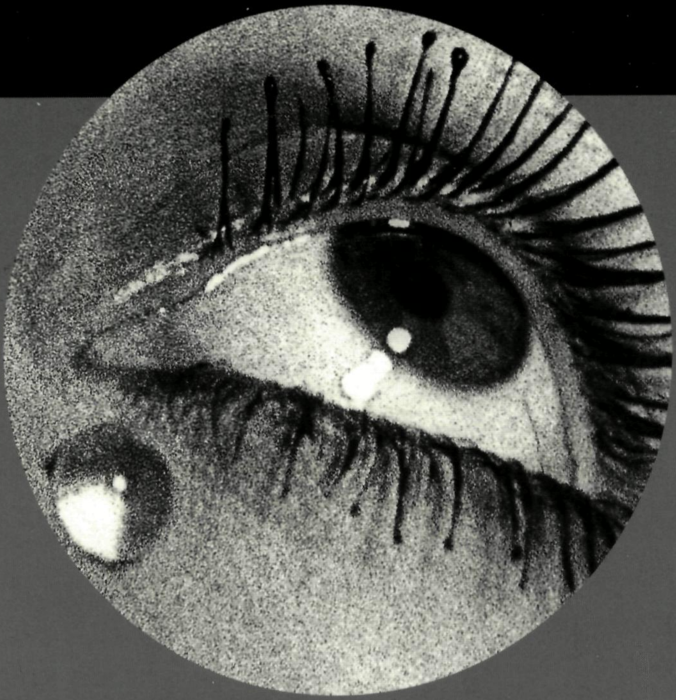

The Lexical Processing Nature of the N400 Priming Effect

Dorothee Chwilla

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The Lexical Processing Nature of the N400 Priming effect

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op het gebied van de Sociale Wetenschappen

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Promotor	Prof. Dr. R. Schreuder
Co-promotores:	Dr. C.M. Brown
	Dr. P. Hagoort

Manuscriptcommissie
Prof. Dr. W.J.M. Levelt
Prof. Dr. G. Mulder (RUG)
Prof. Dr. H.J. Schriefers

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to Marguerite Duras a word artist

Woord tegen niet-woord,

"Ik begrijp je niet".

Niet-woord antwoordt,

"Jij bent de benoeming

en ik de fantasie."

Lagos, 1990

DANKWOORD

An erster Stelle mochte ich meinen Eltern danken. Insbesondere dafur, dass sie die Vorraussetzungen dafur geschaffen haben, dass ich mich in die Dinge habe vertiefen konnen. Bis zum Wesen der Dinge vordringen zu wollen, sei es auf eine eher abstrakte Weise, hat mich von jeher fasziniert. Zudem haben die zahlreichen Diskussionen mit meinem Vater uber Gott und die Welt mein Interesse fur philosophische Angelegenheiten noch weiter verstarkt.

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Croonen (een insider in de wetenschappelijke arena van de dertigers), die soms dreigende wetenschappelijke depressies het hoofd konden bieden. Een speciaal woord van lof aan mijn proefpersonen voor hun grote inzet om de moeilijke instruktie op te volgen om stil te blijven zitten, snel te reageren, weinig fouten te maken en met name geen oogbewegingen te maken.

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CHAPTER I

INTRODUCTORY REMARKS

This thesis presents an electrophysiological approach to the study of human language comprehension One of the most fascinating aspects of language processing is the rapid rate at which a reader or a listener identifies individual words, retrieves their meaning as well as their grammatical form, and builds up a higher-order meaning representation of the entire sentence or discourse. Language processing, like other cognitive functions is a dynamic process, and trying to understand the dynamics of the lexical processes involved has proven to be not an easy task. For instance, one of the basic issues in language comprehension is the way in which readers or listeners identify words Despite the fact that research directed at answering this question has been carried out for more than 100 years (Cattel, 1885, Huey, 1908), a full understanding of how word recognition takes place has remained relatively elusive

The study of the dynamic process of language comprehension requires the use of experimental techniques that allow an examination of the real time characteristics of language processing The traditional method within psycholinguistics has been the reaction time method A disadvantage of the reaction time method is that it reflects the state of affairs at one particular moment in time during the language comprehension process. Throughout this dissertation the Event Related Brain Potential technique is used, a technique that has become quite well established in cognitive psychology (see for reviews Coles, & Gratton, 1985, Donchin, Karis, Bashore, Coles, & Gratton, 1986, Meyer, Osman, Irwin, & Yantis, 1988), but only recently has been applied to issues in psycholinguistics (see for reviews Kutas & Van Petten, 1994 and 1988, Osterhout & Holcomb, 1994)

Event-Related Brain Potentials (ERPs) reflect components in the spontaneous electrical brain activity that are time-locked to a particular information processing event The major advantage of ERPs compared to reaction times, is that the ERP signal is continuous and therefore allows an on-line examination of language processes as they unfold in real time Let me illustrate this with an example. The fact that ERPs can be recorded in an uninterrupted way makes it possible to track the effects of a particular experimental variable (e g., word frequency, contextual strength, a semantic or syntactic violation) throughout the course of a sentence. In this way we can assess not only at what point in time and in response to which word a variable exerts its effect, but also what the consequences are of this variable for the continued processing of the sentence. For instance, ERP studies have shown that the violation of a syntactic constraint evokes a local ERP effect due to the violation, but also that the syntactic violation yields an increase in processing load as reflected by differences in ERPs to words occurring later in the sentence (e g., Hagoort, Brown, & Groothusen, 1993). Thus, ERPs might give a more complete picture of the timing of the different language processes as well as the interaction of different types of information during language comprehension. A second, for psycholinguistics important aspect of ERPs is that the brain response to the stimuli of interest can be investigated in the absence of an additional task, such as lexical decision. Within the psycholinguistic literature there has been quite some discussion about the possible "side-effects" of the use of experimental tasks The question has been to what extent the results obtained in a particular task reflect task-induced effects and to what extent they reflect normal language comprehension processes Chapter three of this thesis provides an example of how such questions can be addressed with ERPs.

The more general aim of the present research programme was to assess the value of ERPs, in particular of one ERP component, the so called N400, as a new method for psycholinguistic research. To date it is not clear which aspects of the comprehension process are reflected by the N400 Before the ERP method can be efficiently applied to the field of psycholinguistics it has to be clarified how the N400 relates to the lexical processes involved in language comprehension. In models of lexical processing a basic distinction is made between lexical access and lexical integration functions (e.g., Frauenfelder & Tyler, 1987, Marslen-Wilson, 1989). A main purpose of the experimental programme was to assess whether the N400 mainly reflects lexical access or lexical integration functions

In the following paragraphs I will first present in a nutshell the theoretical framework within which this research programme has been conducted. The second part of this chapter provides a description of the ERP method as well as an overview of the ERP results that served as the basis for the ERP work set out in this thesis.

THEORETICAL FRAMEWORK

Before presenting a functional model of word recognition, there is one theoretical concept that needs some elucidation. In most theories of language comprehension a crucial role is assigned to the mental lexicon (Forster, 1976, Levelt, 1989, Morton, 1969). The mental lexicon plays an important role in mediating between the sensory input and the interpretation attached to a message. The mental lexicon is conceived as a dictionary in the mind, that contains all the knowledge that a language user has at his disposal about the words in his language. The words in the lexicon are assumed to be organized as a network of representational nodes and the activation level of these nodes can be either increased or decreased via excitatory or inhibitory links with other nodes (e.g., Morton 1969). In its simplest form the content of the mental lexicon can be represented as comprising only one component, namely stored word-form representations (e.g., Morton, 1969, Besner & Smith, 1992), which are directly mapped onto a general knowledge base that is not specifically part of the lexicon itself. Other theories, however, assume that the lexicon in addition to word-form representations consists of other components, specifically stored word meanings and their syntactic properties (e.g., Levelt, 1989). In accordance with the latter view I assume that the lexicon consists of a well-defined word meaning component. The focus in this thesis will be on this semantic part of the lexicon.

It has been proposed that the words in the lexicon are clustered in some meaningful fashion (cf Collins & Loftus, 1975), namely according to semantic relations or according to associative relations. A semantic relation refers to an overlap in the mental representations of the meanings of words, for instance a semantic relationship exists between a word and its hypernym (e.g., between "table" and "furniture", or between "blue" and "color"). Two words are associatively related when presentation of one of the words generates the other word in an association test. For example, the word "mouse" yields the associate "cheese". In this example the words are mainly associatively related, which means that they do not share semantic features and also do not share a simple semantic category relationship (see for word association norms e.g., De Groot, 1980, De Groot & De Bil, 1987). Knowledge of the real world, however, immediately reveals what the relationship is between the two words, namely that "mice love cheese". Although associatively related words do not necessarily share semantic properties, they most often are also semantically related (e.g , "bread" and "butter" are associatively related, but share the properties of being foods eaten by humans).[1] Empirical evidence for this clustering of (related) word meanings is provided by semantic priming effects that will be discussed later on in this chapter.

When recognizing a word the semantic and syntactic information associated with this word is retrieved from the mental lexicon This retrieval process that is called word recognition will be outlined in the next paragraph.

In functional models on visual and auditory word recognition three lexical processes are commonly distinguished lexical access, lexical selection and integration (e.g., Frauenfelder & Tyler, 1987, Marslen Wilson, 1987, Zwitserlood, 1989a). Lexical access refers to the earliest phase in lexical processing and is concerned with the relationship between the mental lexicon and the sensory input Before the lexical system is involved, based on the perceptual analysis of the written or the spoken word information is extracted from the sensory input that is relevant for the lexical system. These processes provide the lexical system with some kind of form information. The process of lexical access involves the mapping of this information onto word form representations that are stored in the mental lexicon. This process results in the activation of these lexical elements and their semantic and syntactic attributes. The process of lexical selection refers to the process of selecting from the subset of accessed elements the lexical element that best matches the input available to the system. The models differ with regard to the way in which selection is accomplished. For instance, selection has been explained in terms of the passive crossing of a threshold (Morton, 1969, 1979), the drop out of items from the set of activated word forms (Marslen-Wilson, 1984), or in terms of a serial search through a frequency-ordered list (Forster, 1976). The third phase, lexical integration refers to the process of integrating a lexical element into a higher order meaning representation of the entire sentence or discourse. Let me illustrate with an example of adjective-noun combinations what is meant by lexical integration In adjective-noun combinations the semantic representation of the adjective is dependent upon the semantic interpretation of the noun For example, the adjective-noun combination "good knife" versus "good orchestra" yields quite different semantic interpretations

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[1] *Therefore, the basic difference between semantically and associatively related words is not that one is semantically related and the other is not, but rather, that usually associatively related pairs in addition to being semantically related are also associatively related*

of the adjective due to the meaning aspects activated by the noun, that in this example correspond with the higher order meaning representation of the context. Since the function of a "knife" is to cut things the adjective good is interpreted in terms of the sharpness of the blade. In contrast, the noun "orchestra" is associated with a group of musicians playing different instruments, so that a "good orchestra" refers to a good performance of musicians and yields the interpretation of a nice piece of music.

In this view of word recognition lexical access precedes the selection of one lexical candidate. Whether lexical selection precedes the phase of integration is not clear. In principle, lexical integration can take place as soon as the semantic and syntactic information of the lexical elements becomes available. Since this information could already be available upon lexical access, it is possible that the processes of lexical selection and integration run in parallel One basic question that remains is what is the nature of these lexical processes?

Within models on word recognition and throughout this thesis the distinction between automatic and controlled processes is of central importance (Posner & Snyder, 1975, Shiffrin & Schneider, 1977) Here we follow the tradition of most researchers in the field of visual word recognition (e.g , Fischler, 1977, Neely, 1991, Tweedy, Lapinski, & Schvaneveldt, 1977) to use the term automatic and controlled as exemplified in the dual-process model of Posner and Snyder (1975). According to Posner and Snyder automatic and controlled processes have to fulfill a number of criteria. More specifically, automatic processes (1) occur without a person's intention or awareness, (2) are fast-acting, (3) of short duration, and (4) do not draw upon a common pool of resources. In contrast, controlled processes are (1) under a person's strategic control and cannot occur without a person's intention or awareness, (2) relatively slow, and (3) limited in processing capacity

According to the view of word recognition described above, lexical access is a reflex-like automatic process. Lexical selection is at the interface of lexical access and lexical integration. The fact that the selection process can be affected by sentential context (e g., Zwitserlood, 1989a) questions its fully automatic nature and points to a possible contribution of more controlled processes. In contrast to access (and selection), lexical integration is thought of as a more controlled process that can be guided by the subject's awareness of the informational content of the discourse and that requires more processing resources than does lexical access. However, at the same time lexical integration is a mandatory process (Fodor, 1983), in normal discourse, subjects of necessity engage in the integration of individual word meanings into message level representations. Since in this thesis we are mainly interested in the distinction between automatic and more controlled lexical processes, the major focus will be on the lexical access and integration function.

WORD CONTEXT EFFECTS

This thesis presents a series of experiments in which the effects of context on lexical processing were investigated with ERPs The term context effect here, refers to the impact of lexical-semantic information and not sentential semantic information The main difference between both types of semantic information is whether the information is thought to be represented at the level of the mental lexicon. Lexical semantic context effects can arise exclusively from meaning representations inside the mental lexicon, whereas sentential semantic effects are thought to reflect higher order information, that is represented outside the lexicon [2]

A classical example of a lexical-semantic context effect is the semantic priming effect, that was first reported by Meyer and Schvaneveldt (1971) and ever since has proven to be one of the most robust findings in the psycholinguistic literature. Semantic priming refers to the finding that words are recognized faster when they are preceded by an associatively or semantically related compared to an unrelated word. For example, subjects are faster in indicating that the word "tiger is a word, when this word is preceded by the word "lion" than when it is preceded by the word "pipe". Although the priming effect has been referred to as "semantic", most of the studies investigating semantic priming have used word pairs that are not only semantically but also associatively related In fact, only a small number of studies have looked at priming for word pairs that are not associatively related

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In the psycholinguistic literature a basic distinction is made between autonomous and interactive models A major difference between these models refers to the stage at which higher order information (i e , lexical sentential information) affects lexical processing Autonomous models claim that the processes of lexical access and lexical selection proceed on the basis of sensory information in a strictly bottom-up manner and that higher level information such as integrating a word into a context exerts its effects only after the selection phase has been completed (Forster, 1976, 1979, Seidenberg, 1985) In contrast, fully interactive models, such as Morton's Logogen model (Morton, 1969, 1979), and connectionist models (e g , McClelland & Elman, 1986) claim that lexical sentential context can affect any stage of lexical processing In its most extreme form higher order context information can have an effect even before the sensory input has been delivered, by changing the activation level of the lexical elements in accordance with the context, for example as a function of the predictability of a word within a particular context Due to the fact that the experiments reported in this thesis investigated the effects of a single word context and not of sentential contexts, the present results are of less importance for the debate between autonomous and interactionist models but are only semantically related (e.g., Fischler, 1977, Hodgson, 1991, Seidenberg, Waters, Sanders, & Langer, 1984). However, the results for priming for word pairs that are exclusively semantically related and thus associatively unrelated have been inconclusive. Recent results of Shelton and Martin (1992) indicate that automatic priming comes about for associatively related words but not for words that are semantically but not associatively related.

Priming has often been considered as an index of automatic processing, reflecting the passive spread of activation between semantically related nodes in the mental lexicon (e g., Collins & Loftus, 1975, Marcel, 1983, Posner & Snyder, 1975). The reason why priming was considered to be largely automatic was that response facilitation was found, even though the subject was not required to make any explicit judgement concerning the semantic relationship between the prime and the target, nor was the use of this information necessary for the response. However, there is now convincing evidence that priming effects do not necessarily only reflect the automatic access to lexical-semantic information but can also be evoked by controlled forms of lexical processing (e.g., Balota & Chumbley, 1984, De Groot, 1984, Neely, 1977, Seidenberg et al., 1984) Below I will present the different accounts of semantic priming in more detail.

The major focus of this thesis is on the relative contributions of the processes of lexical access and lexical integration to semantic priming obtained with ERP measures Therefore, I will describe the different mechanisms that have been proposed to underly associative priming. In this thesis, the effects of word context were investigated within the framework of the semantic priming model as proposed by Neely and Keefe (1989, see also Neely, 1991). According to this model at least three mechanisms contribute to the priming effect. Only one of these mechanisms is claimed to be automatic, the other two reflect more or less controlled forms of processing

The first mechanism is automatic spreading of activation (ASA, Collins & Loftus, 1975). ASA assumes that in semantic memory links exist between words that are closely related in meaning. Presentation of a word activates the corresponding node of this word in semantic memory, and via the links to nearby nodes part of this activation automatically spreads to words that are related in meaning. As a consequence, the activated nodes representing related words need less time for subsequent processing ASA has all the characteristics of an automatic process. It is fast-acting, of short duration, does not require attention or awareness, and presupposes no or only minimal resource capacity Another important feature of ASA is that it is usually assumed to facilitate the processing of related targets, but not to inhibit the processing of unrelated targets (Neely, 1977, Posner & Snyder, 1975). ASA is most effective at short stimulus onset asynchronies (SOA), and its effects are assumed to occur within some 500 milliseconds (ms) (Balota & Lorch, 1986, McNamara & Altarriba, 1988, Neely, 1977) After this interval, automatic priming effects will rapidly decay.

The second mechanism is expectancy induced priming (Becker, 1985, Posner & Snyder, 1975) This is a predictive strategy, in which the subject uses the information provided by the prime to generate an expectancy set for related target words. If the target is included in this set it will be recognized more quickly If it is not, the recognition for the target word will be slowed down. Expectancy induced priming, therefore, can explain facilitation for related targets as well as inhibition for unrelated targets Since the generation of the expectancy set is under a subject's control this mechanism is seen as a controlled process. As such this mechanism can be influenced by instruction as well as by the list structure of the material. Especially when the stimulus list contains a large proportion of related word pairs, the probability that the expectancy mechanism contributes to the overall priming effect is large (Keefe & Neely, 1990) In contrast to ASA, the generation of an expectancy set is time-consuming, so that effects of this mechanism are only observed at intervals that are longer than approximately 250 ms (Neely, 1977, Neely & Keefe, 1989, Stolz & Neely, 1995, but see De Groot, 1984).

The third priming mechanism is semantic matching (Neely & Keefe, 1989, or "post-lexical coherence checking" in the terminology of De Groot, 1984). In a lexical decision task subjects are assumed to match primes and targets postlexically (i e., following lexical access and selection) for semantic similarity, and the word/nonword decision is affected by the result of this matching process. The detection of a relationship between primes and targets leads to a bias to respond 'Yes'. If no such relation is detected, then there is a bias to respond 'No'. Semantic matching can account both for facilitation of related targets and inhibition for unrelated targets. In the case of unrelated targets, the semantic matching process fails, yielding a bias to respond 'No' and consequently the correct 'YES' response is inhibited Typically semantic matching is thought of as a process that is under strategic control and as such it is conceived of as a more or less controlled process (Humphreys, 1985, Neely, 1991). However, in contrast, it has also been proposed that semantic matching reflects a fast acting process (De Groot, 1985), that may operate in an automatic mode (Hodgson, 1991).

The theoretical analysis of semantic priming in terms of the underlying mechanisms is of great importance, because semantic priming provides us with an instrument that helps to investigate how the meanings of words are accessed and integrated with a context. For this reason the field of semantic priming has functioned as a well-defined playground to test different models of context effects and of word recognition. The vast majority of the studies that employed the semantic priming paradigm used experimental tasks, namely lexical decision and naming. However, it has been proposed that the priming mechanisms refer to lexical processes that also play a role in normal language comprehension. This in particular holds for the automatic process of spreading of activation as well as for semantic matching processes (De Groot, 1984, Henderson, 1982, Neely, 1991). Therefore, insight into the relative contribution of the different mechanisms to N400 semantic priming effects may further our understanding of the fundamental processes that underly the N400 in relation to language comprehension.

Within the last twenty years much experimental work has been aimed at teasing apart the automatic versus attentional aspects of priming by assessing the contributions of the different priming mechanisms to the observed response facilitation. A review of the extensive research literature on reaction time semantic priming effects falls outside the scope of this thesis (see Neely, 1991, for a review on visual word recognition). In the next part of this chapter I will illustrate in more detail how the same line of research has been employed with ERPs.

WHAT ARE EVENT-RELATED POTENTIALS?

ERPs are part of the electrical brain activity, which can be recorded at the scalp. The record of this brain activity is called the electroencephalogram (EEG). The EEG reflects patterns of neural activity in cortical and subcortical structures. The spontaneous EEG has been divided into a number of rhythms according to their frequency band. In the awake state the alpha and the beta rhythms are distinguished with frequencies of 8 to 12 Hz and 12 to 32 Hz. The alpha rhythm is characteristic for a relaxed awake state of the subject. An increase in mental activity is typically accompanied by a desynchronisation of the alpha rhythm reflected by the predominance of the high-frequent low amplitude beta rhythm. In contrast to ERPs, changes in background EEG activity reflect large changes in the general state of the subject, for example as a function of being awake or asleep.

Technical aspects of ERP measuring

ERPs are much smaller in amplitude (5 10 µV) than the spontaneous EEG (50-100 µV). Therefore, ERPs are usually not visible in the raw EEG. In order to extract the ERP from the background EEG we have to average the EEG across several stimulus presentations. The averaging procedure is illustrated in Figure 1. In the upper part of this Figure nine raw EEG registrations of two seconds each are presented: one second preceding a click and one second following a click. The averaged signal illustrates that the spontaneous EEG approaches zero, whereas only those potential changes remain that have a fixed temporal relationship with the stimulus. Averaging improves the signal-to-noise ratio of the ERP in proportion to the square root of the number of responses included. The number of trials needed for a reliable ERP average depends on the size of the signal, but 25 observations per condition should be considered as a minimum (e.g., Kutas & Van Petten, 1994).

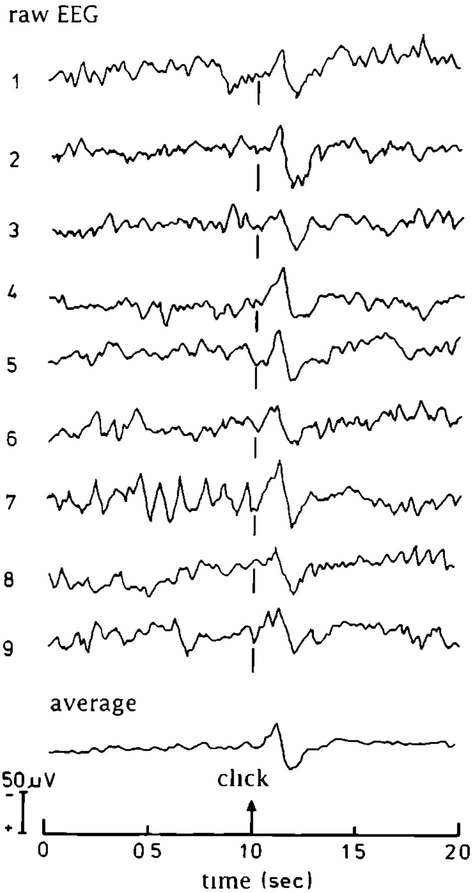

__Figure 1__ Presents nine raw EEG registrations derived from the central midline electrode and their average. The EEG was recorded during two seconds: one second preceding an auditory click (70 dB) and one second following the click. Note that the evoked potential elicited by the click is also visible in the raw EEG.

The EEG is recorded by attaching electrodes to the scalp. The electrodes are placed within the coordinates of the international 10 20 system of Jasper (1958, see Figure 2). The specific configuration of the electrodes depends upon the research question Typically this configuration includes some standard positions across the midline in addition to recording sites over those areas that are supposed to be active during the performance of a particular task (e g., in language research electrodes are often placed over the areas of Broca and Wernicke)[1]

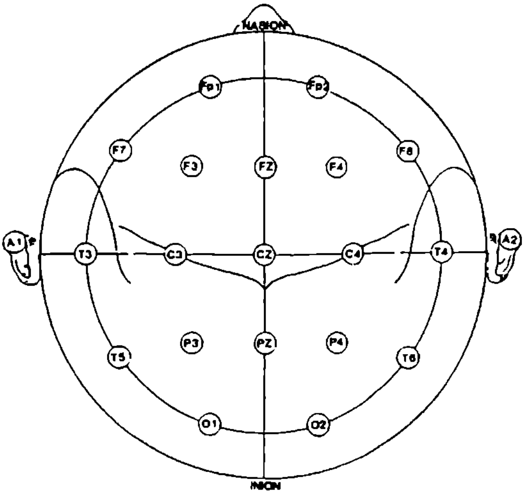

Figure 2 *The placement of the electrodes according to the 10-20 system (Jasper, 1958). Letters refer to the general area of the cortex F = frontal, C = central, P = parietal, O = occipital and T = temporal Odd numbers indicate the left side (e g., C3), even numbers indicated the right (e g , C4) and z indicates the midline position The distance between the electrode locations is always 10% or 20% of the distance between nasion (nose bridge) and inion (occipital bone) and the distance between the two ear lobes.*

The ERP measurement is differential, which means that we place the active electrode over the brain area of interest and subtract from it the activity of a passive, i e., electrically silent area, the so called reference electrode Most often the mastoids or the earlobes are chosen as references, because these are

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[1] *Note, however, that it is not possible to infer from the visual inspection of the distribution of the ERPs at the scalp where the underlying generators are localized Typically other brain imaging techniques with a higher spatial resolution (i e , Positron Emission Tomography, PET or functional Magnetic Resonance Imaging fMRI) are used to localize the brain areas involved in particular aspects of cognition*

considered to be little affected by the electrical brain activity Since eye movements seriously distort the EEG recording, it is necessary to record the vertical as well as horizontal eye movements during the experiments. Before analysing the ERP data, trials with ocular artefacts above a critical value (usually about 100 µV) as well as trials contaminated by other biological artifacts (e.g , muscular activity, large electro-cardiographic potentials, and changes in skin conductance) have to be rejected. The ERPs elicited by a stimulus consist of a series of positive and negative peaks that are typically labeled according to their polarity and latency measured from stimulus onset For instance, a P300 stands for a positive peak with a mean peak latency of 300 ms On occasion, the peaks are labeled by their polarity and ordinal position in the waveform (e g., N1, P1, N2)

A general distinction is made between exogenous and endogenous ERP components The exogenous components occur within less than 100 ms after the presentation of a stimulus and represent the obligatory brain response to the stimulus. The amplitude and the form of these early components is largely determined by physical parameters of the stimulus, such as intensity, duration and modality. In contrast, endogenous components, with latencies beyond 100 ms[4], are hardly affected by the physical stimulus parameters, but instead are mainly affected by psychological factors. Therefore, endogenous ERP components are not evoked by a stimulus as such but are elicited by the cognitive operations that are evoked by a particular stimulus. The same stimulus may or may not evoke a particular endogenous component depending upon how the subject "chooses" to process that stimulus.

The term ERP component here, does not refer to a "peak" or a "deflection" in the waveform, but refers to a theoretical entity as defined by Donchin, Ritter, and McCallum (1978), "A component is a set of potential changes that can be shown to be functionally related to an experimental variable or to a combination of experimental variables. A number of sources of such experimental variables can be employed in any given study Electrode site is one example The essential point is that a component can be assumed to exist only if it has been shown to vary systematically as a function of some such independent variable" (p. 353). According to these authors an endogenous ERP component has to meet the following criteria 1) it has to be a non obligatory brain response to a stimulus, therefore, the most stringent test for

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[4] *Note, that endogenous components with shorter latencies have also been reported For example, visual selective attention studies have shown that an attentional modulation of early ERP components (the P1 component) can already be observed within 70 to 100 ms after stimulus delivery (Mangun, Hillyard, & Luck, 1993)*

demonstrating the endogenous nature of an ERP component is to show that under appropriate conditions it can also be evoked by the absence of a stimulus (e.g., when a stimulus is expected but omitted), 2) its amplitude, latency and scalp distribution should be relatively invariant to physical stimulus changes, 3) it should be mainly affected by psychological factors.

In addition to this functional definition, endogenous ERP components have also been classified according to neurophysiological criteria. The neurophysiological approach is primarily based on the scalp distribution of an ERP component and is directed at localizing the neural tissue that is generating the component. In this thesis ERPs are used in the functional sense and topographical information is mainly used to identify a particular component and to distinguish it from other ERP components

As a heuristic for the reader I will provide two general guide-lines for interpreting ERP waveforms (see Kutas, 1993) First, differences in waveshape and/or scalp distribution between two or more conditions are usually interpreted as reflecting the activity of distinct neuronal populations subserving qualitatively different processes. Second, differences in amplitude and/or latency are usually interpreted as modulations in the activity of the same or related neuronal populations subserving processes that differ quantitatively .

ELECTROPHYSIOLOGICAL SIGNS OF PRIMING

Sentential context effects on the N400

Kutas and Hillyard (1980, 1982, 1983) assessed the effects of lexical-sentential context and expectancy on the processing of individual words with ERPs. ERPs were recorded to visually presented sentences, presented one word at a time, that ended in a semantically predictable or semantically incongruent way. Subjects were instructed to silently read the sentences, no additional task was given. The ERPs to the semantically incongruent endings (e.g., "He spread the warm bread with socks") showed a prominent negative shift that peaked at about 400 ms. This negative shift with a mean peak latency of about 400 ms has been referred to as the N400. In contrast, the ERPs in response to semantically congruent endings showed a late positive shift. Further studies have shown that the modulation in N400 amplitude as a function of semantic relatedness is not restricted to sentence final words but is also observed at intermediate positions in the sentence (Kutas & Hillyard, 1983). Subsequent research has indicated First, that the N400 is a reliable index of the degree of meaning relationship between the sentence and an open class word as it is systematically related to the predictability of the open class word, as a continuation of the sentence. More specifically, N400 amplitude is inversely related to cloze probability , i.e., the higher the cloze probability the smaller the N400. Second, N400 amplitude is reduced for words which are semantically related to the best completion but are not sensible completions in themselves (e.g., The picnic was ruined by the umbrella.) (Kutas & Hillyard, 1984, Kutas, Lindamood, & Hillyard, 1984). The latter finding is of particular importance, because it reveals that the N400 does not reflect the violation of a previously built up expectancy, but instead is affected by the degree to which the sentence fragment "prepared the way for the word which actually follows" (Kutas & Van Petten, 1994) In addition, this result shows that the N400 is sensitive to associations between single lexical items, and thus suggests that the N400 is also evoked in single-word contexts

Word context effects on the N400

Reliable modulations in N400 amplitude as a function of semantic relatedness are found when two semantically related words are embedded in a list (Bentin, McCarthy, & Wood, 1985, Rugg, Furda, & Lorist, 1988) or when they are presented as a word pair and subjects are instructed to perform a lexical decision or a category membership categorization task (e g., Boddy, 1986, Brown & Hagoort, 1993, Holcomb, 1988 and 1993, Kutas & Hillyard, 1989) The typical finding is that N400 amplitude to the target word is reduced when it is preceded by an associatively or semantically related word, than when it is preceded by an unrelated word. This difference in amplitude is referred to as the N400 priming effect. Moreover, N400 priming effects have also been reported in a silent reading task (Mitchell, Andrews, Fox, Catts, Ward, & McConaghy, 1991) as well as in tasks that do not require semantic processing (Kutas & Hillyard, 1989). In all these studies the latency, topography and the duration of the N400 effect was remarkably similar. The ERPs to unrelated target words were more negative between 200 and 500 ms poststimulus than the ERPs to related targets. The N400 effect started around 200 ms and reached its peak at about 400 ms. The N400 effect was broadly distributed across the scalp, but was maximal over centro-parietal sites and was typically larger over the right than the left hemisphere (e.g., Holcomb, 1988).[6]

All of the ERP priming studies cited above used written words, but similar N400 effects have been observed when words are presented either auditorily

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[5] *The amount of contextual constraint imposed by a sentence fragment can be assessed by means of a cloze probability test The cloze probability refers to the proportion of subjects that fill in a particular word as the best completion of a sentence fragment (cf Taylor, 1953)*

(e.g., Anderson & Holcomb, 1995, Bentin, Kutas & Hillyard, 1993, Holcomb & Neville, 1990) or cross-modally (Holcomb & Anderson, 1993).

The N400 as a measure of semantic priming

The reliability with which N400 amplitude is modulated by semantic relations has made it possible to tentatively use it as a new measure for semantic priming. In the remaining of this chapter I will focus on those ERP findings that are directly relevant for the central issue of this thesis, that is the contribution of automatic versus controlled processes to the N400 priming effect The experimental manipulations used to determine the processing nature of the N400 mirrored those used in behavioral studies and have included manipulations of the following variables (1) stimulus materials, (2) stimulus onset asynchrony between the prime and target, (3) forward and backward masking of the prime, and (4) attentional manipulations. What follows is a review of what has been found with each of these types of manipulations Note that although in most of the ERP studies reaction time data were gathered, I will only report these data in cases when a dissociation between the two measures was observed.

Ad (1) Stimulus materials Two ERP studies investigated the effects of the proportion of related to unrelated word pairs in the lexical decision task (Holcomb 1988, Koyama, Nageishi, & Shimokochi, 1992). Holcomb (1988) found that increasing the number of related word pairs from 12.5% to 50% (with an SOA of 850 ms) was accompanied by an increase in the size of the N400 priming effect, assessed as the difference in N400 amplitude between related word pairs and a neutral priming condition in which a blank was followed by the target word.

Somewhat different results were reported by Koyama et al. (1992) who assessed the effects of relatedness proportion (.25 versus .75) in Japanese. Although in the high proportion list N400 amplitude was larger to unrelated word pairs compared to the related and the neutral pairs, no difference in N400 amplitude was observed between the latter two conditions. The results of Koyama et al , however, are inconclusive, due to a confounding of the ERP

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[6] *Note that a right hemisphere preponderance does not imply that the N400 generator is localized in the right hemisphere The reason for this is that the distribution over the scalp is not only determined by the location of the neurons but also by the orientation of neural current flow*

[7] *Since this thesis is primarily concerned with the link of the N400 to semantic processing, the review does not include studies of phonological processes (e g , Rugg, 1985, Kramer & Donchin, 1987, Praamstra & Stegeman, 1993) and repetition priming (e g , Besson & Kutas, 1993 Rugg, 1985, 1987)*

effects of semantic priming with those of stimulus repetition In this study the same primes were repeated within and across conditions The prime repetition across all three priming conditions, in combination with the use of a long SOA of 1500 ms, could have led to processing strategies that were absent in Holcomb's study. The repetition of the same words in the unrelated and the related condition might also explain why Koyama et al., in contrast to the Holcomb study, did not obtain an N400 priming effect when the proportion of related word pairs was low.

The results of Holcomb are in agreement with reaction time studies (e.g., Shelton & Martin, 1992, Tweedy, Lapinski, & Schvaneveldt, 1977) that showed greater semantic priming with a high than with a low proportion condition

Ad (2) Stimulus onset asynchrony Boddy (1986) assessed the effects of SOA on the N400 priming effect in a visual lexical decision task. N400 priming effects were obtained at SOAs of 200, 600 and 1000 ms, but no modulation as a function of SOA was found However, due to the analysis procedure used, this result was called into question In particular, Boddy subtracted the ERPs of the long SOA from the ERPs of the short SOA This subtraction procedure is problematic because in the short SOA the prime and the target processing overlaps in time, although the use of the subtraction procedure presupposes that the associated ERP effects are independent from each other. Moreover, Boddy's results are inconsistent with sentence data showing that the N400 effect is generally delayed in onset at short SOAs relative to long ones (see Kutas, 1987)

Recently, Anderson and Holcomb (1995) examined the time course of semantic priming effects in a lexical decison task in both the visual and the auditory modality. The SOA manipulation yielded different N400 priming patterns for the two modalities In the visual modality an N400 priming effect of comparable size was observed at short and long SOAs (0, 200 and 800 ms) However, the waveshape of the N400 and the time course of the effect differed between SOAs In the 0 SOA condition the N400 effect at several electrodes started later and was more temporally extended lasting into the 500 800 ms epoch [6] In contrast, in the auditory modality reliable N400 priming effects were only obtained at the long SOA of 800 ms. Reaction time analyses yielded a different pattern of results Although in the visual modality a priming effect was found at each of the SOAs, the priming effect was modulated by SOA In particular, the reaction time priming effect was larger in the 0 SOA condition (53 ms) compared to the longer SOA conditions and the effect steadily decreased with increasing interval. In the auditory modality an increase in reaction time priming effect from 18 to 142 ms was observed with an increase in SOA, with significant effects for the SOA of 200 and 800 ms.

The demonstration of N400 priming effects for written words at short intervals, especially at an SOA of 0 ms, suggests that the N400 effect is affected by automatic aspects of priming. The results for the auditory modality are less clear and an interpretation will have to await further ERP studies in the auditory domain. One possible explanation for the observed differences in N400 priming patterns between modalities is that they reflect differences in the word recognition processes between written and spoken words, namely that spoken words unfold over time and that in contrast to written words the sensory information is not immediately available, but accumulates over time.

Ad (3) Forward and backward masking Strong support for the contribution of automatic processes to the reaction time priming effect comes from subliminal priming studies in which priming effects have been reported despite the fact that subjects were not able to perceptually identify the prime (e.g., Marcel 1983).

To date, there are two ERP studies that investigated the effects of semantic priming in a lexical decision task when the prime word was masked to a level which precluded better than chance performance in a forced choice identification test (Brown & Hagoort, 1993, Neville, Pratarelli, & Forster, 1989). Brown and Hagoort (1993) obtained an N400 priming effect under full viewing but not under masked conditions when the prime was flashed for 40 ms and was forward and backward masked for 200 ms by a row of hashmarks. In contrast, for reaction time a small but significant reaction time priming effect was found under the same masking conditions. On the other hand, Neville et al. observed a small semantic priming ERP effect even with the prime masked. However, as this ERP effect was earlier (between 100-200 ms) and more frontally distributed than the typical N400 effect it is unclear whether both effects are functionally related or not. To settle this issue further investigations of ERP priming effects under masking are needed.

Ad (4) Attentional manipulations Recently, the effect of visual and auditory selective attention has been assessed on the N400 priming effect. McCarthy and Nobre (1993) presented a list including semantically related words in a visual spatial selective attention task. The task of the subject was to detect

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[8] *Note, that in the 0 SOA condition an early frontally distributed effect of relatedness (150 330 ms) as well as a late effect of relatedness (550 800 ms) were observed At present, it is not clear whether these effects are reliable, and if so, what their functional significance might be*

members of a specified semantic category in the attended location. They observed an N400 priming effect only for target words in an attended spatial location (one visual field) and not in an unattended location (the other visual field) However, there are two methodological points that might be criticized. First, McCarthy and Nobre used vertically presented words and the question remains whether the same effects would have been observed under more natural reading conditions. Second, the visual angle between the words and the fixation point was quite large (about 5) Therefore, the impact of selective attention might depend upon a large spatial separation between the attended and unattended locations. The ERP results of Gunter, Jackson, Kutas, Mulder and Buijink (1994) and Otten, Rugg and Doyle (1993) indeed suggest, that under certain circumstances unattended words receive further processing when the visual angle is small (less than 1).

Bentin, Kutas, and Hillyard (1995) investigated the effects of selective attention on the N400 priming effect in a dichotic listening task. They presented different lists of words dichotically and instructed their subjects to memorize the words presented to one ear while ignoring the words presented to the opposite ear. Selective attention effects were measured by comparing the brain response to the second word of semantically related versus unrelated word pairs in the attended and the unattended channel. The semantic priming effect on ERPs was clearly affected by attention. An N400 priming effect was found in the attended channel, but not in the unattended channel.

Less severe attentional manipulations such as the use of a task which does not require processing the semantic relation of word pairs have been used by a number of investigators. The results of these studies were mixed. In some of these studies an N400 effect was observed For example, Kutas and Hillyard (1989) found an N400 priming effect in a delayed letter search task, in which a single letter was presented 1200 ms after a word pair and subjects had to indicate whether the letter had been present in either or both of the words. N400 amplitude to the target words was modulated by the semantic relationship, although the task did not require semantic processing. Likewise, Besson, Fischler, Boaz and Raney (1992) observed a small but reliable N400 priming effect in a graphemic task, in which subjects had to indicate whether the first and the last letter of two words that were presented with an SOA of 300 ms were the same or different In a similar vein, Mitchell et al (1991) obtained an N400 priming effect when a sentence fragment was followed by a congruent or incongruent word pair and subjects had to indicate whether the word pair consisted of the same or different words. In all three studies the N400 priming effect was significant but smaller than when the task directs attention to the semantic relationship (Kutas & Van Petten, 1988, Mitchell et al 1991).

Other studies, however, did not observe N400 priming effects in shallow processing tasks (Bentin et al 1993, Deacon, Breton, Ritter, & Vaughan, 1991) Deacon et al (1991) presented lists that either included semantic associates or words that differed in size, or a combination of both Subjects performed a semantic categorization task or a size discrimination task The results showed that an N400 priming effect was only obtained when changes in semantic category were task relevant.

Similar results were obtained by Bentin et al (1993) who presented two lists of words monaurally through headphones The lists included semantically related pairs of words and/or filler words or pronounceable nonwords separated by an SOA of 1750 ms In one task subjects had to memorize the words in anticipation of a recognition test The other task was a variant of the lexical decision task in which subjects were asked to silently count the number of nonwords An effect of semantic relatedness on the N400 was found in the memorize task, but not in the count nonword task

Taken together, the results of the ERP studies that assessed the effects of task demands on the N400 accord well with the behavioral literature, showing that semantic priming effects are much larger for tasks that impose a deeper level of processing than for tasks for which a more shallow level suffices (e g , Smith, Theodor & Franklin 1983)

What do these results reveal about the processing nature of the N400 priming effect? In the first place, the results suggest that the N400 priming effect is affected by controlled processes This notion is supported by the following findings (a) the increase in N400 effect with relatedness proportion (b) the presence of an N400 effect at long SOAs and (c) the reduction in N400 effect in shallow processing tasks In the second place, the results also seem to point to an automatic component in the N400 effect The following observations have been taken as evidence for this notion (a) the presence of an N400 effect in a list with a low proportion of related word pairs, (b) the presence of N400 effects for written words at an SOA of 0 ms, and (c) the demonstration of N400 effects in shallow processing tasks. Taken together, the results seem to suggest that the N400 priming effect is modulated by both controlled and automatic processes While there is a general consensus that the N400 effect is affected by controlled processes, its sensitivity to automatic lexical processes is more controversial The reason for this is that although some of the results suggest a role of automatic processes in producing N400 priming effects, other data (e g , the absence of an N400 effect in masked priming studies) seem to indicate the opposite, namely that automatic processes most likely do not contribute to the N400 effect. The goal of this dissertation was to settle the issue of the processing nature of the N400 by investigating whether the N400 effect is mainly a reflection of the automatic process of lexical access or of the more controlled lexical integration process.

An intriguing aspect about the reviewed data is that they include two examples of dissociations between the N400 and reaction time. Although for a large part the N400 results are similar to the reaction time results, both measures are differentially affected by SOA and masking. These dissociations suggest that the N400 and reaction time index somewhat different processes.

AIMS OF THE THESIS

From the review of the current ERP literature it is clear that it is still an open issue whether the N400 effect mainly reflects automatic or controlled processes. Given the relevance of this issue for the possible applications of the ERP method to psycholinguistic research, this thesis attempts to further pinpoint the lexical processing nature of the N400 effect. This was accomplished by conducting a series of experiments that (from different angles) were aimed at separating the effects of the automatic process of lexical access from those of the more controlled lexical integration process. As illustrated above a well-defined testing ground within psycholinguistics for clarifying this issue is that of semantic priming. In accordance with the model of Neely and Keefe (1989) it is proposed that three priming mechanisms contribute to the semantic priming effect. In this thesis it is assumed that two of these mechanisms share basic features with mechanisms involved in ordinary language processing. In the first place, automatic spreading of activation shares basic features with the process of lexical access. In the second place, we assume that semantic matching shares basic features with the process of lexical integration (cf De Groot, 1984, Henderson, 1982, Neely, 1991). Insight in the contribution of these different mechanisms to the N400 semantic priming effect will therefore be of substantial value in relating the N400 to the processes of lexical access and lexical integration

In most of the experiments a lexical decision task was used. Discussions about task effects in the literature suggest that the naming task would be the preferred task for assessing the effects of ASA (Balota & Chumbley, 1984). However, recent studies demonstrate that purely automatic priming effects can be obtained in lexical decision (McNamara & Altarriba, 1988, Shelton &

Martin, 1992), and even suggest that the naming task may underestimate the size of automatic priming effects (Perfetti, Bell, Delaney, 1988) The reason for using an additional task was that this allowed a direct comparison of the N400 results with the reaction time results

In the other experiments a silent reading task was used, a task that par excellence allows an investigation of the processes involved in ordinary language comprehension without effects of additional, specific task-dependent processes.

Structure of the thesis

In the next four chapters the descriptions and discussions of the different experiments are presented. Each chapter is written in such a way that it can be read independently from the other chapters. An unavoidable consequence of this structure is that some overlap exists between the introduction and the method sections. In the following paragraphs I will sketch the rationale underlying each of these chapters.

Chapter two investigates the effects of the level of processing on the N400 priming effect. N400 effects in shallow processing tasks have been taken as evidence that the N400 effect is sensitive to automatic lexical processes An alternative explanation for these N400 priming effects is that they reflect controlled forms of lexical processing This chapter addresses this issue by assessing whether N400 priming effects occur when the task performance does not involve lexical processing. This chapter has been published in Psychophysiology (Chwilla, Brown, & Hagoort, 1995).

Chapter three investigates the lexical processing nature of the N400 by assessing the effects of relatedness proportion on the N400 effect. The task-dependent nature of the relatedness proportion effect was determined, by comparing the N400 priming effects in a lexical decision task with those in a silent reading task The argument is, that if relatedness proportion effects form part of normal language comprehension processes, then a proportion effect should be obtained in a silent reading task If, however, the effect is restricted to the task requirements in the lexical decision task then the impact of such priming effects for functional models of lexical processing is rather limited Parts of the data have been reported at the 1991 Annual Meeting of the Society for Psychophysiological Research (Chwilla, Brown, & Hagoort, 1991).

Chapter four attempts to determine which of the three priming mechanisms is responsible for the effects of backward priming (i e., a facilitation in performance due to a unidirectional relationship from the target to the prime). The effects of ASA and semantic matching are separated by comparing the effects of backward priming on the N400 and reaction time The effects of ASA and expectancy induced priming are distinguished by manipulating the inter stimulus interval between prime and target. This chapter has been submitted for publication (Chwilla, Hagoort, & Brown, 1995) Parts of the data have been reported at the 1992 Annual Meeting of the Society for Psychophysiological Reseach (Chwilla, Brown, & Hagoort, 1992)

Chapter five tests the sensitivity of the N400 effect to the lexical access and/or integration function by investigating whether it reflects effects of multiple activation. The framework was provided by the model of Marslen Wilson (1987), according to which presentation of a partial auditory prime activates a word-initial cohort, containing all word forms that are compatible with the sensory information. Auditory word fragments were presented as prime, the length of which was varied with respect to the word recognition point (before/after the recognition point) Effects of multiple activation were assessed by pairing a partial prime with a visual target word that was either (i) related to the auditory word from which the prime was derived, (ii) was related to one of the "competitors" (i e., words that share the initial sensory information), or (iii) was unrelated to the prime. If the N400 reflects lexical access, then its amplitude before the recognition point should be reduced for the actual word and the competitor, compared with the unrelated word The ERP data presented in this chapter have been presented at the 1994 Annual Meeting of the Society for Psychophysiological Research (Chwilla, Hagoort, & Brown, 1994)

Finally, chapter six provides a summary of the main results of the experimental chapters and a general discussion. The focus of the general discussion will be on the consequences of the experimental results for the lexical processing nature of the N400 priming effect It will be argued that the results of this research programme support the notion that the N400 effect mainly reflects lexical integration processes Alternative views will be discussed

CHAPTER II

The N400 as a function of the level of processing

ABSTRACT

In a semantic priming paradigm, the effects of different levels of processing on the N400 were assessed by changing the task demands In the lexical decision task, subjects had to discriminate between words and nonwords, and in the physical task, subjects had to discriminate between uppercase and lowercase letters The proportion of related versus unrelated wordpairs differed between conditions A lexicality test on reaction times demonstrated that the physical task was performed nonlexically Moreover, a semantic priming reaction time effect was obtained only in the lexical decision task The level of processing clearly affected the event related potentials An N400 priming effect was only observed in the lexical decision task In contrast, in the physical task a P300 effect was observed for either related or unrelated targets, depending on their frequency of occurrence Taken together, the results indicate that an N400 priming effect is only evoked when the task performance induces the semantic aspects of words to become part of an episodic trace of the stimulus event

INTRODUCTION

In this study, we investigated the influence of task demands on the N400 semantic priming effect. In particular, we focused on the impact on the N400 of different levels of processing of lexical stimuli. In this report, we first discuss the relevant semantic priming effects and the mechanisms responsible for these priming effects then we introduce the levels of processing framework within which semantic priming effects were investigated.

One of the most consistent findings in the psycholinguistic literature is that words are processed faster and more accurately when they are preceded by a semantically related or associated word than by an unrelated word (e.g., Meyer & Schvaneveldt, 1971, see Neely, 1991, for a review) More recently, it has been demonstrated that semantic priming effects can also be recorded with the use of the event-related brain potential (ERP) method. Kutas and Hillyard (1980, 1984) identified an ERP component, the N400, a negative peak with a mean latency of 400 ms and a centroparietal distribution, that is larger in amplitude for words that are semantically incongruent with a preceding sentence context. Subsequent research has shown that the N400 is tied more to semantic expectancy than to anomaly (e g , Kutas, Lindamood, & Hillyard, 1984)

A modulation in N400 amplitude as a function of semantic context is not only obtained in sentences but also when a single word provides the context (see Kutas & Van Petten, 1988, for a review). If a target word is preceded by a semantically related prime, it elicits a smaller N400 than when it is preceded by a semantically unrelated word (e.g , Bentin, McCarthy, & Woods, 1985, Holcomb, 1988, Holcomb & Neville, 1990, Kutas & Hillyard, 1989). This difference in amplitude is referred to as the N400 priming effect. Because of the sensitivity of this ERP component to language processes, the N400 has been used as a new measure for psycholinguistic research (Kutas & Van Petten, 1988). It is by now well established that the amplitude of the N400 varies as a function of the degree to which the eliciting word relates to its preceding semantic context. On the basis of the literature, however, it is less clear which processing aspects of the language comprehension system are reflected in the N400.

In functional models of word recognition (e.g , Frauenfelder & Tyler, 1987, Marslen Wilson, 1989, Zwitserlood, 1989) three processes are commonly distinguished lexical access, selection, and integration. Lexical access involves the process of computing a form representation of the physical signal and of mapping this representation onto corresponding entries in the mental lexicon. This processing results in the activation of a subset of lexical elements and their semantic and syntactic attributes. The process of selection refers to the process of selecting from the subset of accessed elements the element that best matches the input available to the system. Integration refers to the process of integrating a lexical element into a higher order meaning representation of the entire sentence or discourse.

Within this functional model of word recognition, lexical access is conceived of as a reflexlike automatic process In contrast, lexical integration is thought of as a more controlled process that can be guided by the subject's awareness of the informational content of the discourse and that requires more processing resources than lexical access. However, at the same time lexical integration is a mandatory process (Fodor, 1983), in normal discourses, subjects of necessity engage in the integration of individual word meanings into message level representations.

To assess the value of the N400 as a measure for psycholinguistic research, how the N400 relates to these different lexical processes must be clarified. A well defined testing ground within psycholinguistics for clarifying this issue is that of semantic priming (cf. Neely, 1991). From the vast amount of reaction time semantic priming studies, a fairly well developed picture has emerged of the mechanisms responsible for priming effects. According to Neely and Keefe (1989), at least three mechanisms are needed to account for the full spectrum of reaction time priming effects

The first mechanism is automatic spreading of activation (ASA, Collins & Loftus, 1975). ASA assumes that in semantic memory strong or direct links exist between words that are closely related in meaning. Presentation of a word activates the corresponding node of this word in semantic memory, and via the links to nearby nodes part of this activation automatically spreads to words that are related in meaning. As a consequence, the activated nodes representing related words need less time for subsequent processing. ASA has all the characteristics of an automatic process It is fast-acting, of short duration, does not require attention or awareness, and presupposes no or only minimal resource capacity

The second mechanism is expectancy-induced priming (Becker, 1985, Posner & Snyder, 1975). This is a predictive strategy in which the subject uses the information provided by the prime to generate an expectancy set for related target words If the target is included in this set, it will be recognized more quickly If it is not, the recognition for the target word will be slowed down. This mechanism can be influenced by instructions as well as by the list structure of the material. Especially when the stimulus list contains a large proportion of related wordpairs, the probability that the expectancy mechanism contributes to the overall priming effect is large (Keefe & Neely, 1990)

The third priming mechanism is semantic matching (De Groot, 1984, Neely & Keefe, 1989). If letter strings are processed lexically, subjects are assumed to mandatorily match primes and targets postlexically (i e., following lexical access and selection) for semantic similarity. In a lexical decision task, the word/nonword decision is influenced by the result of this matching process. The detection of a relationship between primes and targets leads to a bias to respond 'Yes'. If no such relation is detected, then there is a bias to respond 'No'.

In summary, three mechanisms are supposed to underly semantic priming The assumption is that two of these mechanisms share core characteristics with mechanisms involved in ordinary language processing. That is, ASA shares core characteristics with lexical access, and semantic matching shares core characteristics with postlexical integration processes (De Groot, 1984, Henderson, 1982, Neely, 1991). Insight into the contribution of these different mechanisms to the N400 semantic priming effect will therefore be of substantial value in relating the N400 to the processes of access, selection, and integration The aim of the present study was to separate the contribution of these priming mechanisms to the N400 effect in the semantic priming paradigm. In particular, we attempted to separate the effects of ASA from the effects of semantic matching by varying the level of processing.

The levels of processing framework as described by Craik and Lockhart (1972) have often been used to investigate episodic memory. This literature has consistently demonstrated a better recognition and recall for words that have to be processed on the basis of semantic features (a deep level of processing) than for words that have to be processed on the basis of visual or phonemic features (a shallow level of processing, see, for example, Jacoby & Dallas, 1981) The basic idea is that shallow processing of the word stimuli discourages analysis of their semantic aspects. As a result, the semantic context might not be incorporated in the formation of the episodic trace of the stimulus event. If semantic priming effects are nevertheless obtained, they probably result from automatic activation spreading within semantic memory. Consequently, semantic priming effects obtained in a shallow task most likely arise from ASA. In contrast, deeper processing presumably involves the processing of the semantic aspects of the presented words. In this case, the semantic context does exert its influence on the formation of the episodic trace Because both expectancy induced priming and semantic matching presuppose the formation of an episodic trace for a particular wordlike stimulus event, priming effects obtained in a situation that is compatible with deeper levels of processing might, therefore, also reflect the effects of these additional priming mechanisms.

In contrast to the popularity of the levels of processing framework within memory research, there are only a few psycholinguistic studies that have assessed the effects of the level of processing on semantic priming. In these studies the effect of the level of processing was assessed by manipulating the nature of the information (e.g., orthographic, semantic) required to accurately make a lexical decision on target letter strings. This manipulation was done in two ways (a) by varying the kind of nonwords that were presented as targets (De Groot, 1987, Schulman & Davison, 1977), or (b) by varying the kind of discrimination required on the prime word (Smith, Theodor, & Franklin, 1983) or the target word (De Groot, 1987). Taken together, the results of these studies reveal that the semantic priming effect is much larger for tasks that impose a deeper level of processing than for tasks for which a more shallow level suffices Although the size of the reaction-time priming effects depends on the depth of processing, significant priming effects have also been reported with shallow processing tasks. Smith et al. (1983) obtained a priming effect when a phonemic analysis was performed on the prime. Mitchell, Andrews, Fox, Catts, Ward, & McConaghy (1991) found a reaction time priming effect in a task in which subjects had to discriminate words on the basis of physical features. These findings demonstrate that the use of shallow processing tasks in itself does not necessarily exclude the processing of a word's semantic aspects

The levels of processing approach has also been used to determine the processing nature of the N400. The results of these ERP studies were not conclusive. Some studies demonstrated N400 priming effects with shallow processing tasks (Besson, Fischler, Boaz, & Raney, 1992, Kutas & Hillyard, 1989). Other studies, however, did not observe N400 priming effects under shallow processing conditions (Bentin, Kutas, & Hillyard, 1993, Deacon, Breton, Ritter, & Vaughan, 1991). The fact that in some studies N400 priming effects have been obtained in shallow processing tasks has been taken as evidence that the N400 is sensitive to automatic lexical semantic processes (Kutas & Van Petten, 1988). However, this conclusion critically depends on the claim that the N400 priming effects obtained in these shallow processing tasks cannot be attributed to priming mechanisms other than ASA. To examine this issue these studies will be described in more detail

Kutas and Hillyard (1989) obtained an N400 priming effect in a letter search task. In this task, the first word was followed after a stimulus onset asynchrony (SOA) of 700 ms by the second word, which in turn was followed after 1,200 ms by a single letter. Subjects had to indicate whether the letter had been present in either or both of the words In response to the second word, an N400 priming effect was observed Although Kutas and Hillyard (1989) correctly assumed that performing this task does not require semantic processing, subjects may still have matched the words for semantic similarity The delay between the presentation of the words and the moment subjects were asked to respond might have given subjects ample opportunity to in fact perform some kind of semantic matching, in which case the observed N400 priming effect does not necessarily stem from ASA A similar argument holds for the study of Besson et al (1992), in which subjects had to indicate whether the first and the last letter of two words that were presented with an SOA of 300 ms were the same or different In this task, a small (<1 µV) but reliable N400 priming effect was observed The authors attributed this small N400 priming effect to automatic lexical semantic processing However, because the subjects were also required to perform memory tests on the stimuli, paying attention to word meanings was probably reinforced by the design

The contrasting results of various studies testing the effects of depth of processing on the N400 and the N400 priming effects obtained with shallow levels of processing in some studies might reflect the fact that the shallow task did not in all cases effectively prevent the occurrence of semantic matching Alternatively, these shallow N400 priming effects might result from ASA To decide between these two possibilities, more objective criteria are needed to ascertain whether the performance of a particular task involves lexical processing One objective method is computation of the lexicality effect, that is, the difference in overall reaction times between all word and all nonword targets In general, words are responded to faster than nonwords In models of word recognition, lexicality effects are attributed to operations at a lexical level of processing (cf De Groot, 1987)

The aim of the present study was to separate the effects of ASA from the effects of semantic matching on the N400 priming effect by varying the level of processing It is assumed that N400 priming effects for tasks that are compatible with deeper levels of processing are mediated by ASA and by semantic matching In contrast, N400 priming effects for shallow processing tasks were assumed to exclusively reflect ASA To control for task related levels of processing, we established whether or not the task performance depended on lexical characteristics of the presented letter strings If the task were performed nonlexically, that would suggest that indeed the task discourages semantic analysis If N400 semantic priming effects were obtained in the absence of a reaction time lexicality effect, then this N400 effect would most likely be due to automatic spread of activation in semantic memory

In the current study, the effects of the level of processing on the reaction time and the N400 measure was assessed by comparing the processing of the same words and nonwords in a lexical decision task and a physical task. The choice of the tasks was based on previous studies that demonstrated differences in ERPs between a lexical decision and a physical task. In these studies a clear reduction in the size of repetition priming (Rugg, Furda, & Lorist, 1988), and semantic priming effects (Mitchell et al., 1991) was observed for the physical task, which required subjects to respond on the basis of certain physical aspects of the letter strings. Therefore, it was assumed that the level of processing for the two tasks is different A visual word priming paradigm was used, in which a prime word was followed after 700 ms by a target word. The level of processing was manipulated by varying the target discrimination between tasks. In the lexical decision task, the target discrimination was based on a word/nonword discrimination. In the physical task, the target discrimination was based on purely physical features (letter case), which does not require lexical processing. The use of the lexical decision task does not necessarily guarantee access to word meaning, because this task could be performed solely on the basis of the word form. However, there is ample evidence from the semantic priming literature that normally this task yields semantic priming effects. Therefore, it is reasonable to assume that the lexical decision task is compatible with semantic analysis, whereas the physical task discourages semantic analysis, because paying attention to the relationship between the words does not help to perform the letter case discrimination.

To test whether the physical task is indeed performed nonlexically, the lexicality effect was assessed If lexical processing were involved in the task performance, the processing of words would be faster than the processing of nonwords.[1] If, however, a task were performed nonlexically, the reaction times to word targets would not be different from the reaction times to nonword targets. In the absence of a reaction time difference between words and nonwords, we can address the question of whether an N400 priming effect occurs when the task performance does not involve lexical processing The absence of a lexicality reaction time effect does not necessarily imply that semantic aspects of the stimuli go unnoticed at all levels of the processing system. Whether or not these aspects are processed to some degree must be inferred from the ERP waveform If the ERP data allow us to infer that semantic

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[1] *Although it is an extremely robust finding that words are processed faster than nonwords, there are a few exceptions to this rule For example, words take longer to process when very low frequency words are used or if subjects are asked to classify items according to whether they have more than one meaning (see Forster & Bednall, 1976)*

processing has gone on at some level in the language system, then we can use the presence or absence of N400 effects to make claims about the priming mechanisms that the N400 is particularly sensitive to Assuming that we can ensure that the physical task is performed nonlexically, the following predictions can be made. If the N400 priming effect is mediated by semantic matching and expectancy but not by ASA, we expect an N400 priming effect in the lexical decision task but no effect in the physical task. In contrast, if the N400 effect also reflects ASA, an N400 priming effect should additionally be obtained in the physical task. An N400 priming effect in the physical task would imply that N400 priming effects occur relatively automatically, that is, that they are independent of the task demands.

In addition to the task manipulation, we also varied the proportion of related word pairs in the stimulus list. The proportion of related word pairs determines the probability that subjects use the prime to generate an expectancy about the target (Keefe & Neely, 1990). The generation of this expectancy requires access to the semantic aspects of the prime Contrasting the effects for a list with a small number of related word pairs with those for a list with a large number of related word pairs under both task conditions further allows us to determine whether or not semantic factors leak through under the shallow processing task conditions

METHOD

Subjects

Thirty-six right-handed subjects, 20 women and 16 men (mean age=24 years) participated in the experiment. Hand dominance was assessed with an abridged Dutch version of the Edinburgh Inventory (Oldfield, 1971). Seven subjects reported left handedness in their immediate family. All were native speakers of Dutch and had normal or corrected-to-normal vision. They were paid DFL 10/hr.

Apparatus and stimuli

Subjects were seated in a comfortable reclining chair in a dimly illuminated, sound attenuating, and electrically shielded chamber. The response device containing two push buttons was fixed on a small table in front of the subjects The stimuli consisted of 960 visually presented pairs of letterstrings (prime and target combinations). Half of the target stimuli were real Dutch words and the other half were nonwords. The nonwords were constructed in accordance with the phonotactic constraints of Dutch and were derived from real words by substituting one or two letters. The word targets were preceded by a related or by an unrelated prime (e.g., BLACK-WHITE vs SOAP-BIRD). A pair was considered related if the target appeared as the highest word association to the prime in Dutch word-association norms (De Groot, 1980, De Groot & de Bil, 1987, Lauteslager, Schaap, & Schievels, 1986). Associative strength was determined by the percentage of occurrence of the target as an associate of the prime among 100 university students. The mean percentage of association between the prime and the target for the related pairs was 47.41% (SD=15.30%). A pair was considered unrelated if the target neither occurred as a word association of the prime in these norms nor had any other obvious semantic relation to the prime. Strings of three to eight letters were presented as targets. Across conditions, targets were balanced on mean word frequency (Uit den Boogaart, 1975, corpus size 720,000), word class (nouns, adjectives, verbs), and the number of letters and syllables. There was a total of 160 related and 160 unrelated word pairs.

A pilot study was conducted to select a subset of target words from the related and unrelated wordpairs that are matched on the basis of reaction times. In this pilot study, word and nonword targets were presented in isolation. Subjects (n=20) performed a speeded lexical decison task. They had to indicate as fast as possible whether the target word was a real word or not. On the basis of these reaction times, 40 related and 40 unrelated wordpairs were selected. These pairs are referred to as the critical pairs. (The Appendix gives all critical pairs and the mean reaction time and language frequency of the targets.) The mean reaction time for both the critical related and unrelated targets was 506 ms (SD=27.6 and 28.0 ms for related and unrelated targets, respectively).

Two lists of 480 prime-target pairs were constructed. One list had a high proportion of related word pairs (.80). The other list had a low proportion of related word pairs (.20).[2] The 40 critical related and 40 critical unrelated word pairs were the same in both lists. In the high-proportion list, the critical word pairs were supplemented by 120 related word pairs and in the low proportion list by 120 unrelated word pairs. Two hundred prime-target pairs with a nonword target were added to each list. Additionally, in each list 80 prime-target pairs were included with the Dutch word BLANK as a prime, half of these were followed by a real word and the other half were followed by a nonword. These pairs were used as fillers in this experiment.

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[2] *The relatedness proportion in psycholinguistic studies does not refer to the overall probability but is defined as the ratio of related and unrelated word pairs within a list (cf. Neely, 1991).*

In the lexical decision task primes and targets were presented in uppercase letters In the physical task, primes were in uppercase letters, whereas half of the word and nonword targets were presented in lowercase and the other half in uppercase letters. All critical targets were presented in uppercase letters The stimuli were presented at moderate contrast at the center of a PC monitor (window of 8 x 2 cm, white on black). The stimuli subtended a visual angle of approximately 3 x 0.8 .

The electroencephalogram (EEG) was recorded with Ag/AgCl (d=9mm) electrodes monopolarly from three midline positions (Fz, Cz, Pz), and two pairs of lateral electrodes. Symmetrical anterior temporal electrodes were placed halfway between F7 and T3, and F8 and T4 sites, respectively Symmetrical posterior temporal electrodes were placed lateral (by 30 % of the interaural distance) and 12.5 % posterior to the vertex The left mastoid served as reference Electrode impedance was less than 3 kOhms. The electro oculogram (EOG) was recorded bipolarly using four Ag/AgCl (d=6mm) electrodes The vertical EOG was recorded by placing an electrode above and below the right eye The horizontal EOG was recorded via a right-to left canthal montage EEG and EOG signals were amplified by Nihon Kohden amplifiers (type AB-601G, time constant=8s, low-pass filter= 3 dB cutoff at 30 Hz). A calibration pulse (peak-peak amplitude 2 mV, duration 1 s) was recorded before each session All physiological signals were digitized on line with a sampling frequency of 200 Hz using a 12 bit A/D converter. Control of the presentation of stimuli and recording of performance data were accomplished by a Miro GD laboratory computer

Procedure

Subjects were randomly assigned to task (lexical decision or physical) and list (high proportion or low proportion) Nine subjects were tested in each of the four task/list combinations. Subjects were told that pairs of letter strings would be presented in rapid succession The first word (the prime) was followed after an SOA of 700 ms by a second word (the target) The stimulus duration was 200 ms and the intertrial interval between the offset of the second word and the onset of the first word was 3.2 s Subjects were asked to pay attention to the second word, the target stimulus The kind of target discrimination varied as a function of the task.

In the lexical decision task, subjects had to decide whether the target stimulus was a Dutch word or not. If the target was a word, they had to press the response button on the right side, if not, they had to press the button on the left. They were asked to respond as fast as possible but to remain accurate.

In the physical task, subjects were asked to decide whether the target stimulus was written in upper- or lowercase. If the target appeared in uppercase they had to press the button on the right side, if the target appeared in lower case they had to press the button on the left side. Subjects were asked to respond as quickly as possible.

In both tasks, subjects gave right-hand (right button press) and left-hand (left button press) responses. To facilitate fast responses and avoid motor artifacts, subjects were asked to keep their index fingers on the response keys. Subjects were not informed about differences in relatedness between the different types of word pairs. The stimuli were presented in two blocks of 240 trials each (mean duration=16 min). There was an interval of 5 min between blocks. A short training session in which the proportion of related word pairs was .50 preceded the experimental session Subjects were trained to speed up reaction time (< 1 s) and to control their eye movements. They were trained to make eye movements approximately 1 s after the button press and to fixate on the center of the screen in anticipation of the prime-target pairs

Data-analysis

EEG and EOG records were examined for artifacts and for excessive EOG amplitude during the epoch from 150 ms preceding the prime to 1 s after the onset of the target. Only trials in which the EOG amplitude did not exceed 100 µV and in which no other artifacts were present were used for averaging. ERPs were averaged time locked to the target, relative to a 100-ms pre-target baseline

The window for scoring ERP components was based upon visual analysis and depended upon the time interval in which maximal differences between conditions were obtained. The following measures were obtained for each derivation N400 (average amplitude in the 300-400 ms epoch after the target stimulus), and P300 (average amplitude in the 400-500 ms epoch after the target stimulus).

Unless explicitly stated otherwise, all analyses were carried out on the 40 critical items per condition only. Analyses of the ERP data involved analyses of variance (ANOVAs) with task (lexical decision, physical task) and proportion (high, low) as between-subject variables and relatedness (related, unrelated) and electrode (Fz, Cz, Pz, anterior temporal bilateral sites, and posterior temporal bilateral sites) as within subject variables Where interactions with the electrode variable are reported, ANOVAs were performed after performing a Z score normalisation procedure to equalise the mean amplitudes across experimental conditions. This normalization procedure is equivalent to the

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3 The Z score normalisation procedure was described by Rosler, Heil, and Glowalla (1993) normalization procedure suggested by McCarthy and Wood (1985)[1]

At the reaction time level, the lexicality effect was assessed to reveal whether the physical task was indeed performed nonlexically. For each subject, the mean reaction time was calculated for correct responses to all word targets, related and unrelated combined (cf. De Groot, 1987). Also, each subject's mean reaction time for all correct nonword target responses was calculated.

To analyse reaction time priming effects, separate ANOVAs were performed for both tasks, with proportion (high, low), and relatedness (related, unrelated). To control for an increase in Type I error in within-subjects tests, the degrees of freedom for the F tests were adjusted using the procedure as described by Greenhouse and Geisser (1959, cf. Winer, 1971). The adjusted degrees of freedom and p values are presented. The significance of contrasts was assessed by post hoc Newman-Keuls tests. All effects mentioned are significant at the .05 level or beyond.

RESULTS

Reaction Time Data

The lexicality test revealed that the physical task was performed nonlexically, that is, on the basis of nonlexical form information only. In the physical task, no difference in mean reaction time was found between the 240 word targets (419 ms) and the 240 nonword targets (416 ms). For the lexical decision task, a lexicality effect was found reaction times were shorter to word targets (525 ms) than to nonword targets (592 ms) ($F[1,16] = 99.38$, $p < .0001$).

Table 1 *Reaction Time (ms) for the High- and Low-Proportion Conditions*

Task	Related	Unrelated	Difference
Lexical decison			
High	510	569	59
Low	527	548	21
Physical task			
High	448	460	12
Low	404	408	4

The reaction time results for the critical word pairs are summarized in Table 1. A priming effect was obtained in the lexical decision task (F[1,16] = 72.05, p < .0001), but not in the physical task (F[1,16] = 0.30, n.s.). In the lexical decision task, a decrease in reaction time was found for related word pairs (519 ms) as compared with unrelated word pairs (559 ms). For the lexical decision task a Proportion x Relatedness interaction (F[1,16] = 20.76, p < .001) revealed that the priming effect was more pronounced for the high-proportion condition (59 ms) than for the low proportion condition (21 ms). Post hoc tests demonstrated that the priming effect in the lexical decision task was significant for the high-proportion (p < .01) as well as for the low-proportion (p < .01) condition. In the physical task, no significant differences in reaction times between related and unrelated word pairs were found.

ERPs

Grand averages for the lexical and the physical task and for high and low proportion are presented in Figure 1 and Figure 2 respectively, in which related and unrelated word targets and nonword targets are superimposed.

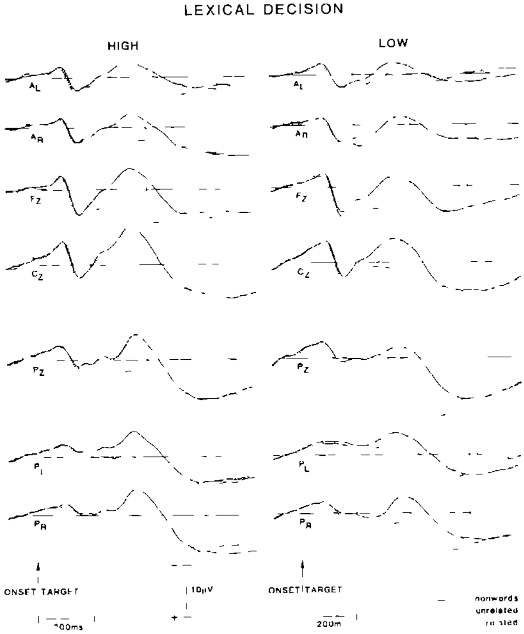

Figure 1. *Grand ERP averages of the lexical decision task (n=9 subjects) for the left and right anterior (AL, AR), the three midline (Fz, Cz, Pz), and posterior (PL, PR) electrodes, superimposed for related (thin line), unrelated (broken line), and nonword (thick line) targets separately for high and low proportion.*

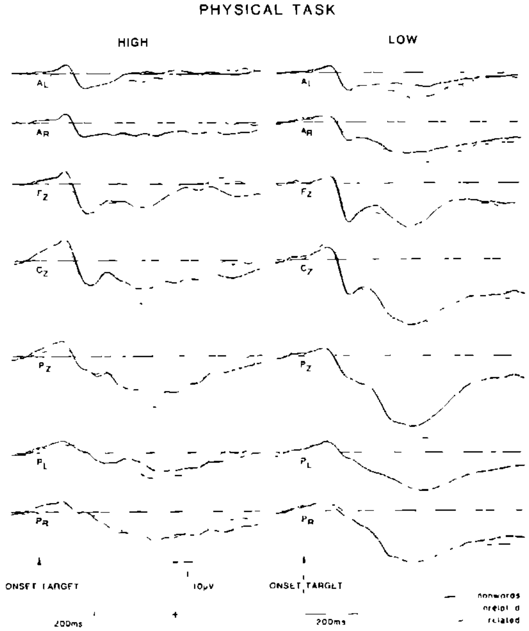

Figure 2. *Grand ERP averages of the physical task (n=9 subjects) for the left and right anterior (AL, AR), the three midline (Fz, Cz, Pz) and posterior (PL, PR) electrodes, superimposed for related (thin line), unrelated (broken line), and nonword (thick line) targets separately for high and low proportion.*

Inspection of the waveforms suggests that in the lexical decision task an N400 priming effect clearly developed, which was absent in the physical task. In both tasks, a P300 was evoked, reflecting that a decision was required on the target. The N400 in the lexical decision task was affected by relatedness: larger amplitudes were observed for unrelated than for related targets. The N400 and the P300 were widely distributed. The N400 in the lexical decision task was largest at the vertex, whereas the P300 in the physical task showed maximal amplitudes at Pz.

The main results of the overall analyses are summarized in Table 2[4]. The main effect of task indicated that overall amplitudes were more positive in the physical than in the lexical decision task, in particular within the N400 window. The interaction between task and relatedness revealed that the N400 in the lexical decision task was larger for unrelated than for related word pairs,

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[4] *Additional ANOVAs with broader latency regions, in which the N400 was measured as the mean amplitude within the 300-500 ms epoch and the P300 was measured as the mean amplitude of the 400-600 ms epoch, confirmed all effects reported in Table 2.*

Table 2 *F Values for ANOVAs for the N400 and the P300*

Effect	df^{a}	N400	P300
Task	1,32	35 31	8 62 *
Proportion	1,32	5 97	ns
Relatedness	1,32	22 13	12.47
Electrode	1,32	15 77	28.26
Task x Relatedness	1,32	20.52	22.21
Task x Proportion x Relatedness	1,32	5.81	7 26
Task x Electrode	1,32	10 43	4 77
Relatedness x Electrode	1,32	9 78	5.13

Note Interactions with *p* values > 05 are omitted

^{a}*Degrees of freedom were adjusted according to Greenhouse and Geisser (1959)*

**p* < 0 05, ** *p* < 0 01, ****p* < 0 001

whereas no such difference was found in the physical task. A main effect of proportion within the N400 window reflected that overall amplitudes were less positive in the high-proportion condition (2.4 µV) than in the low-proportion condition (5.1 µV). A Task x Proportion x Relatedness interaction was present. This interaction revealed that for the two tasks a different interplay between proportion and relatedness was observed.

In addition to the overall ANOVA, semantic priming effects were analysed for each task separately. These ANOVAs involved proportion, relatedness, and electrode

Lexical decision task The ANOVA yielded a significantly larger N400 amplitude for unrelated than for related word pairs (F[1,16] = 28.50, p < .001). An interaction of Electrode X Relatedness (F[1,16] = 10.51, p < 01) indicated that the N400 priming effect was most pronounced at the midline sites, in particular at Cz and Pz. The N400 priming effect was smaller at right and left posterior sites and further decreased at lateral anterior sites (Figure 3) The N400 tended to be larger (about 0.5 µV) above right posterior than above left posterior sites In parallel to the reaction time results, Figures 1 and 3 suggest that the difference in N400 amplitude between related and unrelated word pairs was larger for the high proportion (4.4 µV) than for the low-proportion (2.5 µV) condition. This increase in priming effect was caused by a larger N400 amplitude for unrelated word pairs than for related word pairs in the high- than in the low-proportion condition. Although in the overall ANOVA the Proportion X Relatedness interaction was not significant (p <.20), a significant

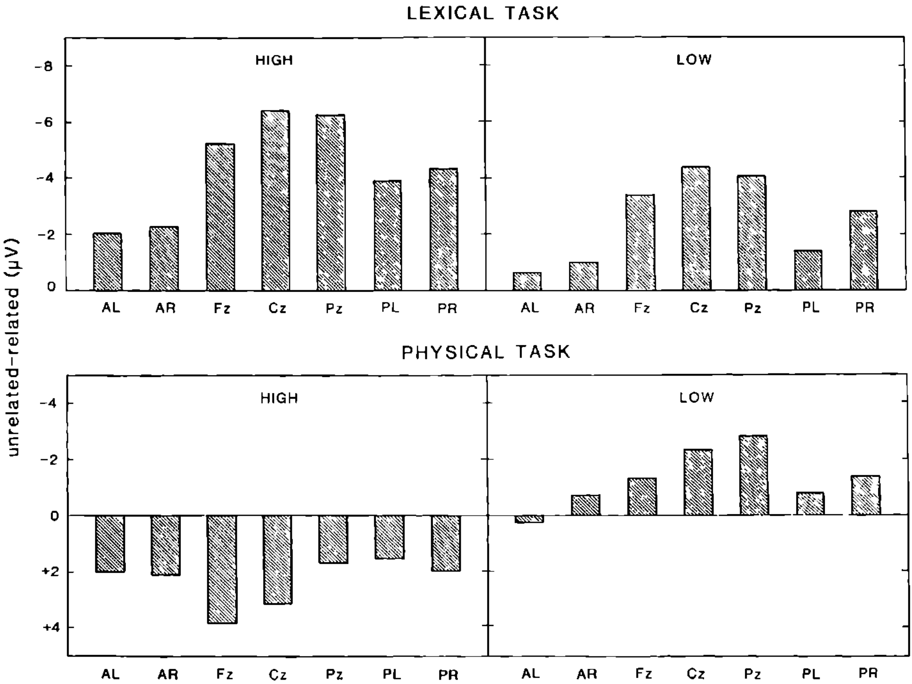

Figure 3. Difference in amplitude between unrelated and related targets for the N400 in the lexical decision task and for the P300 in the physical task separately for the high and the low proportion condition for the three midline (Fz, Cz, Pz), left and right anterior (AL, AR) and posterior (PL, PR) electrodes.

interaction was obtained at the left posterior site (p <.05). In a recent extension of this study with a larger number of subjects (n=15), we observed a similar increase in N400 priming effect for the high-proportion condition, which was statistically reliable (Brown, Hagoort, & Chwilla, submitted).

Analysis of the P300 revealed a main effect of electrode (F[1,16] = 8.14, p < .05), with the largest amplitude at Pz. As Figure 1 shows, the N400 priming effect extends up to at least 600 ms posttarget, yielding larger P300s for related than for unrelated word pairs (F[1,16] = 28.35, p < .001). Therefore overlap of N400 and P300 cannot be excluded. Because of this overlap, it is difficult to assess the effects of the experimental manipulations on the P300 in the lexical decision task.

Physical task: A main effect of electrode was observed for the physical task (F[1,16] = 24.02, p < .001). Post hoc tests demonstrated that P300 amplitude was larger (p < .01) at Pz, than at all other electrodes (p < .01), except Cz.
The P300 was affected by the proportion of related word pairs (F[1,16] = 4.66, p < .05); its amplitude was larger in the low-proportion (9.1 μV) than in the

high-proportion (5.4 µV) condition. The ANOVA also yielded an interaction of Proportion X Relatedness (F[1,16] = 12.18, p < .01). This interaction indicated that the P300 was affected by probability (see Figure 3). In the high-proportion condition, in which related word pairs were presented with a high probability, P300 was larger in response to unrelated (6.5 µV) than to related word pairs (4.2 µV). A post hoc test revealed that this difference in P300 amplitude was significant at the 1 % level. In contrast, in the low-proportion condition, P300 was larger for the infrequent related (9.7 µV) than for the frequent unrelated (8.4 µV) word pairs. A post hoc test demonstrated that this difference in P300 amplitude was significant at Pz (p < .05), but not at other electrodes.

Lexicality Test

To investigate the effect of lexicality, ERPs were averaged separately for word and nonword targets. Separate ANOVAs were carried out for the lexical and the physical task with between subject variable proportion (high, low), and within-subject variables lexicality (word, nonword) and electrode (seven levels).

The ANOVAs of the lexical decision task yielded a main effect of lexicality for both the 300-400 ms epoch (F[1,16] = 71.39, p < .0001), and the 400-500 ms epoch (F[1,16] = 93.58, p < .0001). In the early and the late epoch, the waveform was more negative going for nonwords than for words. The lexicality effect was widespread across the scalp, with a trend towards a larger difference between words and nonwords above the right hemisphere.

A significant effect of lexicality was also obtained in the physical task (300-400 ms epoch F[1,16] = 74.18, p < .0001), 400-500 ms epoch F[1,16] = 65.04, p < .0001). In both epochs, the waveform was less positive for nonwords than for word targets. No interaction of proportion and lexicality was obtained, indicating that the lexicality effect was of similar size for the high- and the low-proportion condition[5].

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[5] *However, a possible problem is that in the previous test unrelated and related words were collapsed and contrasted with nonwords and that the inclusion of related words confounds the priming effect with the lexicality effect. Therefore, it might be argued that to get a more appropriate estimate of the lexicality effect, nonwords should be contrasted only with unrelated words. To control for the possibility that the lexicality effect actually arises from a confounding with the priming dimension, additional ANOVAs were performed in which only unrelated words were contrasted with nonwords. These analyses essentially revealed the same results. Significant lexicality effects for both epochs were obtained in the lexical decision task (300-400 ms epoch F[1,16] = 16.89, p < .001, 400-500 ms epoch F[1,16] = 17.55, p < .001) and also in the physical task (300-400 ms epoch F[1,16] = 16.91, p < .001, 400-500 ms epoch F[1,16] = 23.39, p < .001). The only difference with respect to the original analyses was that for the late epoch in the physical task a Proportion by Lexicality interaction (F([1,16] = 7.37, p < .02) was obtained. This interaction indicated that the lexicality effect was more pronounced in the high- than in the low-proportion condition (see Figure 2). However, the probability for nonwords and unrelated words*

Topography of the Priming Effect and the Lexicality Effect

Inspection of Figures 1 and 2 suggests that there might be topographical differences between the priming effect and the lexicality effect In the lexical decision task, for instance, both effects result in a modulation of the N400 The priming effect is largest at centroparietal midline sites and much smaller at anterior sites (see also Figure 3) In contrast, the lexicality effect has a more frontal distribution.

To test for possible differential distributions of priming and lexicality effects, for each task separate ANOVAs were performed in which the scalp distributions of the priming effect and the lexicality effect were compared directly. This analysis was performed for the early (N400) and the late (P300) latency region (300 400 ms and 400-500 ms, respectively)

The priming effect was computed by subtracting the mean amplitudes for related targets from the mean amplitudes for unrelated targets The lexicality effect was computed by subtracting the mean amplitudes to unrelated targets from the mean amplitudes to nonword targets For each task, ANOVAs were performed on these difference scores, with proportion as the between-subject variable, and dimension (semantic versus lexical) and electrode as within subject variables

For the lexical decision task, a marginally significant Dimension x Electrode interaction was obtained for the early window ($F[1,16] = 3.19$, $p < .10$), but not for the late window No significant Proportion x Dimension x Electrode interactions were obtained. These results confirm that the N400 lexicality effect was more frontally distributed compared to the centroparietally distributed N400 priming effect. Also in the physical task, a marginally significant Dimension x Electrode interaction was obtained for the early window ($F[1,16] = 3 62$, $p < 10$), but not for the late window

Whether the distributional differences between priming and lexicality effects have any functional significance is, however, unclear. Because both N400 and P300 generator ensembles seem to have their effects in at least partly overlapping time windows, their differential contributions to the waveforms might have resulted in overall topographic differences between lexical and priming effects It, therefore, seems premature to interpret these differences in a functional sense

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differed between conditions such that in the high proportion condition unrelated words were presented with a low probability If the lexicality effect in the physical task is due to a modulation in P300 amplitude, then these differences in probability might affect the amplitude of this positivity Figure 2 indeed suggests that probability is the most important determinant of the differential amplitude modulation of the positivity

DISCUSSION

The present findings replicate earlier results that showed that N400 priming effects are evoked in a lexical decision task. The duration of the N400 observed in this study, its topography, and the size of the priming effect are in agreement with those reported in the literature (see, for example, Holcomb, 1988, Holcomb & Neville, 1990). The N400 is also quite similar to the classical N400 observed in sentence completions (Kutas & Hillyard, 1980).

The goal of this study was to examine which aspects of lexical processing (access, selection, integration) are reflected by the N400 effect. This issue was addressed by assessing the effects of different semantic priming mechanisms on the N400 priming effect. More specifically, we attempted to separate the effects of automatic spreading of activation from the effects of semantic matching by varying the level of processing. We compared the ERPs in a lexical decision task with the ERPs in a physical task At the reaction time level, the lexicality test indicated that different levels of processing were induced by performing the two tasks. There was no difference in the reaction times for word and nonword targets in the physical task, indicating that this task was performed nonlexically. In contrast, a significant lexicality effect was obtained in the lexical decision task. In addition, a reaction time semantic priming effect was obtained in the lexical decision task but not in the physical task.

After having established that the physical task was performed nonlexically, we can address the question whether an N400 priming effect occurs when the task performance does not involve lexical processing. An N400 priming effect clearly developed in the lexical decision task and was absent in the physical task (Figures 1 and 2). In the lexical decision task, the N400 was modulated by the relatedness of prime and target, yielding much larger amplitudes for unrelated than for related word pairs. In contrast, no indication for an N400 priming effect was obtained in the physical task. Once it is made sure that for task related performance the target words are processed nonlexically, an N400 priming effect is no longer observed. This result suggests that the modulation of the N400 amplitude requires the explicit identification of a word, including its meaning. If word meaning does not become part of the episodic trace of a particular wordlike stimulation event, N400 priming effects do not seem to arise. This result also lends credibility to the suggestion that previous studies in which N400 priming effects were obtained in shallow processing tasks (Besson et al., 1992, Connolly, Stewart, & Philips, 1990, Kutas & Hillyard, 1989) might have been unsuccessful in preventing explicit identification of the words and their meaning.

The N400 Effect and Lexical Processes

What are the implications of these results with respect to the processing nature of the N400 effect? The absence of an N400 priming effect in the physical task challenges the view that the N400 effect reflects the automatic process of lexical access and its concomitant ASA. This conclusion is further supported by the absence of an N400 priming effect when the prime is masked, thereby preventing conscious identification of the stimulus (Brown & Hagoort, 1993). The presence of N400 priming effects in the lexical decision task provides further evidence that the N400 effect is closely tied to lexical integration processes, mediated by the mechanism of semantic matching Brown and Hagoort (1993) argued that lexical processing in the context of word priming shares core characteristics with the process of lexical integration in the ordinary process of sentence comprehension. That is, once lexical information has been accessed automatically on the basis of the speech signal or the orthographic input, the syntactic and semantic information associated with the activated word form has to be integrated with the preceding context into an overall interpretation of the whole utterance The N400 effect is claimed to reflect this process of lexical integration (see Holcomb, 1993, and Rugg et al , 1988 for similar views).

Processing in the Physical Task

So far, the results for reaction time and N400 are compatible with two conclusions (a) the absence in the physical task of a lexicality effect and a priming effect is due to the fact that nonlexical task performance prevented word meaning from becoming part of the episodic trace, and (b) even accessing word meaning in semantic memory was prevented under the shallow task conditions This latter possibility is, however, excluded by the P300 results.

In the physical task, we observed a modulation of the parietally distributed positivity as a function of the probability of related and unrelated word pairs, with larger amplitudes for the stimulus category that occurred with the lower probability (see Figures 2 and 3) Both the distribution of this positivity and its sensitivity to the probability of a certain stimulus event suggests that this positivity reflects the P300 component (see Johnson, 1988, for a review). The important point here is that the P300 results demonstrate that the subjects assigned related and unrelated word pairs to different categories This assignment presupposes that subjects accessed word meanings when processing the primes and targets. As such, it implies that even in the absence of reaction time and N400 effects in the physical task, accessing word meaning in semantic memory was not prevented. The more reduced positivity to nonwords as compared with unrelated and related target words fits well with the above picture, because the nonwords were presented with a higher probability (.50) than were both unrelated word pairs (overall probabilities of .08 in the high proportion condition and .33 in the low-proportion condition) and related word pairs (.33 and .08 in high- and low-proportion list, respectively). Although on the basis of these results we cannot fully specify all the dimensions that might have entered into the categorization of the prime-target pairs by the subjects, it seems clear that lexical and semantic characteristics were both involved.[6]

This study was not designed to investigate the relationship between the P300 and lexical processes. Nevertheless, we observed an intriguing dissociation between the reaction time and N400 results on the one hand and the P300 results on the other hand. What might these P300 effects reflect? A tentative explanation is that the presence or absence (in the case of nonwords) of activation of word meanings in semantic memory and the automatic spread of activation between related nodes in semantic memory might have led to an implicitly generated categorization of stimulus events that became part of the episodic representation in terms of more likely and less likely stimulus events. That is, the semantic aspects of the words did not themselves become part of the episodic trace (as suggested by the absence of N400 effects) but led to an explicitly recognized but unspecified sense of more and less frequent stimulation events, resulting in the observed P300 effects.

Caveats

The above claims can only be made if it can be shown that the observed differences in ERP pattern between tasks could not be ascribed to other factors.

A first, minor consideration is that task difficulty was not controlled across tasks. This resulted in differences in overall reaction times between the lexical and the physical task. It could be argued that the observed differences in ERP pattern between tasks are due to differences in reaction time. However, two aspects of the present data argue against this possibility First, in the physical task, reaction times were the same for related and unrelated targets, as well as

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[6] *In the P300 literature, the probability effect is often related to the task demands In the physical task, the probability of the different categories (related, unrelated, nonwords) was not task relevant However, the P300 probability effect has also been linked to automatic processing Several results indicate that the relationship between P300 and probability meets criteria for automatic encoding (see Campbell, Courchesne, Picton, & Squires, 1979 Duncan-Johnson & Donchin, 1977) Moreover, P300 effects have been reported in neuropsychological patients that did not show behavioral sensitivity to the task relevant dimension (Renault, Signoret, Debruille, Breton, & Bolgert, 1989)*

for words and nonwords, whereas there were clear differences in P300 This dissociation suggests that differences in ERPs cannot be attributed in a simple way to differences in reaction time Second, the fact that different ERP patterns were obtained across tasks, especially the absence of an N400 priming effect in the physical task, supports the idea that the difference in task performance is not of a quantitative but of a qualitative nature

A second issue concerns component overlap Because both the N400 and the P300 component occur within roughly the same latency range, it cannot be excluded that both N400s and P300s were present to different degrees across the conditions The crucial question, however, is whether the main effects of the present study can be explained in terms of component overlap We first discuss the possible implication of component overlap for the N400 effects obtained in the lexical decision task and then consider the implications for the P300 effects in the physical task

Could the N400 priming effect observed in the lexical decision task be explained in terms of an overlapping P300 component? This idea is rejected for the following reasons In the present study the probability of related and unrelated targets was reversed across conditions (80/ 20 and 20/.80) Because of the inverse relationship between stimulus probability and P300 amplitude, we expect different N400 patterns across conditions if the P300 is overlapping Because of the larger P300 to the low probability event, the amplitude of the N400 should be reduced to unrelated targets in the high proportion condition, because unrelated word pairs are only presented in 20 % of the cases If this were the case, the N400 for unrelated targets in the high proportion condition would have been smaller than the N400 for unrelated targets in the low proportion condition However, the opposite pattern was observed The N400 for unrelated word pairs even tended to be larger in the high than in the low proportion condition

The second question is whether the absence of an N400 priming effect in the physical task may be due to overlapping components Here, a distinction should be made between two different types of overlap The first concerns overlap of the N400 component with the P300 component, whereas the second concerns an overlap of N400 priming effects with P300 probability effects From the present data, it cannot be excluded that an N400 component was evoked that overlapped the P300 in the physical task This possibility is suggested by the difference in scalp distribution of the P300 probability effect across proportion conditions (see Figure 3) However, the distributional differences might at least in part be a result of some baseline problems in the high proportion condition, with the larger baseline differences between the related and unrelated conditions at the frontal leads These problems might have contributed to the distributional differences that were obtained. However, the distributional differences were not statistically significant In the physical task, neither the Proportion X Electrode nor the Prime Type X Proportion X Electrode interaction approached significance. We are, therefore, very reluctant to assign strong interpretational relevance to this apparent distributional difference.

Regarding the overlap of N400 and P300 effects, the crucial question is whether the absence of an N400 priming effect in the physical task could be explained by an overlap of the N400 priming effect with the P300 probability effect. The presence of an N400 priming effect in these data is very unlikely. Based on the current literature on N400 priming effects, an underlying N400 priming effect could result from the following two scenarios.

Scenario 1 is that both in the high proportion and in the low proportion conditions a (small) N400 priming effect had been elicited in the physical task by the semantically related or unrelated items. In scenario 1, we assume that this effect is of similar magnitude in both proportion conditions. This scenario leads to the prediction that the positive shift in the high proportion condition is smaller than the positive shift in the low proportion condition. The reason for this prediction is that in the former case the positive shift (as a function of probability) is for the same items as the negative shift (as a function of relatedness). In the low proportion condition, the positive shift is for the infrequent, related words and the larger negativity for the frequent, unrelated targets. The resulting net effect should therefore be smaller in the case where negative and positive effects are for the same items (high proportion), as compared with the situation where the two effects are for different items (low proportion), thereby even increasing the net effect. However, no such difference in the size of the effects was observed If there is a difference at all, it is in the opposite direction (overall positive shift of 2.3 µV in the high proportion condition and of 1.3 µV in the low-proportion condition).

Scenario 2 is that just as for the lexical decision task, the hidden N400 priming effect in the high-proportion condition is larger than in the low proportion condition. In that case, the cancellation effect for the high-proportion condition would have been even greater.

If there had been an overlap between N400 priming effects and P300 probability effects in the physical task, we expected it to have the predicted consequences on the basis of our knowledge about factors responsible for N400 priming effects. These consequences were not observed. Therefore, acknowledging the principled impossibility of excluding component overlap with surface recordings, the likelihood that overlap is responsible for the pattern of results observed is sufficiently low to warrant our conclusions.

A possible critique of the interpretation of the P300 effects in the physical task is that the absence of an N400 priming effect might arise from a baseline problem. This problem indeed might play a role in the high proportion condition, where the waveforms for related and unrelated pairs separate very early in time (Figure 2). This difference in the baseline at least enhances the P300 probability effect The reasoning here is that if the waveforms were forced to align, then an N400 priming effect might emerge and the P300 effect might disappear. It is indeed difficult to interpret the early onset of the effect, and the possibility cannot be discarded that the P300 probability effect in this condition might result from noise or baselining problems.

To check whether baseline problems might underly the observed effects, additional analyses were performed, in which a later baseline of 30 130 ms posttarget was used, thereby aligning the waveforms to counter their seemingly early separation These ANOVAs revealed a significant interaction of Proportion X Relatedness for the P300 ($F[1,16] = 4.81$, $p <.05$) (latency epoch 400-500 ms) but not for the N400 (latency epoch 300 400 ms). Moreover, with the use of this baseline no main effect of Relatedness was obtained for the early and the late latency epoch. The additional ANOVAs, therefore, strongly suggest that the P300 probability effect was not evoked by differences in baseline but is due to modulation of the P300 component.

CONCLUSIONS

Under shallow processing conditions, the amplitude of the P300 is sensitive to category probability, which in the present study was related to word and nonword stimuli. The dissociation between no reaction time differences for words and nonwords in the physical task, with P300 differences for these same stimuli, provides evidence that despite the shallow task requirements lexical information can still impact the ongoing analysis process. Under these conditions, however, the N400 is not sensitive to lexical information.

The amplitude of the N400 is modulated when semantic aspects of word stimuli enter into the episodic trace of wordlike stimulus events. However, automatic spreading of activation between related nodes in semantic memory does not appear to affect the N400. These results support the idea that within the context of normal language processing the N400 effect primarily reflects lexical integration processes.

CHAPTER III

An Event-Related Brain Potential Analysis of Visual Word Priming Effects

Colin M. Brown, Peter Hagoort, & Dorothee J. Chwilla

ABSTRACT

Two experiments are reported that provide evidence on task-induced effects during visual lexical processing in a prime-target semantic priming paradigm. The research focuses on target expectancy effects, by manipulating the proportion of semantically related and unrelated word pairs. In Experiment 1, a lexical decision task was used and reaction times and event-related brain potentials (ERPs) were obtained. In Experiment 2, subjects silently read the stimuli, without any additional task demands, and ERPs were recorded. The reaction time and ERP results of Experiment 1 demonstrate that an expectancy mechanism contributed to the priming effect when a high proportion of related word pairs was presented. The ERP results of Experiment 2 show that in the absence of extraneous task requirements, an expectancy mechanism is not active. However, a standard ERP semantic priming effect was obtained in Experiment 2. The combined results show that priming effects due to relatedness proportion are induced by task demands, and do not reflect normal on-line lexical processes.

INTRODUCTION

The starting point for the research reported here is the perennial worry of psycholinguists about the impact of reaction time tasks on the ongoing lexical analysis process. In using reaction times to tap into real-time performance during language comprehension, researchers are confronted with contaminating effects of the invasive technique they are employing. Indeed, within one of the major research areas of psycholinguistics - visual word processing - quite some discussion has focused on (explaining away) potential artifacts due to task specific effects, such as originate from the requirement to make a binary and/or speeded response, or to monitor the input for some prespecified letter string The susceptibility of reaction time tasks to response strategies has been a particular concern (cf. Besner & Johnston, 1989, Keefe & Neely, 1990, Neely, Keefe, & Ross, 1989, Seidenberg, 1989) What we mean by strategy here, is some process that is not part of ordinary language comprehension, and that subjects (consciously or unconsciously) invoke to help them meet the task demands of a particular experimental setting.

The main purpose of this paper is to present new evidence on task-induced effects during visual lexical processing in a semantic priming paradigm. The research uses prime-target pairs, and focuses on a comparison of lexical decision and silent reading.

The effect we will be concerned with is the relatedness proportion effect (cf. Fischler, 1977, Neely, 1977, Tweedy, Lapinski, & Schvaneveldt, 1977). This effect modulates the standard semantic priming effect, in which target words preceded by associatively and/or semantically related primes are responded to faster and with fewer errors, compared to words preceded by unrelated primes (see Neely, 1991, for a review). In the relatedness proportion effect, the size of semantic priming effects increases as the proportion of related word pairs relative to unrelated word pairs in the stimulus list increases. This modulation has been reported both with a lexical decision task (e.g., De Groot, 1984, Neely et al., 1989, Seidenberg, Waters, Sanders, & Langer, 1984, Shelton & Martin, 1992), and a pronunciation task (Keefe & Neely, 1990), and occurs for long but not short prime-target stimulus onset asynchronies (e.g., Den Heyer, Briand, & Dannebring, 1983, but see De Groot, 1984). In the present paper we discuss event-related brain potential (ERP) and reaction time data from which we claim that the priming mechanism underlying the relatedness proportion effect is not a natural part of the lexical analysis process, but originates from the response requirements of reaction time tasks.

The discussion of response strategies and their effects has primarily evolved within research using the visual word word semantic priming paradigm. This research has attempted to explain the semantic priming effect by postulating a number of different priming mechanisms, two of which are claimed to be more or less strategic, in part dependent on the particular reaction time task being used (usually either lexical decision or pronunciation) Neely and Keefe (1989) present a detailed analysis of semantic priming effects, and argue that three different mechanisms are needed to account for the entire range of reaction time priming effects (1) Automatic spread of activation (ASA), (2) Expectancy induced priming, (3) Semantic matching The latter two are thought to be open to strategies, although semantic matching has been claimed to be a more natural component of ordinary language comprehension (cf Neely, 1991)

With ASA it is assumed that links exist between semantically and/or associatively related nodes in the mental lexicon (cf Collins & Loftus, 1975) Analysis of a prime word results in activation spreading within the lexicon to nodes representing words that are related in meaning Due to their enhanced activation, activated nodes need less time for subsequent processing, relative to non primed words

In expectancy induced priming, subjects generate - under certain circumstances - an expectancy set on the basis of the information contained by the prime This expectancy set contains potential target words that are semantically related to the prime If the actual target is a member of this set it will be recognized more quickly If it is not in the set, recognition will be slowed down In reaction time tasks, expectancy-induced priming therefore not only facilitates the processing of expected targets, but it also inhibits the processing of unexpected targets (cf Becker, 1980, Neely, 1977)

Semantic matching, finally, is a postlexical process in which subjects check for semantic overlap between primes and targets once they have been accessed Semantic matching is thought to influence the results in the lexical decision task, but not in the pronunciation task In the lexical decision task it is assumed that subjects bias their decisions according to the result of this matching process The detection of a relationship between primes and targets leads to a bias to respond 'yes' If no relation is detected, then there is a bias to respond 'no' Thus, semantic matching results in facilitation for related targets For unrelated targets, however, semantic matching does not succeed, which induces a bias to respond 'no' Therefore, the required yes-response will be inhibited

On the basis of an analysis of relatedness proportion effects in both lexical decision and pronunciation, Keefe and Neely (1990) conclude that the relatedness proportion effect is mediated by an expectancy mechanism that contributes to priming in both the LDT [lexical decision task] and the pronunciation task (Keefe & Neely, 1990, p. 296). That is, the presence of a relatively high proportion of related word pairs (e.g., 80%) induces subjects to generate an expectancy set of potential target words on the basis of the meaning of the prime.

The specific question we address in the following experiments is whether the expectancy mechanism is a task induced effect, peculiar to the response requirements of reaction time tasks. An answer to this question is important in order to weigh the implications of particular semantic priming effects (such as those brought about by manipulating relatedness proportion) for a functional characterization of the visual lexical analysis process. If expectancy induced priming and its effect on reaction time measures is shown to be an artifact of the reaction time task requirements, then the impact of such priming effects on functional models of lexical processing is very limited.

To find out whether expectancy induced priming is artifactual, we assess relatedness proportion effects on two dependent measures: reaction times and ERPs, under two task conditions: Lexical decision (gathering both reaction times and ERPs) and silent reading (gathering only ERPs). In the latter situation subjects are not required to perform any task (hence, no reaction times are gathered) other than the natural one, which is simply to read the stimuli. Here, we capitalize on an appealing feature of the ERP method (which it shares with eye movement recording), namely that significant effects of independent variables can be obtained in the absence of extraneous and additional task demands (see McNamara & Healy, 1988, for an reaction time version of 'silent reading'; see also Lorch, 1986). The critical comparison, then, is between a manipulation of relatedness proportion under lexical decision and under silent reading conditions, using the exact same list of stimuli. This allows us to focus on the possibly task dependent nature of the expectancy induced priming mechanism. If relatedness proportion effects obtain with lexical decision but not with silent reading, then we can comment on the importance of expectancy induced priming effects with respect to functional models of visual word processing.

In the experiments to be reported below, subjects are presented with a list of stimuli with either a low (.20) or a high (.80) proportion of related word pairs, and both reaction times and ERPs are registered. The reaction times serve to validate the basic relatedness proportion effect as it has been reported in the reaction time literature (1) In the high relatedness proportion list, facilitation of related targets, and inhibition of unrelated targets, relative to a neutral baseline, (2) in the low relatedness proportion list, facilitation of related targets relative to a neutral baseline, and no difference between the unrelated and the neutral condition, (3) overall larger priming (related versus unrelated) in the high compared to the low relatedness proportion list. The ERPs in the lexical decision and the silent reading task serve primarily to assess the influence of task demands, but also to validate the standard semantic priming effect on the brain's electrical activity This priming effect is predicted to occur at the level of the so called N400 component of the ERP waveform (Kutas & Hillyard, 1980)

The N400 is a negative polarity component, with a centro parietal maximum over the scalp, that reaches its maximal amplitude roughly 400 ms after the onset of word stimulation. There is ample evidence that the N400 is sensitive to ongoing linguistic analyses. Generally speaking, every word elicits an N400 The particular latency and amplitude characteristics of the N400 depend on the context within which the eliciting word occurs, as well as on specific properties of the word itself (such as its frequency and form class) A large number of studies has shown that the N400 is particularly sensitive to semantic information processing, both in prime-target and in sentential contexts The standard semantic priming reaction time effect is mirrored in the N400, where unrelated target words elicit a larger amplitude than related targets This amplitude difference is referred to as the N400 effect (see Kutas & Van Petten, 1988, 1994, for reviews). Within the context of the experiments described here, we predict a standard N400 effect as a function of semantic relatedness.

To the extent that an expectancy induced priming mechanism is operative, we expect relatedness proportion effects to also emerge as modulations of the amplitude of the N400 The size of the N400 effect is predicted to vary as a function of relatedness proportion, with the largest N400 effect in the high proportion list. This prediction is supported by a study reported by Holcomb (1988). Holcomb measured ERPs and reaction times in a lexical decision task on lists with high and low proportions of semantically related trials. His main finding was that the N400 effect was larger in the high compared to the low proportion list. However, in contrast to the present study, Holcomb's research cannot be used (and was not intended) to assess the nature of the relatedness proportion effect There was no silent reading comparison in his research

The remainder of this paper is organized as follows. We first present the lexical decision experiment, which shows a semantic priming effect and a modulation of this effect by relatedness proportion, both in the reaction time and the ERP measure. We then assess the validity of this result in the silent reading experiment. These analyses and discussions focus entirely on the processing of the target word. Following these sections, we will present ERP data on the processing of the prime words. In the experiments we report here, we used the Dutch word blanco (English translation blank) as the prime in the neutral condition. The ERP data for the primes provide evidence concerning the validity of the stimulus blanco as an appropriately neutral prime. This evidence connects to discussions in the reaction time priming literature, where it has been something of an issue whether an essentially meaningless real word (such as blank) is to be preferred over a string of non-letter symbols (e.g., asterisks, hash marks) as the neutral prime stimulus, and, more in general, whether a truly neutral stimulus can at all be achieved (cf. De Groot, Thomassen, & Hudson, 1982, Fischler & Bloom, 1980, Shelton & Martin, 1992). In the General Discussion we will remark on this issue, and then focus the remainder of the discussion on the implications of the results obtained for the target words.

Since - with the exception of the experimental task - the stimuli, design, and procedure are the same for the two experiments, we will start with a general method section

METHOD

Subjects

Sixty eight subjects (mean age 23, n=24 men) were paid to participate in the experiments. Due to excessive EEG and EOG artifacts, the data of 8 subjects could not be adequately analyzed, leaving a total of 60 subjects, of which half were tested with a lexical decision task, and half with a silent reading task None of the subjects had any neurological impairment or had experienced any neurological trauma according to their responses on a questionnaire All subjects had normal or corrected to normal vision, and were right handed according to their responses on an abridged Dutch version of the Oldfield Handedness Inventory (Oldfield, 1971). Twenty five subjects reported left handed relatives in their immediate family.

Materials

Two lists of stimuli were constructed, one with a high proportion of related word pairs (.80), and one with a low proportion of related word pairs (.20) Each list consists of 480 prime target pairs. Half of these pairs have a nonword target, half have a Dutch word as target. The word pairs consist either of associatively related words (e.g., ship sailor), of unrelated words (e.g., star-hour), or of word targets preceded by the neutral prime 'blanco' (the Dutch word for 'blank') Of the 240 nonword targets, 200 are preceded by a word prime (e.g., dog-wunk), and 40 are preceded by the neutral prime The nonwords were constructed according to the phonotactic constraints of Dutch, and were derived from real words by substituting one or two letters. Of the 240 word pairs, 120 are critical test items, on which reaction time and ERP analyses will be reported These 120 items are divided into three sets of 40 related, unrelated, and neutral word pairs.

All targets consist of one- or two-syllable strings, ranging in length from 3 to 8 letters. The targets in the three sets of 40 critical word pairs are matched on number of syllables and number of letters. The mean word frequency (and standard deviation) based on a corpus of 720.000 words (Uit den Boogaart, 1975) for the 40 targets in the related set is 82 (108), in the unrelated set it is 62 (106), and in the neutral set it is 79 (111). The mean length and the mean number of syllables of all targets (both words and nonwords) is matched between the two lists of stimuli The mean association strength of the related pairs was obtained from published association norms established with a population of 100 students (De Groot, 1980, Lauteslager, Schaap, & Schievels, 1986) and is 47.4 (15.3). In addition to matching on lexical characteristics, we matched the targets in the three critical sets on the basis of their lexical decision times, gathered in a reaction time pretest in which all targets were presented in isolation The reason for this additional matching procedure is to reduce spurious between-set item variance as much as possible A total of 480 words and 480 nonwords were visually presented in a randomized sequence to 10 subjects and in the reverse order to another group of 10 subjects (using the same procedure as for the main experiments, see Procedure section for details). Subjects had to make a speeded lexical decision on the targets by pushing a YES button as quickly as possible if the target was a word, and a NO button if the target was a nonword. The reaction times to word targets obtained in this way were used to match the set of targets in the related, unrelated, and neutral sets on overall absolute reaction time. Targets from the three sets were matched on the basis of the criterion that their reaction times should not differ more than 4 ms.

The two proportion lists are preceded by the same practice sequence of 20 prime-target pairs. Half of the targets are words, paired with related (n=4), unrelated (n=3), and neutral primes (n=3)

Design

The high and low relatedness proportion lists each contain the same set of 40 critical related, unrelated, and neutral word pairs. To avoid repetition effects, the relatedness proportion manipulation is implemented as a between subjects factor, as is the task instruction (lexical decision versus silent reading). To realize the two relatedness proportions, different numbers of related and unrelated word pairs are added to the critical word pairs in the high and low relatedness proportion lists The high relatedness proportion list is made up of 40 critical related word pairs, an additional 120 related word pairs, 40 critical unrelated word pairs, 40 critical neutral word pairs, and 240 word-nonword pairs (of which 40 are preceded by the neutral prime). So, this list has a 80/20 proportion of related versus unrelated word pairs. In the low relatedness proportion list the additional 120 related word pairs of the high proportion list are replaced by 120 unrelated word pairs, resulting in a 20/80 proportion of related versus unrelated word pairs. The same pseudorandomized sequence is used for the high and the low proportion list, such that each critical word pair occurs in the same position in both lists.

Procedure

The stimuli were generated and controlled by a Miro GD laboratory computer and were centrally presented in a 8 cm by 2 cm window on a high-resolution PC-monitor which was covered by a black non-reflecting shield Viewing distance was between 70 to 80 cm, and the stimuli subtended a vertical visual angle of approximately three degrees. Primes and targets were presented in uppercase letters. A single trial consisted of the presentation of a prime for 200 ms, followed by a blank screen of 500 ms, followed by the presentation of a target for 200 ms. The interval between trials was 3400 ms.

All subjects were tested individually in a dimly illuminated, sound attenuating and electrically shielded booth. At the beginning of the test session subjects were informed that they would see a series of two letter strings. They were told that in some cases the second letter string formed a common word of Dutch, whereas in other cases the second letter string did not exist as a word in the Dutch language

For the lexical decision task, subjects were required to indicate whether the second letter string was a word or not by pressing the YES button on a response keyboard with their right index finger for words, and the NO button with their left index finger for nonwords. Subjects were asked to respond as quickly as possible, but to avoid errors. No feedback concerning correctness of response was given. Both response times and response codes were stored directly with the aid of the computer.

For the silent reading task, subjects were asked to attentively read the stimuli, without attempting to memorize them. Before the test session began, the set of 20 practice stimuli was presented to familiarize the subjects with the procedure.

Electrophysiological recording

EEG activity was recorded using an Electrocap with 7 scalp tin electrodes, each referred to the left mastoid. Three electrodes were placed according to the International 10-20 system (Jasper, 1958) at frontal (Fz), central (Cz), and parietal (Pz) midline sites. Symmetrical anterior temporal electrodes were placed halfway between F7 and T3 (AL), and F8 and T4 sites (AR), respectively. Symmetrical posterior temporal electrodes (PL, PR) were placed lateral (by 30% of the interaural distance) and 12.5% posterior to the vertex. Vertical eye movements and blinks were monitored via a supra- to sub-orbital bipolar montage. A right to left canthal bipolar montage was used to monitor for horizontal eye movements.

The EEG and EOG recordings were amplified with Nihon Kohden AB-601G bioelectric amplifiers, using a Hi-Cut of 30 Hz and a time constant of 8 seconds. Electrode impedance was at most 3 kOhm. The EEG and EOG were digitized on line with a sampling frequency of 200 Hz. Sampling started 150 ms before the prime appeared, and continued for 1750 ms.

THE LEXICAL DECISION EXPERIMENT: REACTION TIME RESULTS

Statistical analyses were performed on the latency data of the 40 critical word target trials in each priming condition. Before the analyses on the latency data, errors and values above 900 ms were replaced by the subject's mean latency in the relevant condition. Two subjects, one in the High Proportion List and one in the Low Proportion List, were excluded from further analyses because of a high percentage of errors and outliers (13% or more) All analyses (including the analyses on the ERP data) were done on the remaining 28 subjects, 14 in each proportion condition. For these remaining subjects, a total of 4.8% of errors in the High Proportion List, and 3 2% of errors in the Low Proportion List was replaced by the mean. The results for both proportion conditions are summarized in Figure 1. An Analysis of Variance (ANOVA) with subjects as random factor was performed with Prime Type (Related, Unrelated, Neutral) as the within-subject factor and Relatedness Proportion (High Proportion, Low Proportion) as the between subject factor. The Greenhouse-Geisser procedure (cf. Winer, 1971) was applied to all repeated measures with more than one degree of freedom. The adjusted degrees of freedom and p values are presented in the text.

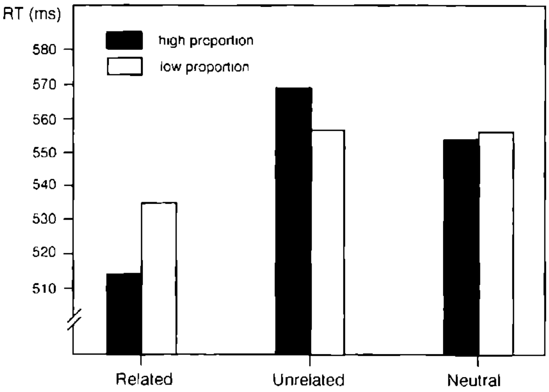

Figure 1 *Lexical decision latencies for the related, unrelated, and neutral conditions, for the high and low relatedness proportion lists.*

The overall ANOVA revealed a significant main effect of Prime Type (F[1,26]= 35.45, p <.01, MSe= 329.02). In addition a significant Relatedness Proportion by Prime Type interaction was obtained (F[1,26]= 5.94, p < 05, MSe= 329.02). Separate ANOVAs were therefore done for the two proportion conditions.

The ANOVA for the High Proportion List yielded a significant effect of Prime Type (F[1,13]= 25.41, p <.01, MSe= 450.03). A post hoc Newman- Keuls test (p <.05) showed a significant facilitation in the related condition relative to both the neutral baseline (40 ms) and the unrelated condition (55 ms) The 15 ms inhibition in the unrelated condition relative to the neutral baseline was marginally significant in a planned comparison (p= .067).

The ANOVA for the Low Proportion List also yielded a significant effect of

Prime Type (F[1,13]= 10.47, p=.01, MSe= 208.03). The post hoc Newman-Keuls test again showed a significant facilitation in the related condition relative to both the neutral baseline (21 ms) and the unrelated condition (22 ms). However, in contrast to the High Proportion List, no inhibition was seen in the unrelated condition relative to the neutral baseline.

In summary, relative to the neutral baseline the reaction time results show a pattern of facilitation (related condition) and inhibition (unrelated condition) in the High Proportion List, but only a pattern of facilitation (related condition) in the Low Proportion List. In addition, the overall facilitation of the related condition relative to the unrelated condition is substantially larger in the High Proportion List than in the Low Proportion List (55 ms vs. 22 ms).

ERP RESULTS FOR THE TARGET WORDS

After artifact rejection, statistical analyses were done on the ERP data of the 40 critical target words in each priming condition. All analyses of variance included Prime Type and Electrode Position as the within-subject factors, and Relatedness Proportion as the between-subject factor. Where appropriate, the degrees of freedom and the p-values have been adapted using the Greenhouse-Geisser procedure (cf. Winer, 1971). Where interactions with the factor Electrode are reported, ANOVAs were performed after z score normalization on the mean amplitudes of each condition separately. This procedure is equivalent to the procedure described by McCarthy and Wood (1985, cf. Rosler, Heil, & Glowalla, 1993, see also Bush, Hess, & Wolford, 1993, for a treatment of z-score transformations). Mean amplitude values were computed relative to a pre-stimulus baseline of 150 ms. Figures with ERP data represent average waveforms for the 40 critical items in each priming condition.

Results for the target segment are represented in Figure 2 for the High Proportion List, and in Figure 3 for the Low Proportion List. The waveforms show a number of distinct endogenous effects. Most prominent among these are modulations at the level of the N400. The N400 effects will be discussed first, we will then turn to the other ERP effects.

N400 effects

The major focus of this experiment is on the sensitivity of the N400 to the three prime types as a function of the relatedness proportion. To statistically test possible N400 effects, an ANOVA was performed on the mean amplitudes

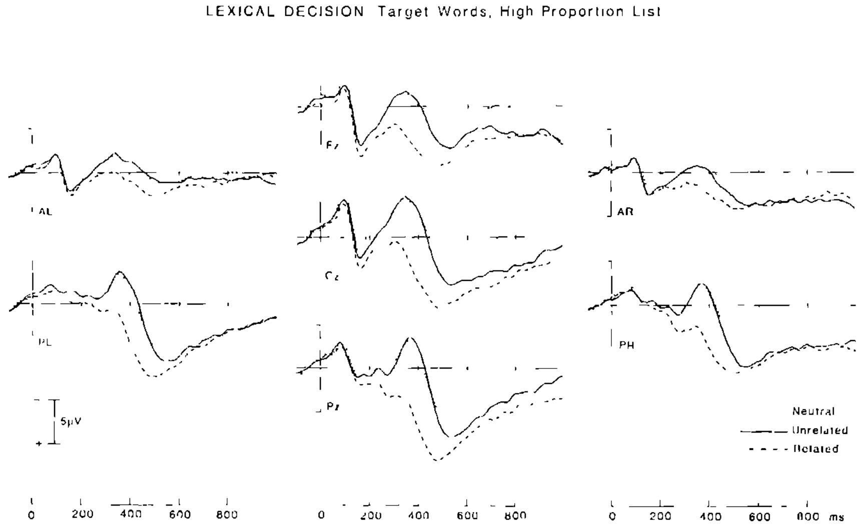

Figure 2 *Lexical decision experiment. ERPs for the target words in the high relatedness proportion list, for the related, unrelated, and neutral conditions. Three midline, two left and two right hemisphere electrode sites are shown. Target onset is at zero ms. Negative amplitude is plotted upwards in this and all following figures.*

in the latency range between 300 and 400 ms after target onset.[1] In addition to a significant main effect of Prime Type (F[1,26]= 40.62, p <.01; MSe= 19.44), this ANOVA revealed a trend towards a Relatedness Proportion by Prime Type interaction, indicating a larger priming effect in the High Proportion List compared to the Low Proportion List. To further substantiate this trend, and because in general N400 effects with visual stimulation are mainly manifest at posterior electrode sites, an ANOVA was performed collapsing over the posterior electrode sites Pz, PL, and PR. This analysis revealed a significant Relatedness Proportion by Prime Type interaction (F [1,26]= 4.45, p <.05; MSe= 10.17). Separate analyses were therefore performed for the High Proportion List and the Low Proportion List.

The ANOVA for the High Proportion List (HPL) yielded a significant main effect of Prime Type (F[1,13]= 28.81, p <.01; MSe= 22.62). A Newman-Keuls test (p <.05) revealed a significantly larger N400 amplitude for both the neutral (-2.18

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[1] *This relatively restricted time window was chosen after visual inspection of the individual subject waveforms. The morphology of the N400 observed in this experiment is quite sharp, with clear ascending and descending flanks. The chosen analysis window does, therefore, capture the relevant aspects of the N400.*

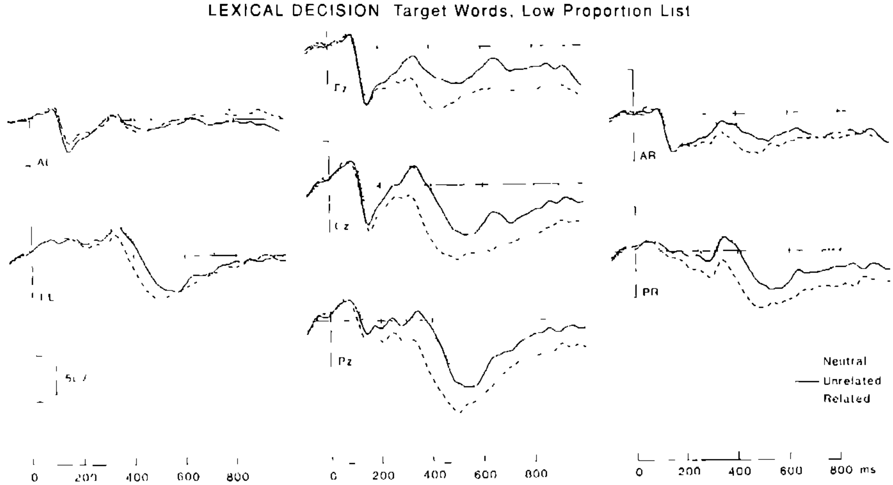

Figure 3 *Lexical decision experiment. ERPs for the target words in the low relatedness proportion list, for the related, unrelated, and neutral conditions. Three midline, two left and two right hemisphere electrode sites are shown.*

uV) and the unrelated condition (-2.07 uV) relative to the related condition (2.34 uV). The neutral and the unrelated condition were not significantly different.

The ANOVA for the Low Proportion List (LPL) similarly revealed a significant main effect of Prime Type (F[1,13]= 12.46, p <.01; MSe= 16.26). The Newman-Keuls test (p <.05) revealed the same pattern of differences as for the High Proportion List, in that both the neutral (-0.55 uV) and the unrelated condition (-0.31 uV) differed from the related condition (2.05 uV), but not from each other.

In addition to the N400 effects, inspection of the waveforms reveals an earlier negative deflection that shows up most clearly at the posterior sites for the neutral condition, as well as a late Slow Wave that also seems to separate the neutral condition from the related and the unrelated conditions. These effects will now be presented in turn.

Early negative effects

The early negative effects, reminiscent of effects on the N200 amplitude, were statistically tested by entering the mean amplitudes in the latency range of 200-300 ms after target onset into an ANOVA. This analysis revealed a significant main effect of Prime Type (F[1,26]= 22.52, p <.01; MSe= 14.53). Neither the main effect of Relatedness Proportion (F[1,26]= 1.72, p= .20; MSe=

53.92), nor the Relatedness Proportion by Prime Type interaction ($F<1$) approached significance. A post hoc Newman-Keuls test ($p < 05$) resulted in a significantly more negative mean amplitude for the neutral condition (HPL 1.43 uV, LPL 0 15 uV) compared to both the unrelated condition (HPL 0.21 uV, LPL 1.02 uV), and the related condition (HPL 1.64 uV, LPL 1.94 uV). Moreover, the difference between the related and the unrelated condition was also significant.

Slow Wave effects

To test the Slow Wave effects, overall mean amplitudes in the area between 600 and 900 ms post-target were entered into an ANOVA. The overal ANOVA yielded a significant main effect of Prime Type ($F[1,26]= 31.80$, $p < 01$; MSe= 14.92). Neither a significant main effect of Relatedness Proportion ($F<1$), nor a significant interaction between Relatedness Proportion and Prime Type ($F<1$) were obtained. A post hoc Newman Keuls test ($p <.05$) showed that the neutral condition was more negative (HPL 0.88 uV, LPL 0.35 uV) than both the related (HPL 3.92 uV, LPL 3.39 uV) and the unrelated condition (HPL 3.38 uV, LPL 2.03 uV). The unrelated condition was more negative than the related condition

Interactions with the factor Electrode. No significant three way interactions with Prime Type and Relatedness Proportion were observed. Significant two way interactions with Prime Type were obtained for the N200, N400, and Slow Wave components. These interactions reflect the distribution of the experimental effects over the scalp The condition effects are minimal at lateral and frontal sites, and maximally different at centro parietal sites. This is in accordance with the standard topography of the components analysed all showing a centro parietal maximum - and has little bearing on the cognitive functional interpretation of the condition effects.

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[2] *Visual inspection of the waveforms indicates a somewhat larger N400 effect over the right (mainly posterior) electrode sites, compared to the left sites, in particular for the low relatedness proportion list This topographic pattern is often seen with visual stimulation (e g , Holcomb, 1988 Holcomb & Neville, 1990 Kutas & Van Petten, 1988, 1994) To investigate whether the effects of the relatedness proportion manipulation interacted with a possible right left topographic difference, we performed two separate ANOVAs with the factors Relatedness Proportion, Prime Type and Hemisphere One ANOVA contrasted right and left sides of the head, collapsing over anterior and posterior electrode sites The other ANOVA focused only on the posterior right and left sites Neither ANOVA revealed any interaction of Relatedness Proportion and Prime Type with Hemisphere*

Summary

In summary, the main finding of this lexical decision experiment is that the overall N400 priming effect as indicated by the difference between the related and the unrelated condition is larger in the High Proportion List (4.41 uV) than in the Low Proportion List (2.36 uV). This resulted in the only significant Relatedness Proportion by Prime Type interaction for the ERP data of this experiment. Relatedness proportion thus has an effect on the amplitude of the N400. In addition, early negative effects and late Slow Wave effects were obtained, but these did not vary as a function of relatedness proportion.

DISCUSSION OF THE TARGET EFFECTS

Reaction time and N400 priming effects

The reaction time results showed the expected effect of the relatedness proportion manipulation (cf. Neely, 1991). That is, inhibition was obtained for the unrelated condition relative to the neutral baseline in the high proportion list, but not in the low proportion list. In addition, the overall semantic priming effect was larger in the high proportion list than in the low proportion list. The relatedness proportion effect is attributed to expectancy induced priming. As was mentioned in the Introduction, this form of priming is thought to emerge because subjects use the prime to generate an expectancy set that contains potential targets related to that particular prime. The relatedness proportion effect results from the increase in the probability that subjects will use the prime to generate an expectancy set as the relatedness proportion increases (Becker, 1980). The pattern of reaction times we obtained indicates that we were successful in making our subjects generate an expectancy set for the high proportion list, and in preventing them from generating an expectancy set in the low proportion list. The presence versus absence of inhibition in the High versus the Low Relatedness Proportion lists, indicates that expectancy induced priming was operative in the High Relatedness Proportion, but not in the Low Relatedness Proportion list.

The statistical analysis of the ERP data revealed that only for the N400 a significant Relatedness Proportion by Prime Type interaction was obtained. This indicates that the size of the N400 effect is influenced by the proportion of related word pairs. Earlier research (Brown & Hagoort, 1993) has shown that the amplitude of the N400 is not sensitive to the automatic spreading of activation between related nodes in the semantic lexicon. The results of the present experiment, then, suggest that the amplitude of the N400 is modulated by expectancy.

However, in contrast to the pattern of reaction time results in the High Proportion List, the amplitude of the N400 for the unrelated condition did not differ from that in the neutral condition That is, the inhibition in the unrelated condition as revealed by longer reaction times compared to the neutral baseline, does not translate into a larger N400 amplitude in the unrelated condition relative to the neutral condition. This result is in line with relatedness proportion effects reported by Holcomb (1988), but contrasts with the work of Koyama, Nageishi, and Shimokochi (1992). However, the two experiments reported by Koyama et al. differ in important respects from those of Holcomb (1988) and of the present study, making a direct comparison difficult[3] To date, the Holcomb (1988) study and the work reported here present the most consistent picture of relatedness proportion effects and the N400 in a lexical decision task.[4]

A possible explanation for the difference we observed between the reaction time and ERP results is that the amplitude of the N400 is especially sensitive to the initial search through the expectancy set, with a reduction in amplitude if the target is a member of the set The inhibition might be more tightly linked to the task related decision process, requiring extra processing of the target features if these do not match candidates in the expectancy set. This, then,

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[3] *Koyama et al found an increased N400 in a high relatedness proportion list for the unrelated condition compared to the related and the neutral condition, but the latter two conditions did not differ In these experiments the same word prime was repeatedly presented both within and across priming conditions, using a stimulus onset asynchrony (SOA) of 1500 ms, which is longer than the SOA used in Holcomb's (1988) and in the present study The prime repetition across all three priming conditions, in combination with the long SOA, could have led to processing strategies that were absent in Holcomb's (1988) and in our experiments In particular the occurrence of one and the same prime with either related or unrelated targets is a factor that could contribute to the saliency for the subjects of the relationship between primes and targets This possibility is enforced by the fact that in the experiment using a low relatedness proportion list, Koyama et al did not observe any effects at the level of the N400, not even the standard difference between the related and unrelated conditions*

[4] *There are, however, some differences, of lesser and greater importance, between Holcomb's study and the present one First, Holcomb did not use a neutral prime stimulus but a blank screen, and so cannot demonstrate as we are able to that the relatedness proportion manipulation brings about the predicted reaction time pattern of facilitation and inhibition In fact, Holcomb did not observe an reaction time difference between his neutral and unrelated conditions Second, Holcomb attempted to influence the subjects' processing of the prime by means of an explicit instruction to attend or not attend to the meaning of the prime This instructional manipulation introduces a degree of uncertainty about the subjects behavior that we have avoided in our study Finally, and in the context of our paper most importantly, Holcomb did not include a comparison with the silent reading task (he had no reason to, given the purpose of the research he was engaged in) This precludes any further analysis of the possibly task induced nature of the relatedness proportion effect, which is of course a major aspect of the work we are presenting here*

would show up in longer reaction times, but not in the amplitude of the N400 Although the amplitude of the N400 seems to reflect semantic expectancy, this cannot be the only priming mechanism that modulates the N400 amplitude Assuming that expectancy did not contribute in any substantial way to the priming effects in the Low Proportion List, the reduction of the N400 amplitude for the related targets in this list indicates that in this case another priming mechanism must be responsible for the N400 effect This priming mechanism most likely is semantic matching (cf Neely, 1991 also called postlexical coherence checking, De Groot, 1984) On the basis of lexical semantic information, the semantic matching mechanism attempts to establish a meaningful (i e , semantic) link between the prime and the target If this matching process is successful, a coherent (i e , integrated) representation results Semantic matching is not considered to be an automatic, reflex like process We would argue, however, that it is a mandatory process (cf Fodor, 1983) and as such a standard part of the task performance during lexical decision The stronger the semantic overlap between prime and target, the better the match, and the more reduced the amplitude of the N400 will be This matching process shares essential characteristics with the integration of word meanings into an overall meaning representation of a sentence

Early negative effects

The separation at the level of the N200 of the neutral and unrelated conditions from the related condition, can be seen as an early indication of the upcoming N400 effect The significant difference between the neutral and the unrelated condition, however, is not linked to the N400 Our explanation here, is that the neutral unrelated difference is reflecting that subjects have aborted any attempt to establish a link between the prime and the target We hypothesize that the reason why this aborted linkage effect should at all come about, is because as a default rule, subjects will always attempt to establish a relation (of whatever nature, but a semantic relation is presumably a standard attempt) between the prime and the target The effect as such, we suggest, arises from stimulus classification operations Specifically, the data indicate that the subjects separately classified the 'blanco' word pairs These pairs represent a separate class for the subjects, both on the basis of their low probability of occurrence within the entire stimulus list, and on the basis of the inability to achieve a match due to the essentially meaningless, and hence non wordlike nature of the neutral prime So, the stimulus classification of the neutral prime leads to a specific effect for the neutral condition, manifesting itself at the level of the N200 as an enhanced negative amplitude Although this interpretation has to remain tentative at this point, there is ample evidence in the ERP literature that stimulus classification effects are reflected in the N200 (see for reviews Pritchard, Shappell, & Brandt, 1991, Ritter, Ford, Gaillard, Harter, Kutas, Naatanen, Polich, Renault, & Rohrbaugh, 1984)

The present data also contribute to the discussion in the psychophysiological literature on the separation of the N200 and the N400 It has at times been claimed that the N400 is nothing but a delayed N200 (see Pritchard et al , 1991, for an extensive review and discussion of the N200/N400 debate) The occurrence of both an N200 and an N400 in our data, together with the fact that only the N400 is modulated by relatedness proportion, strongly suggests that we are dealing with two separate components here

Slow Wave effects

Continued and differential processing of the stimuli beyond the time window of the N400 is reflected in the significant Slow Wave effects in the 600 to 900 ms range post-onset Here no effect of the relatedness proportion manipulation was found, but the waveform for the neutral condition is more negative going than that for the unrelated condition, which, in turn, is more negative than the waveform for the related condition These negative Slow Wave effects can be interpreted as reflecting the differential processing load of the three conditions with respect to the extent to which the subjects can establish any kind of link between the prime and the target The assumption here is that irrespective of the specific task demands, subjects always attempt to construct an integrated representation of the word pair The link that is established can be at any level of representation, be it linguistic or non linguistic, and, hence, involves a broader process than semantic matching, that is restricted to linguistic information If semantic matching is successful, no further attempts at finding a relation between the prime and target are necessary. However, if semantic matching does not establish a link, which will at least initially be the case for the unrelated pairs, and certainly for the targets preceded by a neutral prime, this does not necessarily mean that all attempts at linking the prime and target are abandoned Subjects can continue to try and find a relation of whatever nature, thereby appealing to essentially any kind of knowledge

With respect to the Slow Wave effects that we have observed, the pattern of results is quite clear In the case of a semantic relationship between the prime and the target, a link is readily obtained and, hence, the processing load is low. This is reflected in the Slow Wave for the related condition When the prime and the target are semantically unrelated, a link is more difficult, although not necessarily impossible, given enough time (e.g , *doctor* and *fatigue* are pragmatically related, since doctors often work long shifts). This difficulty is associated with a higher processing load, that emerges as an increased negative Slow Wave for the unrelated condition in comparison with the related condition. The neutral condition, finally, presents the highest processing load in terms of a linkage process Here the subject has essentially almost no features (physical or semantic) available with which to establish a link This interpretation of the negative Slow Wave effects is in accordance with a number of experiments reporting differential Slow Waves as a function of the amount of conceptual processing (see Ruchkin, Johnson, Mahaffey, & Sutton, 1988, for a discussion and functional categorization of Slow Waves).

THE SILENT READING EXPERIMENT: ERP RESULTS FOR THE TARGET WORDS

Whether the expectancy-based priming mechanism is part of the set of processes normally involved in language processing, or whether it is induced by the artificial task situation of reaction time priming studies, cannot be answered on the basis of the current priming literature. To establish priming effects by using reaction time methods, it is necessary to collect responses to the targets in tasks such as lexical decision and pronunciation. Given these task requirements, if the proportion of related pairs is relatively high, generating an expectancy set on the basis of the prime information is a good strategy to meet the demands of the experiment. It might be the case, however, that under the same stimulus conditions the expectancy mechanism is not invoked by subjects if the task requirements do not reinforce such a strategy. Such a situation obtains when subjects are asked to only do what they are used to doing in visual language processing, namely to read the words. An advantage of the ERP method is that in this natural, reading-only task environment, reliable ERP effects can still be obtained. To discover, then, whether expectancy based priming is an artifact of task driven priming studies, or whether it is part of normal language processing, we ran the same experiment in terms of stimuli and conditions as the lexical decision experiment, but without any other task demands over and above the natural one, which is to read the words for understanding.

Results for the High Proportion List and the Low Proportion List are represented in Figures 4 and 5, respectively. All analyses in Experiment 2 were done in exactly the same way as in Experiment 1 We will first discuss the N400 effects, and then turn to the other endogenous effects.

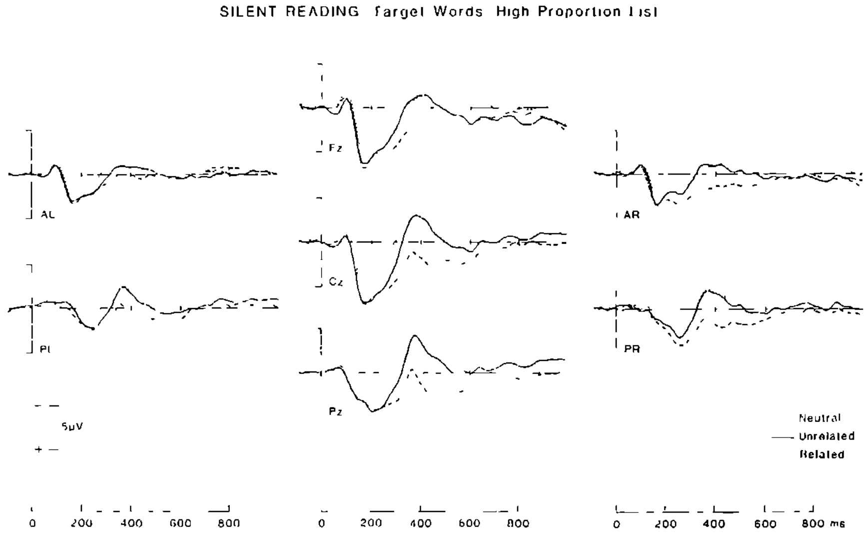

Figure 4 *Silent reading experiment. ERPs for the target words in the high relatedness proportion list, for the related, unrelated, and neutral conditions. Three midline, two left and two right hemisphere electrode sites are shown.*

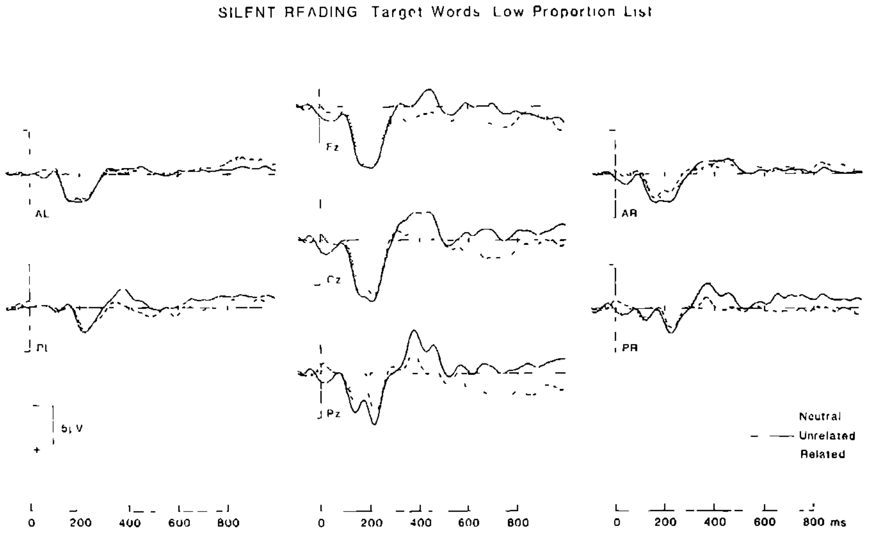

Figure 5 *Silent reading experiment. ERPs for the target words in the low relatedness proportion list, for the related, unrelated, and neutral conditions. Three midline, two left and two right hemisphere electrode sites are shown.*

N400 effects

Inspection of the waveforms indicates that N400 effects emerged slightly later following target onset than in the lexical decision experiment. An ANOVA was performed on the mean amplitudes in the latency range between 350 ms and 450 ms after target onset. This analysis yielded a significant effect of Prime Type (F[1,26]= 25.19, p <.01, MSe= 19.38). However, the Relatedness Proportion by Prime Type interaction did not approach significance (F[1,26]= 1 39, p > 20, MSe= 19.38), indicating the absence of an effect of relatedness proportion on the size of the N400 priming effects. This was substantiated in an analysis on only the posterior electrode sites Pz, PL, and PR (the same analysis as was performed on the lexical decision data), which again did not result in a significant interaction of Relatedness Proportion by Prime Type (F<1). The main effect of Relatedness Proportion was not significant either (F[1,26]= 1.19, p > 25, MSe= 43 60). In order to further substantiate this non-significance, we performed additional post hoc analyses of the relatedness proportion effect for each individual electrode site These analyses clearly confirm the results of the overall ANOVA. In an ANOVA on all three conditions and both relatedness proportions, none of the individual electrode sites show anything approaching a significant interaction of Prime Type with Relatedness Proportion. In an ANOVA contrasting the related and unrelated conditions, 5 of the 7 electrode sites show no effect (PR and AR do show effects). In an ANOVA on the related and neutral conditions, no significant interactions are obtained for any of the electrode sites

A post hoc Newman Keuls test revealed that the neutral condition was significantly more negative (HPL -2.24 uV, LPL 2 72 uV) than both the unrelated condition (HPL -1.68 uV, LPL -1.87 uV) and the related condition (HPL 1 33 uV, LPL -0.26 uV) Moreover, the N400 amplitude in the unrelated condition was more negative than in the related condition.

This difference at the level of the N400 between the neutral and the unrelated condition contrasts with the results of the lexical decision experiment, and is an unexpected finding We do not, however, attach any functional significance to this effect, because its origin most likely lies in a baseline problem for the neutral condition Inspection of the waveforms indicates in particular for the low proportion condition - that the waveform for the neutral condition deviates very early from the baseline, in some cases well before the N1 component The reason for this baseline problem is unknown To investigate whether a baseline shift underlies the effect for the neutral condition, we re analyzed the data, after first normalizing within the 75 125 ms window following target onset This normalization aligns the neutral waveform with the related and unrelated waveforms, at the level of the N1 An ANOVA on the mean amplitudes of the re normalized data in the latency range between 375-475 ms after target onset, yielded a significant effect of Prime Type Once again, the Relatedness Proportion by Prime Type interaction did not approach significance, nor did a main effect of Relatedness Proportion obtain Post hoc

Early negative effects

Although the morphology is not as distinct as in the lexical decision experiment, there are indications of early separations for the different conditions. We tested for possible early effects by entering the mean amplitudes between 200 ms and 300 ms post target into an ANOVA. This analysis yielded a significant effect of Prime Type (F[1,26]= 10 46, p <.01, MSe= 16.62), but not of Relatedness Proportion (F<1). No significant Relatedness Proportion by Prime Type interaction was obtained (F[1,26]= 1.63, p >.25, MSe= 16 62). As in Experiment 1, a post hoc Newman Keuls test (p <.05) showed that the neutral condition was more negative (HPL 1.16 uV, LPL 1 27 uV) than both the unrelated condition (HPL 2.96 uV, LPL 2.64 uV), and the related condition (HPL 3 56 uV, LPL 2 22 uV), but the latter two conditions did not differ from each other.

Slow Wave effects

An analysis of the Slow Wave effects was performed on the mean amplitudes in the area between 600 and 900 ms post target The ANOVA yielded a significant effect of Prime Type (F[1,26]= 11 99, p <.01, MSe= 26.55) Neither the effect of Relatedness Proportion (F<1), nor the Relatedness Proportion by Prime Type interaction (F<1) were significant. A post hoc Newman Keuls test (p <.05) resulted in a significantly larger negativity for the neutral condition (HPL 1.48 uV, LPL 2.48 uV), relative to both the unrelated (HPL 0.06 uV, LPL -0.52 uV) and the related condition (HPL 0.44 uV, LPL 0 55 uV). The unrelated condition and the related condition did not differ.

Interactions with the factor Electrode

The factor Electrode shows the same pattern of effects as in the lexical decision experiment. No three-way interactions with Prime Type and Relatedness Proportion are seen. Significant two-way interactions with Prime Type were obtained for the early negative, N400, and Slow Wave components. Here again, the interactions with Electrode are a straightforward reflection of the distribution of the experimental effects over the scalp, originating from the centro parietal topography of the analyzed components. No significant three way interactions were found with Hemisphere

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Newman Keuls tests showed that the neutral and the unrelated condition were more negative than the related condition Critically, however, after adjusting the neutral waveform with respect to its early deviation from the baseline, no significant difference is obtained between the neutral and the unrelated condition It seems, therefore, that the difference observed in the original analysis should indeed be attributed to a baseline problem for the neutral condition

DISCUSSION OF THE ERP TARGET-EFFECTS

In contrast to the lexical decision task, the silent reading task did not result in a differential N400 priming effect between the High Proportion List and the Low Proportion List. Furthermore, as in the lexical decision experiment, the neutral condition showed a larger early negativity and a larger negative Slow Wave in comparison with the related and the unrelated condition These effects were likewise not affected by the relatedness proportion manipulation.

The early effect for the neutral condition mirrors the effect found in the lexical decision experiment. This can be taken as support for the claim that irrespective of the specific task environment, in the context of a lexical priming paradigm subjects engage in a stimulus classification process. In the present experiments, using a neutral prime (i e , *blanco*), the classification leads to an aborted linkage process for the neutral prime target pairs.

As was argued for the lexical decision experiment, the Slow Wave effects can be interpreted as reflecting differential processing load, connected to continued attempts by the subjects to establish a link - of whatever nature between the members of each word pair The non-significant difference between the related and unrelated conditions, which contrasts with the results of the lexical decision experiment, might be reflecting the fact that subjects are less actively engaged in a linkage process when only silently reading stimuli. It seems reasonable to assume that compared to the silent reading situation, the lexical decision task will elicit more attempts at linking, and, hence, a higher processing load, since it is only in the latter task that a successfully established link can directly aid the task-related decision process.

Although no relatedness proportion effect was found, it is of critical importance to note that a semantic priming effect did obtain in the silent reading task The N400s to the targets in both the neutral and the unrelated condition are significantly larger than elicited by the targets in the related condition. This classical N400 priming effect demonstrates that the subjects accessed the meaning of the primes and the targets, and attempted to relate these meanings together.

ERP EFFECTS TO THE PRIMES IN BOTH EXPERIMENTS

Waveforms for the prime segment (0 700 ms) are represented in Figure 6. Electrode site Cz is shown for both proportion lists and for both experiments

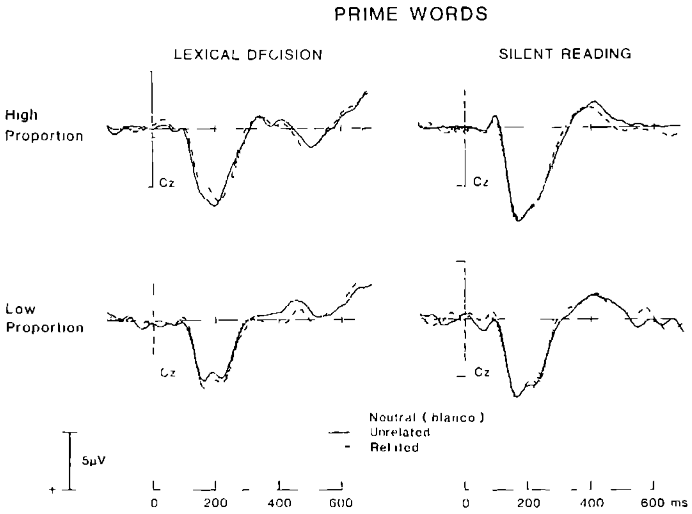

Figure 6 *ERPs to the prime words in both experiments, for both relatedness proportion lists, for the related, unrelated, and neutral conditions. Electrode site Cz is shown.*

Only one electrode site is shown in order to reduce the visual complexity of the figure, but this site is representative of the differential effect for the neutral condition compared to the related and unrelated conditions. Inspection of Figure 6 reveals a clear difference between the waveform for the neutral prime (i.e., the word *blanco*) and the waveforms for the word primes in the related and the unrelated conditions. The waveform for the neutral prime shows a positive deflection relative to the waveforms for the other two conditions The positive deflection starts to become particularly salient at around 300 ms We tested this positivity in an analysis of variance on the mean amplitude in the area between 300 and 500 ms after prime onset, for the lexical decision and silent reading experiment separately.

ERP prime effects in the lexical decision experiment

The overall ANOVA yielded a significant main effect of Prime Type (F[1,26]= 29.93, p <.01, MSe= 13 04). Neither the main effect of Relatedness Proportion (F[1,26]= 1.15, p >.30, MSe= 45.64), nor the Relatedness Proportion by Prime Type interaction (F[1,26]= 1.43, p >.25, MSe= 13.04) approached significance. A post hoc Newman-Keuls test (p <.05) revealed that the neutral condition was more positive (HPL 3.92 uV, LPL 2.78 uV) than both the related condition (HPL 1.09 uV, LPL 1 16 uV) and the unrelated condition (HPL 1.10 uV, LPL 0 37 uV). The latter two conditions did not differ.

In the High Proportion List the positivity is followed by a (more frontal) negative deflection, but carries through as an overall sustained positive shift into the negative shift preceding the target This negative shift can be classified as a contingent negative variation (CNV), reflecting preparatory activity in anticipation of the upcoming target (cf Rosler, Sutton, Johnson, Mulder, Fabiani Plooij van Gorsel, & Roth, 1986) In the Low Proportion List the positivity results in a slightly smaller, but again sustained positive shift in the CNV region

None of the analyses with the factor Electrode show a significant three way interaction with Prime Type and Relatedness Proportion That is, the relatedness proportion manipulation does not elicit different scalp topographies for the analysed components The only significant two way interaction is with Prime Type, and only for the region of the Late Positivity This interaction can be entirely explained in terms of the centro parietal distribution of the Late Positivity for the neutral condition This condition differs greatly at mainly the central and parietal electrode sites from the related and unrelated conditions, which do not differ among themselves at any site

ERP prime effects in the silent reading experiment

The CNV that was observed under lexical decision, is not present under silent reading As in the lexical decision experiment, a clear positive shift is seen for the neutral primes, again starting slightly later than 300 ms after stimulus onset This positive shift is sustained into the time window of the upcoming target, and is largest at posterior sites

The absence of a CNV preceding the target in all of the experimental conditions in the silent reading experiment, in combination with the presence of a CNV in all of the conditions of the lexical decision experiment, might be reflecting differences in the task demands of the two experiments In particular the fact that subjects in the lexical decision experiment are operating under time pressure, having been instructed to respond as rapidly as possible to each target An alternative explanation, however, lies in the presence of the preparation for a motor response in the lexical decision experiment, and in the absence of any motor activity in the silent reading experiment Preparatory motor processes emerge in the Readiness Potential (cf Brunia 1988, 1993), which manifests itself as a slow negative wave in the time window immediately preceding movement

The ANOVA on the positivity resulted in a significant main effect for Prime Type ($F[1,26]= 7.33$, $p < .05$, $MSe= 15.19$). Neither the main effect of Relatedness Proportion, nor the Relatedness Proportion by Prime Type interaction approached significance (both $Fs<1$). A post hoc Newman Keuls test ($p <.05$) revealed that the neutral condition was more positive (HPL 1.67 uV, LPL 1.22 uV) than both the related condition (HPL 0.28 uV, LPL -0.01 uV) and the unrelated condition (HPL 0.41 uV, LPL 0.12 uV). The latter two conditions did not differ.

No three way interactions with the factor Electrode were observed. The only significant two way interaction is with Prime Type and Electrode, and is restricted to the Late Positivity. This topographical effect reflects the posterior distribution of the effect for the neutral condition.

Summary of the ERP prime effects in both experiments

In summary, the results for the prime segment in both experiments do not show a difference between the primes in the related and unrelated conditions. This comes as no surprise given that the word primes in these conditions do not differ in any relevant way. For both the high and low proportion lists, however, the neutral condition is clearly different from the other two conditions, showing a substantial late positive effect. It is important to note that these positivities are not modulated by relatedness proportion.

GENERAL DISCUSSION

On 'neutral' primes

The significant positive deflection in both experiments, and in both relatedness proportion lists, for the primes in the neutral condition compared to the related and unrelated conditions, can be explained as one of two effects, or as a combination of the two.

A first explanation of the positivity is to interpret it as a repetition effect. In contrast to the related and unrelated conditions, in the neutral condition the same prime (i.e., *blanco*) is repeatedly presented. It is by now firmly established that compared to control items, ERPs to repeated words are characterized by a topographically widespread and temporally sustained positive-going shift (e.g., Besson & Kutas, 1993, Rugg, 1985, 1987, Rugg & Doyle, 1992, Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991). The positive shift that we observe for the neutral primes can be interpreted as an effect of the repeated activation of a representation in lexical memory, perhaps in combination with the repeated activation of the episodic trace of that event (cf. Rugg, 1987).

A second explanation of the positivity is to interpret it as an effect of the probability of occurrence of the *blanco* stimulus. It is well-established that task relevant attended stimuli that have a relatively low probability of occurrence, elicit a so-called P300 component in the ERP waveform (cf. Fabiani, Gratton, Karis, & Donchin, 1987). Within the entire list of stimuli of the present experiment, the neutral primes are low probability events. That is, assuming that the subjects classify the neutral prime as a different kind of stimulus than the words and nonwords, then within the entire list of stimuli the neutral prime can be seen as an 'oddball' stimulus. Hence, the positive effect we observe could be interpreted as a P300 oddball effect. What this would mean in the context of the current experiment, is that subjects are sensitive to the fact that the neutral prime stimuli are low probability events relative to all the meaningful word primes they are presented with. Part of this sensitivity possibly stems from the fact that the neutral stimulus *blanco* is essentially meaningless, in clear contrast with the semanticity of all the other primes.

Within the context of the two experiments reported here, we remain agnostic as to whether the positivity we have obtained should best be characterized as a repetition or as an oddball effect The experiment was not intended to investigate this distinction, and the design does not allow to separate the two An important point to reiterate here, is that the positive shift is not in any way affected by the relatedness proportion manipulation, which is the main variable under investigation in the present series of experiments

Turning to the issue of the appropriateness of the *blanco* prime as a neutral stimulus, the data show that the *blanco* prime elicits differential processing compared to the word primes used in the related and unrelated conditions This effect obtains irrespective of whether subjects are engaged in a lexical decision task, or are only reading the stimuli. Note, however, that using this particular neutral prime, we replicate the standard reaction time relatedness proportion effect, and in this respect our results are consistent with the reaction time literature. However, what our ERP results indicate, is that despite the label of 'neutral prime', the *blanco* stimulus stands apart from other word primes

We cannot conclude from the ERP effect for the *blanco* prime that a string of non letter symbols is therefore a more adequate neutral stimulus. In this respect the present data do not resolve the discussion on word versus nonword neutral primes However, our data do indicate that perhaps this discussion is misguided. What might well be at stake is not so much the nature of the neutral stimulus itself, but its relative saliency as a particular kind of stimulus within the entire list of stimuli This saliency is in part determined by the multiple repetition of the stimulus, and in part by its probability of occurrence. These two factors make the neutral stimulus a distinct event during the experiment, and this distinctiveness results in differential processing. This possibility has been speculatively mentioned in the literature (e.g., De Groot, 1983, Jonides & Mack, 1984, Shelton & Martin, 1992). Our ERP data provide the first firm evidence that neutral primes can indeed be less neutral than one might want.

Priming mechanisms and task effects

One of the most striking aspects of the current results is the processing difference observed between the lexical decision and the silent reading task at the level of the N400 to the target words. In the lexical decision task the amplitude of the N400 is modulated by the proportion of related word pairs in the list, whereas in the silent reading task no statistically significant modulation occurs. At the same time, both tasks show N400 effects of semantic relatedness The amplitude of the N400 to unrelated target words is larger than the amplitude to related words. This latter finding demonstrates that in both of the ERP experiments subjects were engaged in the conjoint processing of the meaning aspects of the primes and targets, and that the priming mechanism responsible for bringing about this semantic effect is reflected in the N400, independent of the particular task requirements. It would seem then, that the N400 effects due to relatedness proportion arise from a priming mechanism that, in the context of the word priming studies presented in this paper, is specific to the lexical decision task

The accepted explanation for relatedness proportion effects is to posit an expectancy-induced priming mechanism (cf. Neely & Keefe, 1989). That is, the presence of a relatively high proportion of related word pairs induces subjects to use a strategy in which they generate an expectancy on the basis of the meaning of the prime about which target word(s) will follow. If this expectancy is met, then processing of the target word will be facilitated relative to a neutral baseline, and the processing of unrelated (i e., unexpected) targets will be inhibited. In lists with a relatively low proportion of related word pairs, expectancies are not generated, and, hence, no inhibition effect for unrelated word pairs relative to a neutral baseline is predicted. This is exactly the pattern of results we obtained in the reaction time data of the lexical decision experiment. We can, therefore, confidently claim that an expectancy-induced priming mechanism was instantiated by the subjects whilst reading the high relatedness proportion list during the lexical decision experiment.

We learn, then, two main things from the differential pattern of N400 effects for the lexical decision and silent reading experiments. First, the N400 is sensitive to expectancy induced priming. This finding has implications for characterizing the processing nature of the N400. Second, expectancy-induced priming as brought about by manipulating relatedness proportion, is not a natural part of the language comprehension process. This finding has implications for the inferences that can be made from (lexical decision) reaction time data to the process of on-line language comprehension. We will expand on each conclusion in turn

The processing nature of the N400

What processes are reflected by the N400 effect in the silent reading task? Given the absence of a relatedness proportion effect in this task, we can rule out expectancy induced priming Previous research by Brown and Hagoort (1993) has shown that under conditions of masked priming no N400 effect is obtained. Masking prevents conscious identification and, hence, eliminates strategies such as expectancy and semantic matching (cf. Holender, 1986, Marcel, 1983, Neely, 1991). Masking thereby enables a relatively uncontaminated assessment of the process of automatic spreading of activation. The absence of N400 effects under masking conditions of the prime, therefore demonstrates that automatic spreading of activation is not reflected in the N400. Besson, Fischler, Boaz, and Raney (1992), and Kutas and Hillyard (1989) have presented data on the basis of which they claim that automatic spreading of activation does emerge in the N400. However, their results can also be explained by other priming mechanisms, and do not necessitate an explanation in terms of automatic processes (see Chwilla, Brown, & Hagoort, 1995, for an extended discussion of this issue).

In terms of the three semantic priming mechanisms discussed earlier, only semantic matching remains as the eliciting factor for the semantic priming ERP effect in the silent reading data. This fits well with our assumptions concerning the processes that are operative during silent reading. Given that the subject is not confronted with extraneous task demands, all he/she has to do is to read the letter strings. Subjects are engaged in this relatively natural reading process, and as part of the lexical analysis process gain access to the meaning of the individual words The N400 effect reflects the fact that subjects engage in a matching process based on the meanings of the words of each pair. Even in the absence of overt task performance, it appears that an attempt to bridge the meanings of the two words is a standard aspect of the comprehension process. This makes sense when we consider that constructing a coherent higher-order meaning representation is one of the most basic characteristics of ordinary language comprehension

On a more general level, the following picture emerges from the present and previous findings with respect to the processing nature of the N400. First, the N400 amplitude is not modulated by the automatic process of spreading activation in the semantic lexicon (cf. Brown & Hagoort, 1993). Second, the controlled process of expectancy-induced priming does emerge in the N400 amplitude. However, this is not a general but a task-specific effect. Third, a semantic matching process underlies the N400 effect in the silent reading data. Combining these three findings leads to the conclusion that outside of possible task contamination effects (which can be avoided as the present research has shown), the N400 effect is primarily a reflection of those lexical processes that are involved in semantic integration, either at the word-word level, or at the level of higher-order sentential semantics (cf. Chwilla et al., 1995, Chwilla, Hagoort, & Brown, 1995, Hagoort, Brown, & Groothusen, 1993, Holcomb, 1993, Rugg, Furda, & Lorist, 1988).

Effects specific to reaction time tasks

Turning to the implications of the second main conclusion that follows from the present results, the ERP data provide a novel line of evidence concerning the impact of task specific effects. In particular, the link between lexical decision reaction time data and on line language comprehension processes is shown to be problematic, in as far as the relatedness proportion effect is concerned.

On the basis of the fact that a relatedness proportion effect is observed at the level of the N400 in the lexical decision task, but not in the silent reading task, we suggest that expectancy-induced priming is not a natural aspect of the language comprehension process. Note that in principle there is no reason why in the silent reading task subjects should not instantiate an expectancy-induced priming mechanism. After all, subjects are confronted with exactly the same list of stimuli as in the lexical decision experiment, and as is shown by the significant N400 effect between related and unrelated targets, subjects are processing the stimuli at a semantic level during silent reading. The absence of a relatedness proportion effect in the silent reading task does, therefore, strongly imply that the specific mechanism of expectancy-induced priming is not operative during silent reading, and, hence, that in the present experiment the task characteristics of lexical decision are responsible for instantiating expectancy-induced priming. It should be noted here, that these task characteristics are probably not specific to lexical decision, since relatedness proportion reaction time effects have also been reported when using the pronunciation task (cf Keefe & Neely, 1990). In other words, the presence of a binary decision component in the lexical decision task is insufficient explanation for the occurrence of expectancy induced effects. Speed might be a contributing factor, since this is shared by both the lexical decision and the pronunciation task (at least in its immediate articulation variant) An emphasis on speed could incline subjects to invoke any kind of strategy that can assist them. In the case of lexical decision, predicting which word will appear on the basis of the meaning of a prime, can assist the lexical decision if the prediction turns out to be correct, and this will generally be the case in a list with a high proportion of related word pairs. Under the assumption that the silent reading lexical priming paradigm shares aspects of the normal reading process, the current data show that an expectancy strategy of predicting what word(s) will follow a given word, is not a standard part of the reading process. In this respect, the silent reading task is the more natural one No strategies need to be invoked. Subjects can focus on what is the essence of language comprehension, be it written or spoken Grasp the meaning of the input and relate it to the context within which it occurs.

Further research is required to exactly pinpoint the factor(s) involved in bringing about expectancy-induced priming effects. The present data provide the first firm evidence that these effects are indeed artifactual, and do not reflect normal lexical processing.

CHAPTER IV

The Mechanism underlying Backward Priming: Spreading of Activation versus Semantic Matching

ABSTRACT

Backward priming effects are typically ascribed to postlexical strategies However, it has also been proposed that backward priming stems from spreading of activation. We determined the locus of the effect in lexical decision by assessing backward priming effects on the N400 and reaction time. Both measures were used because previous research had suggested that N400 priming effects reflect semantic matching and expectancy-induced priming, but in contrast to reaction time do not reflect spreading of activation. Backward priming effects were obtained for both measures. The sensitivity of the N400 to purely backward relationships indicates that backward priming mainly arises from either semantic matching or expectancy induced priming. The contribution of the latter mechanism was investigated by varying the inter stimulus interval (0, 500 ms) Backward priming effects were obtained for both intervals, but no modulation in N400 effect as a function of interval was found. Taken together, the presence of N400 backward priming effects and the absence of an interaction with interval indicates that postlexical processes arising from semantic matching play a major role in mediating backward priming effects in lexical decision.

INTRODUCTION

In this study we investigate the effects of backward priming, within the framework of the model of semantic priming as proposed by Neely and Keefe (1989) In particular, we focus on the mechanism that underlies backward priming We combine the reaction time and an electrophysiological measure to separate the effects of automatic spreading of activation from the effects of semantic matching in bringing about backward priming Before presenting the experiment, we will first describe the relevant semantic priming effects and the three mechanisms that are supposed to underly these priming effects Second, we will briefly discuss semantic priming effects observed with a particular Event Related Brain Potential (ERP) component, the N400 Finally, we will discuss backward priming and how each of the priming mechanisms may account for backward priming effects

One of the most consistent findings in the psycholinguistic literature of the last twenty years is that words are processed more efficiently, as reflected in decreased reaction times and/or error rates, when they are preceded by a semantically or associatively related compared to an unrelated word (for a review see Neely, 1991) For example, subjects respond faster to the word doctor when it is preceded by nurse than when it is preceded by an unrelated word like carrot This so called priming effect has been observed in a variety of tasks, ranging from sentence verification (Loftus 1973) to lexical decision (e g Meyer & Schvaneveldt, 1971) and naming (e g , Balota & Lorch, 1986 De Groot, 1985)

One mechanism that has often been used to explain this effect is automatic spreading of activation as described by Collins and Loftus (1975) Spreading of activation is based on the assumption that in semantic memory strong or direct links exist between words that are closely related in meaning Presentation of a word activates the corresponding node of this word in semantic memory, and via the links to nearby nodes part of this activation automatically spreads to words that are related in meaning As a consequence, the activated nodes representing related words need less time for subsequent processing Spreading of activation has all the characteristics of an automatic process It is fast acting, of short duration, does not require attention or awareness, and presupposes no or only minimal demands on resource capacity (Posner & Snyder, 1975 Shiffrin & Schneider, 1977)

In a recent review on semantic priming in visual word recognition, Neely (1991) concluded that no single priming mechanism is able to account for the full spectrum of reaction time priming effects One basic problem for any single mechanism is to account for the differences in priming effects that are observed between tasks and under variable intervals between primes and targets. These differences between tasks, in particular between the naming and the lexical decision task, can only be explained by assuming that more than one priming mechanism contributes to the reaction time priming effect. According to Neely, in order to give a complete account of these effects, the existence of at least two other priming mechanisms in addition to automatic spreading of activation has to be postulated.

The first of these is expectancy-induced priming (Becker, 1980, 1985, Posner & Snyder, 1975). This is a predictive strategy, in which the subject uses the information provided by the prime to generate an expectancy set for related target words. The resulting reaction time pattern is dependent upon the size of the expectancy set. If the expectancy set is small, as is the case for antonyms, then a facilitation dominant pattern is observed. In this case, related target words will be recognized very quickly, whereas the inhibition effect for unrelated target words will be small. In contrast, if the expectancy set is large, as is the case for category relationships, then an inhibition dominant pattern is obtained. In the latter case the facilitation effect for related target words will be small because the subject has to search through a large number of category exemplars to find the related target in the expectancy set. The inhibition effect for unrelated target words, however, will be rather large, because the exhaustive search through the expectancy set has to be completed before the response to the target word (typically lexical decision) can be initiated. The generation of an expectancy set takes time, so that the effects of this mechanism are usually only obtained at intervals that are longer than approximately 500 ms (De Groot, 1984, Neely, 1977).[1] Moreover, this mechanism can be influenced by instruction as well as by the list structure of the material, for example by the proportion of related word pairs (e.g., Fischler, 1977). As such, expectancy-induced priming has been characterized as a controlled process.

The second additional mechanism is semantic matching (Neely & Keefe, 1989, also called postlexical meaning integration by De Groot, 1985). Both the semantic matching and the meaning integration model assume that subjects in the lexical decision task match primes and targets postlexically (i.e., following lexical access and selection) for semantic similarity. According to Neely and Keefe who give the most detailed description of the matching process,

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[1] *Note that Neely (1977) showed that it took more than 500 ms to generate an expectancy set for words that are unrelated to the target word Therefore, the question remains how much time is required to generate an expectancy for related word pairs A recent study of Stolz and Neely (1995) indicates that an expectancy set for related pairs is only obtained at SOAs longer than 200 ms*

nonwords activate the lexical entries of words, namely of those words that are visually similar. Because in the typical lexical decision task care is taken that the nonword target never looks like a word related to its preceding prime word, the presence versus absence of a semantic relationship between the prime and the target provides information about the lexical status of the target word. Since a semantic match is only found on related word trials and no such match is found on all nonword trials the word/nonword decision is influenced by the outcome of this matching process Therefore, the detection of a relationship between the prime and the target, leads to a bias to respond 'Word', whereas the absence of such a relation invokes a bias to respond 'Nonword'. When the nonword ratio is high, the use of the semantic matching strategy will be particulary helpful, and thus it should be used more often, as the results of Neely, Keefe, and Ross (1989) have shown.

Neely (1991) and De Groot (1985) differ in their view on the nature of the integration process According to Neely semantic matching is under strategic control and as such it is conceived as a more or less controlled process. In contrast, De Groot (1985) has proposed that the postlexical meaning integration process reflects a fast acting process that can already be observed with very short Stimulus-Onset Asynchronies (SOAs)

In summary, three mechanisms are supposed to underly semantic priming The assumption is that two of these mechanisms share core characteristics with processes involved in ordinary language comprehension Automatic spreading of activation shares core characteristics with the process of lexical access, i.e., the process of accessing the mental lexicon and activating a subset of all the words in the lexicon. Semantic matching shares characteristics with postlexical integration processes, i.e , integrating a lexical element into a higher order representation of the entire sentence or discourse.

More recently, the Event-Related Brain Potential method has been applied to the study of language. It has been established that reliable semantic priming effects are obtained for a particular ERP component, the so-called N400 (see for reviews Kutas & Van Petten, 1988, 1994). The N400, a negative peak with an average latency of 400 ms relative to target onset, is smaller in amplitude when a target word is preceded by a semantically related prime than when it is preceded by a semantically unrelated word (e g., Bentin, McCarthy, & Wood, 1985, Holcomb, 1988, Holcomb & Anderson, 1993, Holcomb & Neville, 1990,

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Here it is assumed that the mental lexicon is comprised of a well defined word meaning component in systematic relationship with linguistic word-forms This implies that associative and semantic relationships are represented at the level of the lexicon

Kutas & Hillyard, 1989). This difference in amplitude is referred to as the N400 priming effect.

Previous studies investigated the processing nature of the N400. More specifically, the question was addressed whether the N400 mainly reflects lexical access or lexical integration functions. The results of these studies indicate that the N400 priming effect mainly, if not exclusively reflects postlexical integration processes (Brown & Hagoort, 1993, Chwilla, Brown, & Hagoort, 1995, Chwilla, Hagoort, & Brown, 1994; Osterhout & Holcomb, 1994, Rugg, Furda, & Lorist, 1988), as well as, in certain task situations, expectancy-induced priming (Holcomb, 1988, Brown, Hagoort, & Chwilla, submitted).[1] Strong support for the notion that the N400 reflects postlexical integration processes that arise from semantic matching, comes from two studies in which a clear dissociation between reaction time and the N400 has been observed.

Brown and Hagoort (1993) did not find an N400 priming effect under masked presentation of the prime (see also Neville, Pratarelli, & Forster, 1989), whereas under the same conditions a reliable reaction time priming effect was obtained. Holcomb (1993) assessed the effects of stimulus degradation on the size of the reaction time and the N400 priming effect. Behavioral studies have shown that degradation reduces the speed of word processing and that this effect interacts with semantic priming (Meyer, Schvaneveldt, & Ruddy, 1975), with larger priming effects for degraded stimuli. According to additive factors logic (Sternberg, 1969) the interaction reveals that degradation and semantic priming affect the same processing stage, claimed to be an early encoding stage (i.e., lexical access). Holcomb found an interaction of degradation with semantic priming for reaction times, but degradation did not modulate the size of the N400 priming effect. Taken together, the results of both studies indicate that the N400 priming effect is not affected by automatic spreading of activation and thus reflects only a subset of the priming mechanisms

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[1] *Note that the issue whether the N400 reflects lexical access or integration functions is not completely settled. In particular, the presence of N400 priming effects in shallow processing tasks, in which the processing of the semantic aspects of the words was not required, has been taken as evidence that the N400 is also sensitive to automatic spreading of activation (Besson, Fischler, Boaz, & Raney, 1992 Kutas & Hillyard, 1989) However, as extensively discussed elsewhere (Chwilla et al, 1995), the presence of N400 priming effects in shallow processing tasks per se is not compelling evidence against a semantic matching account of the N400. The reason for this is that the observed priming effects might reflect that despite the fact that a particular task does not require semantic processing, semantic processing might still have been involved To resolve this issue more objective criteria are needed to determine whether the performance of a so called "shallow task" involves lexical processing or not The only study that demonstrated that the shallow task was indeed performed non-lexically at the reaction time level, did not observe an N400 priming effect (Chwilla et al, 1995)*

measured with reaction times. In the present paper we assume that the N400 priming effect reflects only two of the three postulated priming mechanisms, namely semantic matching and expectancy induced priming, whereas reaction time is also affected by automatic spreading of activation The strongest piece of evidence for the sensitivity of the reaction time measure to the mechanism of automatic spreading of activation is the demonstration of priming effects in masked priming studies, in which conscious perception of the prime is prevented (e.g., Balota, 1983, Fowler, Wolford, Slade & Tassinary, 1981, Marcel, 1983).

Backward priming

The central issue of this paper is the phenomenon of backward priming. Koriat (1981) demonstrated that the presence of a backward association from the target to the prime can yield priming effects and referred to this facilitation as backward priming The goal of the present study is to assess which priming mechanism is responsible for backward priming effects. Before presenting a theoretical analysis of how different priming mechanisms can account for backward priming we will first clarify what we mean by this term. In the literature there are two different notions of backward priming In Koriat's (1981) study, this term refers to the effect of a backward association between two words (the prime and the target) on the lexical decision to the target. For example, presentation of the word "stork" yields the word "baby" in an association test, whereas presentation of the word "baby' does not evoke the word "stork" as an associate Therefore, in the case of the word pair "baby stork" there exists a unidirectional backward associative relationship between the prime and the target In contrast, Kiger and Glass (1983) reversed the temporal sequence, i.e , they presented the prime (e.g ,"baby") very shortly (SOA= -65, 130 ms) after the target (e g.,"stork"), to which a lexical decision was required Kiger and Glass found a facilitation for the short 65 ms SOA and called it "backward priming" [4] They interpreted their results as supporting the view that words are processed in parallel, provided they are presented within some minimal time interval of each other In the present paper the term

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[4] *Prather & Swinney (1988) argue that the facilitation observed by Kiger and Glass does not reflect priming but rather a reduction of an interference effect After all, asking subjects to make a lexical decision in response to a very briefly reported word, and requiring them to immediately process another word following that word (all within 65 milliseconds) is most likely to cause a great deal of interference in lexical decision to that initial word This view is supported by the fact that the reaction times in this study were quite long (about 700 ms), compared to normal lexical decision latencies which are typically in the range of 400 500 milliseconds*

backward priming refers to the first notion, as described by Koriat, namely facilitated recognition of a target due to a unidirectional relationship from the target to the prime.

The main question addressed in this study was, which priming mechanism underlies backward priming? Let us first consider which of the three priming mechanisms can explain effects of backward priming, and if so in what manner

Expectancy-induced priming In expectancy-induced priming it is assumed that the subject uses the information of the prime to generate an expectancy set for potential target words This mechanism can only account for backward priming under the assumption that the subject generates backward associates for the targets that have not yet been encountered In the case of a unidirectional backward relationship between the target and the prime, however, the chance that the subject generates the backward associate is most likely minimal Therefore, a priori it is very unlikely that backward priming is evoked by this mechanism

Automatic spreading of activation At first sight it is unclear how automatic spreading of activation can account for backward priming The problem arises from the fact that the most commonly used spreading activation model (Collins & Loftus, 1975) assumes that the processing of the prime affects the processing of the target *before* the target has been presented It is thereby assumed that the activation only spreads forward from the prime to the target [5] With some elaboration, however, automatic spreading of activation can account for backward priming. In order to do this, it has to be assumed that there is a feedback loop between the target and the prime. Based on the notion that the processing of the target "reactivates" the prime, Koriat (1981) proposed that backward priming effects were due to spreading of activation More specifically, he suggested that when a prime is followed unexpectedly by a related target it tends to be reactivated by the target and that this activation facilitates the processing of the target word. Moreover, he proposed that forward priming effects were brought about by subjects' expectancies, thus reflecting a controlled process. This notion is at odds with the commonly held view that in addition to expectancies, automatic spreading of activation plays a prominent role in evoking forward priming effects Therefore, an alternative

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Note, that the feature of unidirectionality does not apply to all models of spreading of activation In particular, the ACT model of Anderson (1983) accounts for priming in a fundamentally different way According to this model several words can be sources of activation simultaneously Priming effects are obtained because the prime is still active when the target is presented* explanation of backward priming in terms of a postlexical semantic matching strategy has been presented by Seidenberg, Waters, Sanders and Langer (1984)

Semantic matching Seidenberg et al. (1984) proposed that backward priming is due to a postlexical mechanism, and that forward priming is due to automatic spreading of activation. They argued that priming for backward associated word pairs could only arise from a postlexical relatedness checking strategy, because only then the backward relationship from the target to the prime could become obvious to the subject. Notice, that in the case of the semantic matching mechanism, the relatedness checking is probably independent of the order in which the words that have to be matched for semantic similarity are presented. Backward priming is therefore compatible with this mechanism. Seidenberg et al. (1984) tested their hypothesis by investigating the effects of forward and backward associates in the lexical decision and the naming task. This approach was based on the results of West and Stanovich (1982), who had shown that the two tasks were differentially sensitive to pre- versus postlexical processes. More specifically, West and Stanovich (1982) claimed that the naming task is a pure measure of prelexical processes that arise from automatic spreading of activation, whereas the lexical decision task is affected by prelexical and postlexical processes Thus, if the Seidenberg et al hypothesis is correct, forward priming should occur in both tasks, whereas backward priming should only be obtained in the lexical decision task The results confirmed these predictions. Seidenberg et al. (1984) replicated Koriat's finding that backward priming effects are obtained in a lexical decision task, but they obtained no such effect in a naming task From this result they concluded that backward priming effects were restricted to the lexical decision task, probably because this task is especially sensitive to postlexical strategies (cf. Balota & Lorch, 1986, De Groot, 1984, Den Heyer, Briand, & Dannenbring, 1983, Tweedy, Lapinski, & Schvaneveldt, 1977, West & Stanovich, 1982). Based on the results of the Seidenberg et al. study the effects of backward priming have been typically attributed to a postlexical relatedness checking strategy (Balota & Lorch, 1986, Neely & Keefe, 1989, Neely, 1991, Shelton & Martin, 1992), and the possibility of an automatic spreading of activation account of backward priming has been largely ignored

Recent results, however, are not entirely consistent with an account of backward priming in terms of a postlexical relatedness checking strategy. Peterson and Simpson (1989) assessed backward priming effects in the lexical decision and the naming task. They demonstrated that with the use of short inter-stimulus intervals (ISI) of 0 or 200 ms and a cross-modal presentation (an auditory prime was followed by a visual target) backward priming can be observed not only in a lexical decision task but also in a naming task. However, in contrast to the lexical decision task, in the naming task the backward priming effect was strongly reduced in the 200 compared to the 0 ms ISI condition. On the basis of their finding they argued that backward priming in the naming task only occurs when the processing of the prime and the target overlap in time, i.e., that the prime has not yet been fully recognized when the target appears. Peterson and Simpson proposed that the locus of the backward priming effect differs in the two tasks They argued that backward priming in the naming task arises from facilitation in lexical retrieval processes (e g , automatic spreading of activation in our terminology), whereas backward priming in the lexical decision task arises from postlexical processes, at least at the 200-ms ISI. A problem with this analysis is that it leaves unexplained which processes underlie backward priming in the lexical decision task at the 0 ms ISI. According to Peterson and Simpson (p. 1027, note 2) this effect could either be due to automatic spreading of activation, or to a postlexical relatedness checking strategy.

From the above analysis it is clear that the possibility that backward priming arises from automatic spreading of activation cannot be excluded. In fact, the overall pattern of results of the Peterson and Simpson study appears to be not inconsistent with such a view.

The aim of the present study was to further determine which priming mechanism evokes backward priming effects This was accomplished by assessing the effects of backward priming on reaction time and the N400 in a lexical decision task with an auditory prime and a visual target.[6] For reaction time we predict backward priming effects. However, because reaction time is affected by both prelexical as well as postlexical processes it is difficult to determine the locus of the effect with the reaction time measure alone. In this study we combined the reaction time and the N400 measure to separate the effects of automatic spreading of activation from the effects of semantic matching and expectancy-induced priming. Assuming that the N400 reflects processes that arise from semantic matching and expectancy-induced priming, but does not reflect automatic spreading of activation, the sensitivity of the N400 to backward priming has important consequences with regard to the mechanism that underlies the effect. If backward priming effects are obtained for the N400 and reaction time alike, both with a short and a long ISI, this would provide strong evidence in favour of a semantic matching account of

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[6] The reason for using a cross modal presentation was that in a subsequent study we planned to assess the effects of multiple activation on ERPs Since the reaction time studies that investigated these effects typically used an auditory prime and a visual target (e g , Zwitserlood, 1989 Zwitserlood & Schriefers, 1995) it was important to examine N400 priming effects under these presentation conditions

backward priming. In contrast, if backward priming effects are observed for reaction time but not for the N400, this would provide strong support for an automatic spreading of activation account of backward priming.

In addition, we attempted to separate the effects of expectancy-induced priming from the effects of semantic matching by varying the inter-stimulus interval (0 versus 500 ms). The time course provides additional information with regard to the mechanism that underlies backward priming (De Groot, 1984, Den Heyer, 1985, Den Heyer et al., 1983, Tweedy et al., 1977). Since the generation of an expectancy set is time-consuming, expectancy-induced priming could only account for backward priming effects for the ISI of 500 ms. In contrast, most likely semantic matching already takes place at very short ISIs (De Groot, 1985), so that this mechanism can account for backward priming effects at both intervals. Thus, in the unlikely case that backward priming effects arise from the mechanism of expectancy induced priming, both reaction time and N400 backward priming effects should only be obtained at the ISI of 500 ms, but not at the ISI of 0 ms.

METHOD

Subjects

Twenty-eight right-handed subjects, 20 female and 8 male (Mean age=23.7, SD=3.67) participated in the experiment. Hand dominance was assessed with an abridged Dutch version of the Edinburgh Inventory (Oldfield, 1971). Eight subjects reported the presence of left-handedness in their immediate family. All subjects were native speakers of Dutch, and had normal or corrected-to-normal vision. Subjects were paid DFL. 10 per hour.

Apparatus and stimuli

Subjects were seated in a comfortable reclining chair in a dimly illuminated, sound attenuating, and electrically shielded chamber. The response device containing two push buttons was fixed on a small table in front of the subject. The stimuli consisted of 528 cross modally presented pairs of spoken words and visual letter strings (prime and target combinations). The prime was presented binaurally through headphones. The target was presented visually at moderate contrast at the center of a PC monitor (window of 8 by 2 cm, approximately 3.0° X 0.8°). As targets, letter strings of three to eight letters were presented. Half of the target stimuli were real Dutch words and the other half were nonwords. The nonwords were constructed in accordance with the phonotactic constraints of Dutch, and were derived from real words by substituting one or two letters. The primes of the word word and the word-nonword pairs were matched with respect to word class and the number of syllables

The critical prime target combinations consisted of 66 bidirectionally related word pairs (e.g., 'spider-web'), 66 bidirectionally unrelated word pairs (e.g., 'bird soap'), 66 unidirectionally forward related word pairs (e g., 'stork-baby'), and 66 unidirectionally backward related word pairs (e.g , 'baby-stork'). Thus, 198 out of 264 word word pairs were related yielding a relatedness proportion of .75. The nonword ratio as defined by Neely and Keefe (1989) (i.e., the proportion of trials with a nonword target and a word prime out of all trials in which targets are unrelated to their word primes) was .80, since in 264 out of the 330 trials a nonword target was preceded by an unrelated prime word

A pair was considered to be bidirectionally related when prime and target were the first or second associate of each other (43 and 23 word pairs, respectively), according to Dutch word-association norms (De Groot, 1980, De Groot & De Bil, 1987). Associative strength was determined by the percentage of report of the target as an associate of the prime among 100 university students. The mean percentage of association for the bidirectionally related pairs was 43 (SD=19) in forward direction, and 41 (SD=21) in the backward direction A pair was considered to be bidirectionally unrelated if the target neither occurred as an associate of the prime in these norms, nor had any other obvious relation to the prime and vice versa. A pair was considered to be unidirectionally forward related when an associative relation existed from the prime to the target, but not from the target to the prime. Correspondingly, a pair was considered to be unidirectionally backward related when an associative relation existed from the target to the prime, but not from the prime to the target. Association norms were used, where possible, to verify these relations (De Groot & De Bil, 1987, Lauteslager, Schaap, & Schievels, 1986). For some of the word pairs no association norms were available, these word pairs were presented to a small group (N=7) of native speakers Only those pairs that were unanimously judged as being asymmetric in the desired direction were used Both sets of unidirectionally related pairs consisted of associative relationships as well as of compounds For the ease of description we will refer to the bidirectionally related pairs as the related pairs, to the bidirectionally unrelated pairs as the unrelated pairs, to the unidirectionally forward related pairs as the forward related pairs, and to the unidirectionally backward related pairs as the backward related pairs.

A pilot reaction time study was performed to match the word targets of the different relatedness categories on reaction time. In this pilot study all word and nonword targets were presented in isolation A separate group of subjects (N=24) performed a lexical decision task They had to indicate whether the target word was a real word or not On the basis of these reaction times 66 critical target words were selected for each of the four relatedness categories The mean reaction time to the critical items was 504 ms (SD=44 ms) for the forward related, 513 ms (SD=39 ms) for the backward related, 511 ms (SD=37 ms) for the bidirectionally related, and 511 ms (SD=39 ms) for the unrelated word pairs Note that the reaction times for the forward related items were faster than for the backward related items. The forward and backward pairs were comprised of the same word word combinations. To avoid that subjects saw the same word more than once, the order of these unidirectionally related word pairs was reversed between subjects The Appendix lists all critical pairs belonging to the different experimental conditions

All prime words were spoken by a female native speaker of Dutch, who was naive with respect to the purpose of the study All practice, filler, and test materials were recorded during the same session The stimuli were digitized with a sampling frequency of 20 kHz, with a band-pass filter range of 50 Hz to 10 kHz. The onset and the offset of the word stimuli was determined with the aid of a waveform editor, under auditory and visual control All spliced materials sounded natural. The material created in this way was output to DAT tape by means of a 12 bit D/A converter and a DAT taperecorder On the second channel of the tape, inaudible to the subjects, timing pulses were set concurrently with the onset of the spoken words These pulses were used to trigger the presentation of the visual target, as well as for the recording of the reaction times. The duration of the auditory prime varied between 288 ms and 810 ms, with a mean length of 556 ms The mean length of the primes of the different experimental conditions as well as for the word nonword pairs are presented in Table 1 The inter trial interval was at least 3 2 s (for the longest word) and at most 3.7 s (for the shortest word) The target word followed the prime by an inter stimulus interval of 500 or 0 ms. The target was presented for 200 ms in uppercase letters

Electrophysiological recording

EEG was recorded with tin electrodes mounted in an elastic electrode cap (Electrocap International) EEG was derived from three midline sites (Fz,Cz,Pz) and two pairs of lateral electrodes. Symmetrical anterior temporal electrodes were placed halfway between F7 and T3 and F8 and T4 sites, respectively. Symmetrical posterior temporal electrodes were placed lateral (by 30 % of the interaural distance) and 12.5 % posterior to the vertex. The left mastoid served as reference Electrode impedance was less than 3 KOhms The electro

Table 1

The mean length and standard deviation in milliseconds for the auditory primes for the critical word prime word target pairs (N=66) and the word prime-nonword target pairs (N=264)

Critical word prime-word target pairs

	Mean	sd
Meaning relation		
Bidirectional		
related	547 ms	84 ms
unrelated	551 ms	86 ms
Unidirectional		
forward	551 ms	86 ms
backward	546 ms	86 ms
Non critical word prime-nonword target pairs		
Unrelated	586 ms	110 ms

oculogram (EOG) was recorded bipolarly, vertical EOG was recorded by placing an electrode above and below the right eye, and the horizontal EOG was recorded via a right to left canthal montage. EEG and EOG signals were amplified by Nihon Kohden amplifiers (type AB 601G, time constant=8s, low-pass filter= 3dB cutoff at 30 Hz). All physiological signals were digitized on line with a sampling frequency of 200 Hz using a 12 bit A/D converter. Stimulus presentation and recording of reaction time data were under control of a Miro GD laboratory computer

Procedure

Subjects were told that a spoken word would be followed by a visually presented letter string that could be a word or a nonword. They were instructed to attend to both the spoken words and the visual letter strings. Subjects performed a lexical decision task They had to decide whether the letter string was a real Dutch word or not. If the target was a word they had to press the response button on the right side (right hand response), if not they had to press the button on the left (left hand response). Subjects were asked to respond as fast as possible, but to remain accurate

The inter stimulus interval between the prime and the target was varied between subjects The ISI was either 500 ms or 0 ms

The stimulus material consisting of 528 prime target pairs, was divided into 3 blocks of 176 pairs. Each block lasted about 13 8 minutes in the ISI=500 ms condition and about 12.3 minutes in the ISI=0 ms condition There was a pause of 5 minutes between blocks A short practice session with 30 prime target pairs preceded the experimental session. Subjects were trained to speed up reaction time (< 1 s) and to control their eye-movements They were trained to make eye movements approximately 1 s after the button press and to fixate on the center of the screen in anticipation of the prime target sequence

Data-analysis

EEG and EOG records were examined for artifacts and for excessive EOG amplitude during the epoch from 150 ms preceding the prime to 1 s after the onset of the target Only trials in which the EOG amplitude did not exceed 100 µV and in which no other artifacts were present were included in the average ERPs were averaged time-locked to the target, relative to a 100 ms pre target baseline Note, that in the ISI=0 ms condition, the baseline corresponds to the 100 ms epoch preceding prime offset The N400 was measured by computing the mean amplitude in the 330 430 ms epoch following the target The choice of the window for analysing the N400 was based upon visual analysis, and corresponds to the time interval in which maximal differences between conditions were obtained.

Analyses were restricted to word targets Analyses of the ERP (N400) data involved ANOVAs with the ISI (500, 0) as between-subjects factor, and Relatedness Type (bidirectionally related, unrelated, forward related, backward related) and Electrode (Fz, Cz, Pz, left anterior temporal (AL), right anterior temporal site (AR), left posterior temporal (PL) and right posterior temporal site (PR)) as within-subject factors Where interactions with the factor Electrode are reported, ANOVAs were performed after a z score normalization procedure on the mean amplitudes across experimental conditions [7]

Both reaction time and error data were analysed by carrying out ANOVAs with ISI (between subjects), and Relatedness Type (within-subjects) as factors To control for an increase in Type I error in within subjects tests, the degrees of freedom of F-tests were adjusted using the procedure as described by Greenhouse and Geisser (1959). The adjusted degrees of freedom and p values

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This normalization procedure is equivalent to the normalization procedure suggested by McCarthy and Wood (1985) The z score normalization procedure is described by Rosler Heil and Glowalla (1993) are presented in the text. The significance of contrasts was assessed by post hoc Newman-Keuls tests, with a significance level of .05 unless explicitly stated otherwise

RESULTS

Table 2 summarizes the behavioral results, i e., the mean reaction times and error rates as a function of relatedness type and ISI.

Table 2

Mean reaction times and error rates for both of the ISI conditions for the different types of prime-target pairs as a function of the direction of the relationship.

	ISI= 500 ms			ISI= 0 ms		
	ms	Priming effect	Errors	ms	Priming effect	Errors
Meaning relation						
bidirectional						
unrelated [baseline]	540		5.50	542		4.79
related	491	49	0.86	472	70	1.14
unidirectional						
forward related	510	30	1.71	494	48	1.64
backward related	518	22	2.00	507	35	1.71

Error data

Analysis of the error data yielded a main effect of Relatedness Type (F[1,26]= 31.49, p <.0001, MSe= 3.05) Subjects made more errors to unrelated word pairs (5.1), than to bidirectionally related (1.0), forward related (1.7) or backward related word pairs (1.9). A post hoc test revealed that the difference in error rate between the unrelated and the other three relatedness types was significant at the 1 % level. No main effect of ISI (F[1,26] < 1) or interaction with Relatedness Type (F[1,26] < 1) was obtained. The results of the error data are in agreement with the picture emerging from the reaction time data. There was no evidence for a speed accuracy trade-off.

Reaction time results

Priming effects were computed by subtracting the related lexical decision times (bidirectionally related, forward related, and backward related response latencies, respectively) from the unrelated lexical decision times. The overall analysis yielded a main effect of Relatedness Type (F[1,26]= 84.88, p <.0001, MSe= 204.56). As Table 2 shows, reaction times for both ISI conditions were shorter for all three types of related prime-target pairs (bidirectionally related, forward and backward related pairs) compared to the unrelated pairs. Moreover, reaction times were shorter for bidirectionally related than for unidirectionally related pairs. In addition, reaction times to forward related pairs were faster than to backward related pairs. Post hoc Newman-Keuls tests verified this apparent pattern. Significant differences in reaction times were obtained for bidirectionally related, forward related pairs (p <.01), and backward related pairs (p <.05) compared to unrelated pairs. Table 2 indicates that reaction times were faster for forward than for backward related word pairs. However, since there were already differences in reaction time between the two conditions when the target words were presented in isolation (see Appendix) we do not assign any functional significance to this finding. The Appendix shows that the reaction time advantage of 9 ms for the forward compared to the backward pairs when presented in isolation is quite similar to the overall difference in reaction time observed between the forward and the backward condition (11 ms).

There was a trend towards an interaction of ISI with Relatedness Type (F[1,26]= 2.92, p <.10; MSe= 204.57). This trend suggested that priming effects tended to be larger in the ISI=0 ms condition than in the ISI=500 ms condition. Note, however, that ISI is a between-subject factor. Therefore, differences in the size of the priming effects might be a result of differences between the two subject groups in the ISI=0 and ISI=500 ms condition.

Event-Related Potentials

Grand averages for the target words and for each electrode position as a function of ISI (500, and 0 ms) are presented in Figure 1, with the four

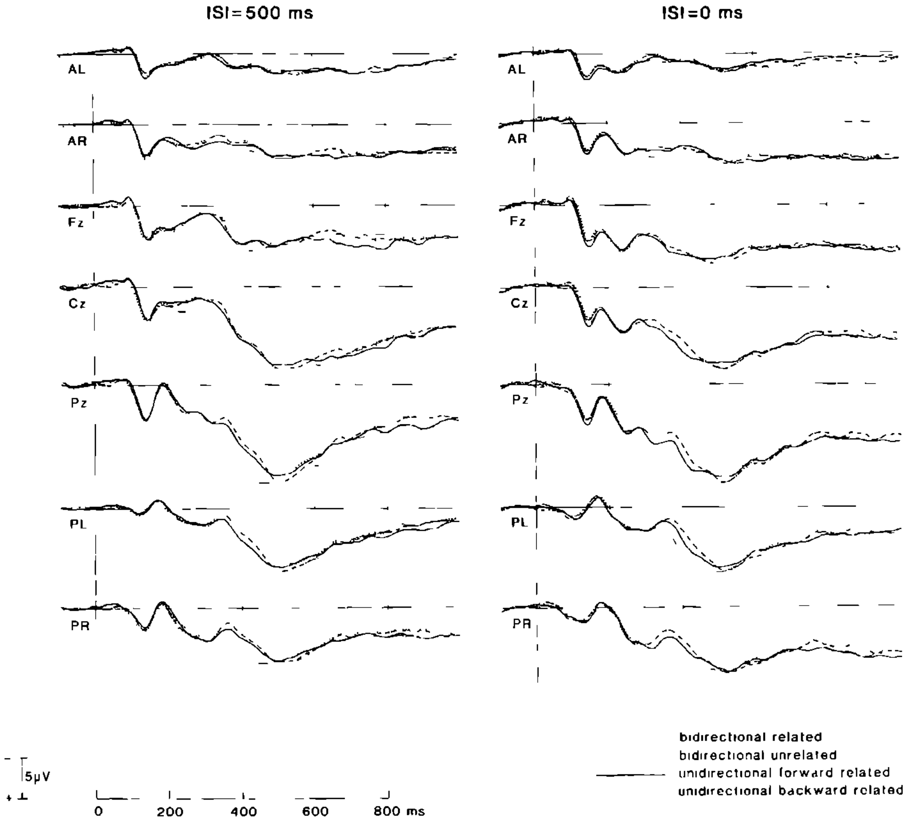

Figure 1 *Grand ERP averages over 14 subjects for the left and right anterior electrodes (AL, AR), the three midline electrodes (Fz, Cz, Pz) and the left and right posterior electrodes (PL, PR), as a function of ISI (500 and 0 ms). The four different relatedness types of the prime-target pairs (unrelated, related, forward related, backward related) are superimposed.*

relatedness types (unrelated, bidirectionally related, forward related and backward related) superimposed. The target word presentation is followed by a small negativity peaking at about 100 ms (N1), maximal in amplitude at fronto-central sites. The N1 was followed by a positive deflection peaking at about 160 ms (P2) with largest amplitudes at the midline sites. After the P2 the ERPs look somewhat different for the two ISI conditions. In the ISI=0 ms condition the P2 is followed by a negativity reaching maximal amplitudes at about 190 ms (N2). In the ISI=0 ms condition the N2 is visible at all electrodes whereas in the ISI=500 ms condition the N2 is primarily visible at the posterior electrodes. This difference in ERPs might arise from the temporal overlap of the processing of the auditory prime and the visual target that only occurs in the ISI=0 ms condition, where the target immediately follows the offset of the prime.

The most distinguishing feature of the waveforms for both ISIs is a broad negative-going wave peaking at about 370 ms post-target The amplitude of this negative shift was powerfully affected by the semantic relatedness between prime and target, yielding largest amplitudes to unrelated prime-target pairs. Due to the sensitivity of this negativity to semantic relatedness, and its centro-parietal distribution we refer to this component as the N400. The N400 is followed by a parietally distributed positivity (P3) that peaked at about 550 ms.

The N400

Figure 1 clearly shows that an N400 to the target word was elicited in both ISI-conditions. The N400 was strongly affected by the relatedness type (F[1,26]= 36.76, $p < 0001$, MSe= 21.51) and this relatedness effect on the N400 did not interact with the ISI factor (F[1,26] < 1).[8] The amplitude of the N400 was largest in response to unrelated targets and smallest to bidirectionally related targets, the amplitude of the N400 to the forward and backward related prime-target pairs fell in between. Figure 2 shows that the topographical distribution of the N400 is the same for backward related pairs compared to forward related and bidirectionally related pairs. This result indicates that there are no qualitative differences in priming effects between the relatedness conditions.

A main effect of Electrode (F[1,26]= 19.16, $p <.001$; MSe= 53.28) indicated that the N400 was maximal at centro-parietal sites. A post hoc test showed that the N400 was larger at Cz and Pz than bilateral anterior and posterior left sites ($p <.05$). An interaction between Relatedness Type and Electrode (F[1,26]= 10.70, $p <.01$, MSe= 1.12) indicated a clear relatedness effect for bidirectionally related as well as unidirectionally related word pairs at all electrodes, except the anterior left electrode (see Figure 2). At the anterior left site there was no effect of the relatedness type. Post hoc tests confirmed these observations significant differences in N400 amplitude between bidirectionally related and unrelated word pairs were present at all electrodes (AR, Fz, Cz, Pz, PL, PR $p <.01$), except at AL. Moreover, significant differences

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[8] *An additional ANOVA in which the N400 was measured within a broader latency window (300-500 ms post target) confirmed all N400 effects reported in this paper*

Moreover, we examined the time course of the N400 priming effect in more detail by dividing the waveform from 200 up to 400 ms post target into 50 ms bins These ANOVAs revealed that the first reliable N400 priming effects were obtained within the 250-300 ms epoch These analyses disclosed that there was no latency difference in the onset of the priming effects between the two ISI conditions, since no ISI X Relatedness Type interaction was obtained for these earlier epochs

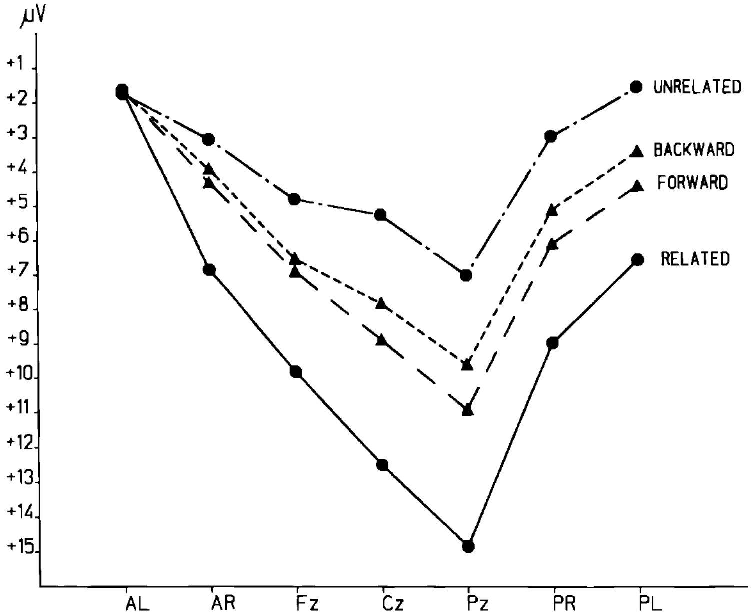

Figure 2 *Mean N400 amplitude within the 330 430 ms epoch post-target, as a function of the relatedness type of the prime target pairs (unrelated, related, forward related, backward related), separately for the left and right anterior electrodes (AL, AR), the three midline electrodes (Fz, Cz, Pz) and the left and right posterior electrodes (PL, PR), and averaged over ISIs*

between both types of unidirectionally related pairs (forward and backward) and the unrelated baseline condition were found at electrodes Fz, Cz, Pz, Pl, and Pr ($p < 05$), but not at the anterior left and anterior right electrode

To further examine the priming patterns for both intervals, separate ANOVAs were performed for each ISI condition.

ISI=500 ms condition

A main effect of relatedness type was obtained ($F[1,13]= 23\ 10$, $p <.0001$, MSe= 15 51) A post hoc test demonstrated that N400 amplitude was larger for unrelated than for bidirectionally related, forward related and backward related word pairs ($p < 05$) In addition, N400 amplitude was larger for forward and backward related pairs compared to the bidirectionally related pairs ($p < .05$) No difference in N400 amplitude was found between forward and backward related word pairs

ISI=0 ms condition

This ANOVA yielded a main effect of relatedness type ($F[1,13]= 15.88$, p

<.0001, MSe= 27.53). Again, N400 amplitude was significantly increased for unrelated compared to the bidirectionally related, forward and backward related pairs (p <.05). N400 amplitude was larger for forward and backward related than for bidirectionally related pairs (p <.05). No difference in N400 amplitude was obtained between forward and backward related pairs.

DISCUSSION

In this study we investigated the phenomenon of backward priming, that is the facilitated recognition of a target word due to a unidirectional relationship from the target to the prime. The framework for the theoretical analysis of backward priming was the model of Neely and Keefe (1989). Based on this model we assumed that at least three priming mechanisms contribute to the reaction time priming effect. In principle each of these mechanisms, that is automatic spreading of activation, expectancy-induced priming and semantic matching could evoke backward priming effects.

The goal of the present study was to clarify which priming mechanism is responsible for backward priming effects in the lexical decision task. The major question was whether backward priming mainly arises from automatic spreading of activation (Koriat, 1981) or from semantic matching (Seidenberg et al., 1984). We addressed this question by comparing the traditional reaction time measure with the N400 measure. More specifically, we tried to separate the effects of automatic spreading of activation from the effects of semantic matching and expectancy-induced priming by assessing backward priming effects on both reaction time and the N400. Based on the assumption that the N400 priming effect is affected by semantic matching and expectancy-induced priming, but not by automatic spreading of activation, the presence or absence of N400 backward priming effects provides important information with regard to the underlying mechanism. Therefore, the crucial question was whether backward priming effects would occur for the N400. The results on this point are clear-cut. Backward priming effects were obtained for the N400 and for reaction time. The N400 amplitude was clearly smaller for backward related than for unrelated word pairs. The fact that the N400 amplitude is modulated by purely backward target-to-prime relationships provides evidence against the notion that backward priming is mainly mediated by the mechanism of automatic spreading of activation, as suggested by Koriat (1981).

Regarding the reaction time data, our results replicate the finding that backward associations yield reaction time priming effects in a lexical decision task (Koriat, 1981, Peterson & Simpson, 1989, Seidenberg et al , 1984, Shelton

& Martin, 1992) Moreover, the present results extend the temporal range under which reaction time backward priming effects are obtained when an auditory prime is paired with a visual target To date backward priming effects under cross modal conditions have only been reported for inter stimulus intervals up to 200 ms (Peterson & Simpson, 1989). The present results clearly show that in the lexical decision task backward priming effects under cross-modal presentation conditions are not restricted to short intervals but are also obtained with an ISI of 500 ms.

Although the presence of backward priming effects for the N400 and reaction time reveals that these effects mainly arise from priming mechanisms other than automatic spreading of activation, we cannot exclude the possibility that automatic spreading of activation also contributed to the backward priming effects obtained in this study A contribution from automatic spreading of activation could be reflected in the reaction times and not in the N400 However, the reaction time results show that this is unlikely, for two reasons First, a significant interaction between ISI and Relatedness Type would have been predicted. The fact that the interaction was not significant, therefore, argues against a contribution of automatic spreading of activation to our reaction time results. A second argument against a possible contribution of automatic spreading of activation is that the size of the reaction time priming effect (after correcting for the differences in reaction time that were already present when the target words were presented in isolation see Appendix) was the same for forward and backward related pairs. According to the most frequently used spreading of activation model of Collins and Loftus (1975), the prime facilitates the processing of the target before the target has been presented. It is thereby assumed that the activation spreads forward from the prime to the target. Therefore, if spreading of activation indeed did contribute to our reaction time results, then the priming effect for forward related pairs should have been larger than for the backward related pairs. This is because for the backward related pairs the activation first has to spread back from the target to the prime before it can spread forward to the target to yield the priming effect. Due to this feedback loop one should predict more activational decay for the backward related than for the one step spread of activation for the forward related prime target pairs. Thus, although we cannot rule out with certainty that automatic spreading of activation might have played a role in evoking reaction time backward priming effects, based on the whole pattern of reaction time results as well as the ERP data we consider this possibility as very unlikely

Taken together, the demonstration of backward priming effects for the N400 and reaction time indicates that these effects, at least for a large part, arise from those priming mechanisms that have been shown to affect both measures. Because reaction time and the N400 priming effect are both modulated by semantic matching and expectancy-induced priming, either or both of these mechanisms must contribute to backward priming. As stated earlier, the likelihood that backward priming stems from expectancy-induced priming is considered to be small, because this idea would imply that subjects generate backward associates. Despite this theoretical argument, there are no empirical grounds for excluding the possibility that backward priming emanates from this mechanism. In the present study we tried to disentangle possible backward priming effects of expectancy-induced priming from those of semantic matching by manipulating the inter-stimulus interval (0 versus 500 ms). Since the generation of an expectancy-set takes time, expectancy-induced priming cannot account for backward priming effects at the inter-stimulus interval of 0 ms.[9] In contrast, semantic matching is assumed to be less dependent upon temporal constraints and can therefore account for backward priming effects at short and long intervals.

In the present study no modulation in N400 backward priming effect was observed as a function of the inter-stimulus interval. Importantly, for both intervals significant N400 backward priming effects were obtained. As mentioned above the interaction between ISI and Relatedness Type failed to reach significance. Consistent with the latter result no changes in the number of errors as a function of ISI were found, as reflected by the absence of an effect of ISI and of an interaction of ISI with Relatedness Type. Therefore, based on the N400 as well as the reaction time and the error results the hypothesis that backward priming stems from expectancy-induced priming can be rejected.

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[9] *A possible problem with regard to the temporal constraints for generating expectancies in the 0 ms ISI condition is posed by the auditory presentation of the primes Since spoken words can be recognized before all sensory information has been delivered (e.g , Marslen Wilson, 1987), subjects in fact have had more time to generate an expectancy set than an ISI of zero milliseconds would suggest The critical question, therefore, is what was the effective SOA in our short ISI condition? To estimate the amount of time that subjects, in addition to the ISI, might have had for generating expectancies we have to take into account the recognition point of the spoken prime. Some 58% of the primes were monosyllables The recognition point for monosyllabic words in Dutch is in the vast majority of cases either on the final or the penultimate phoneme. For these words, then the effective SOA will have been very short indeed, in the order of 20 to 40 ms With the exception of three trisyllabic primes, all other primes were bisyllabic In these cases the recognition point will as a rule fall beyond the syllabic boundary So here too, for most primes the effective SOA will certainly fall far short of the mean duration of the prime, i.e , 556 ms In conclusion, then, our effective SOA will in the vast majority of cases not have exceeded 200 ms, and for most prime- target pairs the SOA fell well below 200 ms Recently, Stolz and Neely (1995) showed that an expectancy set for related target words is not obtained at SOAs shorter than 200 ms. Therefore, we can safely rule out that expectancy-induced priming entered into the backward priming effect in the 0 ms ISI condition*

In summary, the sensitivity of the N400 component to backward priming and the absence of an interaction with inter stimulus interval strongly suggests that backward priming effects (in lexical decision) mainly reflect postlexical processes that arise from the mechanism of semantic matching, as has been proposed by Seidenberg et al (1984) Consistent with this view, the size of the N400 and the reaction time priming effect in the present study (after correcting for the differences in reaction time that were already present when the target words were presented in isolation) was the same for pairs that are related in a forward and backward direction The use of a semantic matching strategy can easily account for this result, because the direction of the presentation of the prime and the target most likely does not affect the outcome of the relatedness checking procedure Semantic matching can also explain why priming effects were larger for bidirectionally related than for unidirectionally related word pairs Since only the bidirectional pairs were highly associatively related (i e , the prime and the target were the first or the second associate of each other) the increase in priming effect very likely reflects the greater ease of the semantic matching process, when the mental representations of the meanings of the prime and the target overlap Due to this overlap the related targets of the bidirectionally related pairs can be recognized very quickly

A postlexical account of backward priming gets further support from a study of Shelton and Martin (1992) who obtained reaction time backward priming effects in the paired presentation lexical decision task, whereas no such effect was present in a list presentation of the stimuli In the latter case, relatedness checking was discouraged by presenting primes and targets sequentially in a list and requesting a lexical decision to each word, so that the related prime and target were separated by a response

What are the theoretical implications of the present results? In the first place, the demonstration of N400 and reaction time backward priming effects provides further evidence for the notion that integrative mechanisms, such as semantic matching, play a dominant role in yielding priming effects in the lexical decision task Within the last twenty years there has been a shift from an exclusively prelexical spreading of activation account of associative priming towards an analysis of priming that emphasizes the importance of postlexical integrative mechanisms (De Groot, 1984 1985 Hodgson, 1991 Neely, 1991) Since the first description of such a postlexical integrative mechanism by Neely in 1976, its existence has been considered implausible According to Neely and Keefe (1989) the reasons why most researchers had difficulty in accepting a semantic matching account of priming were twofold

First, why should the prime that precedes the target exert its influence on responding only after lexical access for the target has occurred? Second, because the subject should be able to make the word/nonword decision after lexical access for the target occurs, why then should subjects check back to see if the target is related to the prime? Although counterintuitive, the reliable demonstration of reaction time backward priming effects across experiments using different intervals, materials, and languages reveals that postlexical integrative mechanisms in fact can play a prominent role in evoking priming effects.

The second, more important theoretical implication of our findings is that they shed a new light on the nature of integrative mechanisms. The presence of backward priming effects with an inter-stimulus interval of zero milliseconds (that corresponds with an SOA of at most 200 ms), reflects an important aspect of the time course of integration, namely that subjects very rapidly integrate the lexical information (i.e., the semantic and syntactic information) that is available from the target word with the lexical information that is provided by the prime word. This result is at odds with the commonly held view that integrative mechanisms, such as semantic matching, are under strategic control and as such reflect a more or less controlled process (Neely, 1991). Instead, this result shows that integrative mechanisms can operate instantaneously, and thus may reflect a mandatory process. Recently it has been proposed that integrative mechanisms may operate in an automatic mode (Hodgson, 1991). Although we believe that integrative mechanisms are fast acting, we do not believe that they are automatic. One reason for this is that the semantic matching process under certain circumstances has been shown to be affected by the composition of the stimulus list (Neely et al , 1989), a variable that is usually linked with strategic processes.

The view that integrative mechanisms might reflect a fast-acting process has first been proposed by De Groot (1984, 1985). This notion was initially based on the De Groot (1984) study, in which a facilitatory effect of relatedness proportion in lexical decision was already observed with an SOA of 240 ms. According to De Groot (1984, 1985) this result could not be explained by automatic spreading of activation or time consuming expectancy induced priming. De Groot argued that in order to account for this finding the operation of a fast acting postlexical meaning integration process had to be postulated With regard to the time course of this process she stated (1985, p. 287) "Its effects can presumably already be observed with very short SOAs, since this process starts to operate after the target has been recognized and, thus, after the time interval between prime onset and target onset, however long, has already elapsed." The reason why such a postlexical meaning process is invoked is that the message processor searches for meaningful relationships whenever encountering words, be this in an experimental setting in which single words are presented or in fluent reading outside the laboratory Our view that the N400 priming effect reflects such a mandatory postlexical integration process is supported by the finding that reliable N400 effects are obtained in reading tasks in which subjects are not required to perform any task other than the natural one, which is to read the words for comprehension (Brown et al., submitted).

To summarize, the present study indicates that postlexical integration processes play a major role in generating priming effects. The results show that backward priming effects in lexical decision mainly reflect postlexical integration processes that arise from an integrative mechanism, postulated to be semantic matching. Therefore, in future studies backward priming can be used as a tool to further elucidate the nature of integration processes during language comprehension.

CHAPTER V

The N400 and Early Stages of Lexical Processing in a Cross-Modal Priming Paradigm

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ABSTRACT

In this study the sensitivity of the N400 effect to the process of lexical access was assessed by investigating whether it reflects effects of multiple activation A cross modal priming paradigm was used, in which auditory word fragments were presented as primes The length of these fragments was varied with respect to the word recognition point According to the model of Marslen Wilson (1987), presentation of a partial prime activates a word initial cohort, containing all word forms that are compatible with the sensory information For example, presentation of the fragment CAP activates the words CAPTAIN, CAPITAL, etc Further sensory information reduces the number of possible words (competitors) up to the recognition point The sensitivity of the N400 to lexical access was investigated by pairing the partial prime with a visual target that was either related to the actual word, related to one of the competitors, or was unrelated to the prime If the N400 reflects lexical access, then its amplitude before the recognition point should be smaller for the actual word and the competitor than for the unrelated word N400 priming effects were only found after the recognition point for full word presentations To investigate whether our material yields reaction time multiple activation effects, a lexical decision study was conducted with a different group of subjects As for the N400, reaction time priming effects were only observed after the recognition point The implications with regard to the lexical processing nature of the N400 are discussed

INTRODUCTION

To understand language a listener has to access the mental lexicon, activate a subset of words, select the proper word from this subset, and integrate the word into a higher order meaning representation In order to assess the value of the N400 as a measure for psycholinguistic research it has to be determined which of these lexical processes it reflects

Recent evidence indicates that the N400 priming effect is particulary sensitive to processes of lexical integration (Brown & Hagoort, 1993 Brown, Hagoort, & Chwilla, 1994 Chwilla, Brown, & Hagoort, 1995 Chwilla, Hagoort, & Brown, 1995 Holcomb, 1993 Osterhout & Holcomb, 1994 Rugg, Furda, & Lorist, 1988) However, it has also been proposed that the N400 might be affected by earlier processes that take place during lexical selection (Holcomb & Neville, 1990 O'Rourke & Holcomb, 1992)

The aim of the present study was to determine the sensitivity of the N400 effect to the process of lexical access, by investigating whether the N400 reflects the activation of multiple lexical candidates during early stages of spoken word recognition, specifically lexical access and lexical selection The process of lexical access results in the activation of those lexical elements and their semantic and syntactic attributes that are compatible with the initial sensory input Since, usually more than one lexical item is compatible with this initial input, multiple lexical candidates are accessed The process of lexical selection refers to the process of selecting from the set of accessed elements the lexical element that best matches the input available to the system Lexical selection processes are especially important in auditory word recognition A basic feature of spoken words is that they unfold over time, i e , that in contrast to visually presented words the sensory information is not immediately available, but accumulates over time

Within the last twenty five years several models on auditory word recognition have evolved, ranging from strictly autonomous models (e g , Forster, 1976, Seidenberg 1985) to fully interactive models (e g , Morton, 1969, 1979 McClelland & Elman, 1986) In the present study the sensitivity of the N400 to the process of lexical access was assessed within the framework of the cohort model of Marslen Wilson (1984, 1987) According to this model, lexical access involves the instantiation of a word initial cohort, containing all word forms that are compatible with some stretch of initial sensory information (the first 100 150 ms of a word) For example, presentation of the word *flower* activates candidates starting with *fl* but not words starting with *pl*, *chl* etcetera Continuing analysis of the sensory information yields an increase of activation for compatible candidates whereas the activation of incompatible candidates is reduced. A word is recognized as soon as the selection phase is terminated, and one word candidate remains For a word presented in isolation, this will be at the uniqueness point The point at which, going from left to right through the signal, it becomes uniquely distinguishable from all other words in the lexicon. For words in constraining sentence contexts, the model claims that a word can be recognized earlier, since selection is accomplished on the basis of the simultaneous assessment of sensory and contextual information

An important assumption of the cohort model (Marslen Wilson, 1984, 1987) is that in normal language comprehension the listener combines all different types of information (semantic, syntactic, phonemic, etc.) to identify the word as soon as possible This notion of 'optimal efficient processing' generates clear predictions and therefore has played a prominent role in testing the model. In particular, the idea of optimal efficient processing predicts that reaction times from the uniqueness point (in the case of words) and the deviation point (that is, in the case of nonwords the point in time at which a spoken word fragment becomes a nonword) should be constant This should be the case, because at this point in time all information that is necessary for the decision response is available. Strong support for this notion comes from a study of Marslen Wilson (1984), in which a nonword monitoring task was used and the deviation point of nonwords was varied from the first to the fourth phoneme. The model was tested by performing a regression analysis and predicting reaction times from the latency of the deviation points from stimulus onset. Consistent with the model, reaction times were constant from the deviation point of nonwords as reflected by the fact that the slope from the regression analysis was close to 1 Further evidence was presented by Radeau, Mousty, and Bertelson (1989), who investigated the relationship between overall reaction time and the latency of the uniqueness point of french nouns in a gender classification task. Despite the fact that the correlation between both variables was clearly lower than in the Marslen-Wilson study (.4), it differed significantly from zero. Therefore, the results of both studies suggest that the uniqueness and deviation points play a role when processing auditory words.

A second line of evidence supporting the cohort model comes from cross-modal word priming studies, in which an auditory prime is paired with a visual target word, to which a lexical decision is required. Marslen-Wilson (1987) presented partial auditory primes that were cut at a point in time at which different word candidates were still compatible with the sensory information A facilitation in reaction time was found when these word fragments were paired with a target word that was semantically related with the words belonging to the cohort. Zwitserlood (1989) observed a similar facilitation when partial primes presented at the end of sentences (differing in contextual constraints) were followed by a semantically related visual target word. Both studies provide empirical support for the basic assumption underlying the cohort model that presentation of a partial prime leads to the parallel activation of the semantic information of multiple words belonging to the cohort.

To date, there is only one electrophysiological study (O'Rourke & Holcomb, 1992) that explicitly investigated the relationship between the N400 and the process of lexical selection. In this study Event-Related Potentials (ERPs) were compared to nonwords that either had an early or a late deviation point. Legal pronounceable nonwords were used that were formed by rearranging segments of multi-syllabic words. Both types of nonwords evoked an N400, but the onset of the N400 was earlier for the nonwords with an early deviation point. Indirect evidence for the notion that the N400 might indeed be sensitive to the processes that take place during lexical selection comes from a study of Holcomb and Neville (1990). They compared N400 priming effects in the visual and auditory modality. Reliable N400 priming effects were obtained for both modalities. However, the auditory N400 priming effect showed an ealier onset than its visual counterpart. The authors argued that the earlier onset of the auditory N400 priming effect might reflect that auditory words, in contrast to visual words, can already be recognized before all of the acoustic information has been delivered. If this hypothesis is correct, then the N400 might also reflect the initial activation of the different lexical candidates arising from the process of lexical access.

The aim of the present ERP study was to directly examine the relationship between the N400 and the process of lexical access by assessing the effectiveness of partial auditory primes in yielding N400 priming effects. A cross-modal word priming paradigm was used that was very similiar to the one used by Marslen-Wilson (1987) and Zwitserlood (1989). The length of the auditory prime fragments was varied with respect to the word recognition point (before/after the recognition point). The recognition point is a measure of the amount of sensory information that listeners need to be certain that a particular word is heard, and not another. It is assumed that presentation of a partial prime at a position in the word before the recognition point, taps into the processes of lexical access and lexical selection, whereas presentation of the prime word at a position in the word after the recognition point reflects post selectional processes

Visual targets words were presented that were (a) associatively related to the actual word (e.g., the target *SHIP* preceded by the partial prime *CAP /* or the full-length prime *CAPTAIN*), (b) related to one of the competitors of the actual word (e.g , the target *MONEY* preceded by the partial prime *CAP /* or the full-length prime *CAPTAIN*, where *CAPITAL* is a possible continuation of the fragment *CAP*), (c) the target word was preceded by an unrelated prime (e g., the target *SHIP* was preceded by the partial prime *FLO /* or the full length prime *FLOWER*)

If the N400 reflects lexical access then its amplitude before the recognition point should be reduced for the target related to the actual word and for the target related to the competitor, compared to the unrelated prime If, however, the N400 reflects post-selectional processes, then a reduction in N400 amplitude should only be observed after the recognition point for the target related to the actual word (e.g , *CAPTAIN - SHIP*).

A possible complication in interpreting effects of multiple access is posed by the effects of backward priming as first described by Koriat (1981). Backward priming refers to the facilitation in recognizing a target word due to a unidirectional relationship from the target to the prime. According to the backward priming logic, the presentation of the auditory prime fragment does not lead to the parallel activation of multiple words, but instead the presentation of the target word activates in a backward direction the lexical element it is related to. Thus the target functions as the lexical context for the auditory word fragment and the observed response facilitation does not reflect the initial activation of the lexical element. In the literature backward priming effects have been found in the lexical decision task (Koriat, 1981, Seidenberg, Waters, Sanders, & Langer, 1984, Peterson & Simpson, 1989, Shelton & Martin, 1992) and the naming task (Peterson & Simpson, 1989) Moreover, a recent study by Chwilla et al. (submitted) showed that in the lexical decision task backward priming effects are not only obtained for reaction time but also for the N400 In the present study we controlled for the effects of backward priming by including unidirectionally backward related word pairs in the material. In addition, to minimize the possible contribution of backward priming effects we used a silent reading task, a task that is very likely less susceptible to postlexical processes than the lexical decision task (e.g , Balota & Lorch, 1986 Den Heyer, Briand, & Dannenbring, 1983).

METHOD

The method section consists of two parts. The first part describes the different phases of the stimulus construction process for the cross-modal priming study First, the procedure for selecting the word stimuli is described The selected words were subsequently tested in a gating study to investigate which words are considered by listeners to be compatible with a given input. In the second part the ERP study is reported which uses the cross-modal priming paradigm in a silent reading task.

CONSTRUCTION OF THE MATERIAL FOR THE CROSS-MODAL PRIMING STUDY

Selecting the words

The first phase in selecting the word stimuli was a computerized search through a phonetically coded Dutch corpus containing 72 135 entries. This corpus contains transcriptions of the preferred spellings of all lemmata in the "Woordenlijst van de Nederlandse Taal" (1954), expanded with lemmata from Appendix B1 of the Uit den Boogaart (1975) word frequency listings. A search algorithm was written that produced phonetically ordered sequences of words with maximally overlapping forms, considered from word onset. So, for example, given the entry /strijden/, the algorithm searched for all other entries in the corpus beginning with the sequence /strij/ These entries were then examined for the presence of word pairs. That is, two words whose phonetic forms separate at or close before their offset. One such word pair is /strijden/-/strijken/ In addition to their phonetic overlap, word pairs were selected on the basis of the following criteria

1. The number of additional words that match the phonetically overlapping form of the words making up a word pair had to be small, and the frequency counts of these additional words had to be closely matched. Moreover, the number of additional words had to be relatively constant between the selected word pairs
2. Both words had to be either nouns, verbs or adjectives.
3 Both words had to be morphologically simple So, for example, no prefixed, suffixed, or compound words were allowed

This combination of criteria resulted in a set of 114 word pairs. This material set was complemented by 64 sets used in previous experiments of Zwitserlood (1989) and 28 sets used by Brown (1990). This resulted in a total number of 206 sets of word pairs.

To control for the possible effects of backward priming, the material set was complemented by 66 prime words of unidirectionally backward related word pairs. The material from the backward priming study (Chwilla, et al., submitted, see Chapter IV) was used for this purpose. In addition 35 single words were selected as practice items. In the second phase of the stimulus selection process, the word pairs and the backward and practice items were investigated in a gating study

THE GATING STUDY

The goals of the gating study were to determine the word recognition point, and to establish that at one point in the word two words are compatible with the sensory information. The gating task produces two types of information First, by combining correct responses and confidence ratings to the words presented in isolation, a mean 'Recognition Point' can be established for each word Before this point, there is still uncertainty as to which word is being presented. The second type of information concerns the alternative responses, that is, responses other than the presented word, produced at different points in the gated word.

Stimulus preparation

All words (N= 513) were spoken by a female native speaker of Dutch, who was naive with respect to the purpose of the study All practice and test materials were recorded during the same session. The stimuli were digitized with a sampling frequency of 20 kHz, with a band-pass filter range of 50 Hz to 10 kHz.

The segmentation of the stimuli was done in the Speech Laboratory of the Max Planck Institute for Psycholinguistics Using a waveform editor, the onset of the test words was located and digitally marked. From this mark onwards the word was divided into segments of increasing length. The first segment consisted of the first 40 ms of the word, the second of the first 80 ms, and so on until the final segment which contained the entire signal of the word Each succession of segments making up a word was then recorded onto DAT tape. On the second channel of the tape, inaudible to the subjects, timing pulses were set concurrently with the onset of the spoken wordsegments/full-length words These pulses were used in a later phase of the study to trigger the presentation of the visual targets in the cross-modal priming study.

Design

The gating study consisted of 2 experimental versions. In each version only one member of the same word pair occurred. The sequence of words in the two versions was identical, so that the two members of a word pair occurred in the same position in each experimental list. Given that the total duration of a version was about 6 hours long, it was decided to split each version into four contiguous sequences. This enabled test sessions of on average 90 minutes in duration, which is about the limit in a gating study before the subjects' performance deteriorates due to fatigue. Four breaks of 5 minutes were given during each session. The first sequence of a version was preceded by a practice list of 20 words, the other sequences were preceded by a practice list of two words.

Subjects

Eighteen subjects were tested. Subjects were paid Hfl. 120 for their participation.

Procedure

Subjects were tested in groups of either four or six on four successive days, one session of a sequence per day. Each subject sat in a carrel that provided a visual shield from the other subjects. The stimuli were presented via a DAT taperecorder. Subjects listened to the material consisting of successively increasing word fragments presented one at a time over closed-ear Sennheiser HD-224 headphones They were instructed to listen carefully to the word fragment, and to write down what they thought the word was, or was going to become. In addition, they had to indicate following each word fragment how confident they were about the correctness of their response The confidence ratings could vary along a 9 point scale, with scale value 1 representing a total guess, and value 9 full confidence in the correctness of the response. It was emphasized to the subjects that they were not to reflect at length about which word might match the input, but that they had to respond immediately with the first word that came to mind given the input.

Subjects gave their responses via TANDY 200 micro-computers. They first typed in their word response and then a number from 1 to 9 for their confidence rating. Each response stayed on the screen of the micro-computer until all of the gates comprising a specific word had been presented. Following the response to the last gate (i.e., the whole word), the screen was wiped clear in preparation for the presentation of the next word.

ANALYSIS AND RESULTS OF THE GATING RESPONSES

The gating study provides a database of words which are considered by listeners to be compatible with a given input, and in which the degree of compatibility is indicated by confidence ratings. An analysis of the gating reponses, therefore, provides information about the words that are considered as candidates, and the 'lifespan' of these candidates across gates With respect to the words that are acoustically realized the gating responses reveal how much sensory information is sufficient to activate a particular word, and how much sensory information is sufficient for its unique identification. In the remaining we will refer to the words that are acoustically realized as the actual words, and to the other candidates as the competitor words.

The following criteria were used for the selection of the experimental and the control items. First, at some early point in the signal, both members of a word pair had to occur as a response by at least three and at most fifteen of the (total group of) eighteen subjects. Second, after the recognition point subjects had to be certain that a particular word was heard and not another Third, it had to be possible to find associates for the actual words and the competitors. For those words for which no associates were available from Dutch association norms (De Groot, 1980, De Groot & De Bil, 1987, Lauteslager, Schaap, & Schievels, 1986) an association test was presented to a group of 25 subjects. Based on these criteria, 6 out of 206 sets of word pairs had to be rejected, yielding 100 experimental sets and 100 control sets

The results of the matching procedure for the experimental and the control stimuli are summarized in Appendix 1. The appendix presents the experimental sets, consisting of the actual word and its competitor, together with an associatively related target word. Each experimental set has its control set, consisting of an actual word and a competitor, that are paired with an unrelated target word. More specifically, in the control sets the same target words were presented as in the experimental sets. The number preceding the actual word, respectively the competitor, corresponds with the number of subjects that before the recognition point produced the actual word, respectively the competitor Here, before the recognition point refers to a point in time of the word, where at least one other word was still compatible with the incoming sensory information. The most important criterion for the selection of the control sets, was that the distribution of the gating responses across the actual word and the competitor closely matched the experimental set, i.e., that the number of subjects producing the actual word and the competitor was comparable.

For the experimental sets, overall the mean number of subjects that produced the actual word before the recognition point was 7.71 (SD= 2 82), and the mean number of subjects that produced the competitor word was 6.43 (SD= 2 43). For the control sets, overall the mean number of subjects that before the recognition point produced the control of the actual word was 7 22 (SD= 2.91) and the mean number of subjects that produced the control of the competitor word was 6 43 (SD= 2.88). Thus, for the experimental as well as the control sets there was a slight bias towards producing the actual word over producing the competitor word.

Appendix 1 also presents the association strength between the visual target and the two types of experimental stimuli (actual word/competitor). Associative strength was determined by the percentage of report of the target as an associate of the prime among either 100 university students (De Groot, 1980, De Groot & De Bil, 1987, Lauteslager et al. 1986) or 25 university students. The mean percentage of association for the actual word-target pairs was 35 (SD 18), and 33 (SD 17) for the competitor word-target pairs.

The same criteria that were used for the selection of the experimental and control items were also applied to the backward items. Based on these criteria fourty of the sixty-six prime words of the backward related pairs had to be discarded, yielding a total set of only twenty six items Appendix 2 presents the backward items together with their control sets. For the backward sets, overall the mean number of subjects that produced the actual word before the recognition point was 7.92 (SD= 3.23), and the mean number of subjects that produced the competitor word was 6.31 (SD= 2 83). For the control sets, overall the mean number of subjects that before the recognition point produced the control of the actual word was 7 58 (SD= 2.44) and the mean number of subjects that produced the control of the competitor word was 6.08 (SD= 2.74).

Table 1 presents the mean overall length of the partial and full-length actual words for the experimental and the backward related items together with their control items.

THE EVENT-RELATED POTENTIAL STUDY

METHOD

Subjects

Sixty four right-handed subjects, forty four female and twenty male (Mean age 22.90, SD 4.21) participated in the experiment. Hand dominance was assessed with an abridged Dutch version of the Edinburgh Inventory (Oldfield, 1971). Nineteen subjects reported the presence of left handedness in their immediate family All subjects were native speakers of Dutch, and had normal or corrected-to normal vision Subjects were paid DFL. 10 per hour.

Apparatus and stimuli

Subjects were seated in a comfortable reclining chair in a dimly illuminated,

Table 1

The mean overall length and standard deviation in milliseconds for the partial and full-length actual words of the experimental and the control sets.

	Experimental set (N=100)	Control set (N=100)
Partial		
Actual word	280 (SD=67)	273 (SD=74)
Full length		
Actual word	597 (SD=102)	597 (SD=94)
	Backward sets (N=26)	Control set (N=26)
Partial		
Actual word	235 (SD=60)	264 (SD=77)
Full-length		
Actual word	545 (SD=75)	561 (SD=70)

sound attenuating, and electrically shielded chamber. The stimuli consisted of 252 cross-modally presented prime target pairs. The prime was presented binaurally through headphones. The target was presented visually at moderate contrast at the center of a PC monitor (window of 8 by 2 cm, approximately 3^{0} X $0\ 8^{0}$). Half of the primes were word fragments, the other half were full-length words. In the case that prime fragments were presented subjects listened to the initial part of a word, e.g , the sequence 'CAP' from the word 'CAPTAIN'. The length of the prime fragment was determined by the results of the gating task and corresponded to a point in time before the recognition point of the word, where at least one other word was still compatible with the incoming sensory information (for a full description of the selection criteria for the experimental and control stimuli, see part one of the method section). For example, the string 'CAP' is compatible with the words 'CAPTAIN' and 'CAPITAL'. All visual target stimuli were full-length words.

The auditory partial prime was paired with a visual target word that was either related to the actual word or related to one of the competitors. For example, the fragment 'CAP" derived from the "actual word" CAPTAIN was paired with the visual target word SHIP that is related to the actual word CAPTAIN, or with the target MONEY, that is related to the competitor CAPITAL.

Table 2

	Design	
	before recognition point	after recognition point
actual word	KAPI - SCHIP	KAPITEIN - SCHIP
control actual word	FIE SCHIP	FIETSEN - SCHIP
competitor	KAPI - GELD	KAPITEIN GELD
control competitor	FIE - GELD	FIETSEN - GELD
backward related	VU - DRAAK	VUUR DRAAK
control backward	BLOE - DRAAK	BLOEM - DRAAK

In the control conditions the same visual target words (SHIP/MONEY) were presented but this time they were preceded by unrelated prime fragments (e.g , FLO - SHIP). The design of the experiment is summarized in Table 2

The critical partial prime-target combinations consisted of 25 pairs in which the target was preceded by a word fragment that was related to the actual word (CAP - SHIP), 25 pairs in which the target was preceded by a fragment that was related to the competitor (CAP MONEY), 25 pairs in which the target related to the actual word was preceded by an unrelated word fragment (FLO - SHIP), and 25 pairs in which the target related to the competitor was preceded by an unrelated word fragment (FLO - MONEY). The critical full length prime-target combinations consisted of 25 pairs in which the target was preceded by a word that was the actual word (CAPTAIN - SHIP), 25 pairs in which the target was preceded by a word that was the competitor (CAPTAIN - MONEY), 25 pairs in which the target related to the actual word was preceded by an unrelated prime word (FLOWER SHIP), and 25 pairs in which the target related to the competitor was preceded by the same unrelated prime word (FLOWER MONEY). To avoid repetiton of word stimuli four experimental lists were constructed. Each list was presented to a different group of 15 subjects.

To control for possible effects of backward priming, unidirectionally backward related pairs were added to the total number of 200 prime-target pairs. The total set of twenty-six backward related pairs was divided into 13 partial actual word - target combinations and 13 full-length prime word - target combinations. The backward experimental pairs were complemented by 13 partial control actual word - target combinations and 13 full-length control - target combinations. Notice, that the same target words were presented in the backward experimental and their control pairs. To avoid a confounding of possible effects of backward priming for partial prime-target combinations with effects due to the repetition of the target word, the experimental lists were constructed in such a way that the backward related pairs always preceded their control pairs.

Electrophysiological recording

EEG was recorded with tin electrodes mounted in an elastic electrode cap (Electrocap International). The electrode positions included standard International 10-20 system locations over the left and right hemispheres at the frontal (F7 and F8) and three midline sites frontal (Fz), central (Cz) and parietal (Pz). In addition, eight electrodes were placed at non standard electrode positions previously found to be sensitive to language manipulations (e.g., Holcomb, Coffey, & Neville, 1992, Holcomb & Neville, 1990) left and right anterior-temporal sites (LAT and RAT) 50% of the distance between T3/4 and F7/8), left and right temporal sites (LT and RT 33% of the interaural distance lateral to Cz), left and right temporal-parietal (LTP and RTP) (Wernicke's area and its right hemisphere homologue 30% of the interaural distance lateral to a point 13% of the nasion-inion distance posterior to Cz), and left and right occipital sites (OL and OR 50 % of the distance between T5/6 and O1/2). The left mastoid served as reference. Electrode impedance was less than 3 KOhms. The electro-oculogram (EOG) was recorded bipolarly, vertical EOG was recorded by placing an electrode above and below the right eye and the horizontal EOG was recorded via a right to left canthal montage. EEG and EOG signals were amplified by Nihon Kohden amplifiers (type AB-601G, time constant=8s, low-pass filter=-3dB cutoff at 30 Hz). All physiological signals were digitized on-line with a sampling frequency of 200 Hz using a 12 bit A/D converter. Stimulus presentation were under control of a Miro GD laboratory computer.

Procedure

Subjects were randomly assigned to one of the four experimental lists. They were told that a spoken word or word fragment would be followed by a visually presented word They were instructed to attend to both the spoken word or word fragment and the visual word No additional task was given

The inter stimulus interval (ISI) between the offset of the prime and the onset of the target was 0 ms A short practice session with 18 prime target combinations (half partial primes, half full length primes) preceded the experimental session The experimental list consisting of 252 prime target combinations was preceded by four filler word pairs Subjects were trained to make eye movements approximately 1 s after the presentation of the visual target word and to fixate on the center of the screen in anticipation of the auditory prime

Data-analysis

EEG and EOG records were examined for artifacts and for excessive EOG amplitude during the epoch from 150 ms preceding the prime to 1 second after the onset of the target Only trials in which the EOG amplitude did not exceed 100 µV and in which no other artifacts were present were included in the average Four subjects had to be discarded due to excessive artifacts, leaving 60 for statistical analysis ERPs were averaged time locked to the target, relative to a 100 ms pre target baseline Note, that the baseline corresponds to the 100 ms epoch preceding prime offset The N400 was measured by computing the mean amplitude in the 300 450 ms epoch following the target The choice of the window for analysing the N400 was based upon visual analysis, and corresponds to the time interval in which maximal differences between conditions were obtained

Analyses of the ERP (N400) data involved ANOVAs with the factor Recognition Point (before, after), and Prime Type (actual word, competitor, control actual word and control competitor) and Electrode (Fz, Cz, Pz, F7, LAT, LT, LTP, OL, F8, RAT, RT, RTP, OR) as within subject factors To control for an increase in Type I error in within subjects tests, the degrees of freedom of F tests were adjusted using the procedure as described by Greenhouse and Geisser (1959) The adjusted degrees of freedom and p values are presented in the text The significance of contrasts was assessed by post hoc Newman Keuls tests All effects mentioned below are significant at the 0 05 level or beyond

RESULTS

Grand ERP averages for each of the electrodes, superimposed for the different prime target combinations, before the recognition point are presented in Figure 1, and after the recognition point are presented in Figure

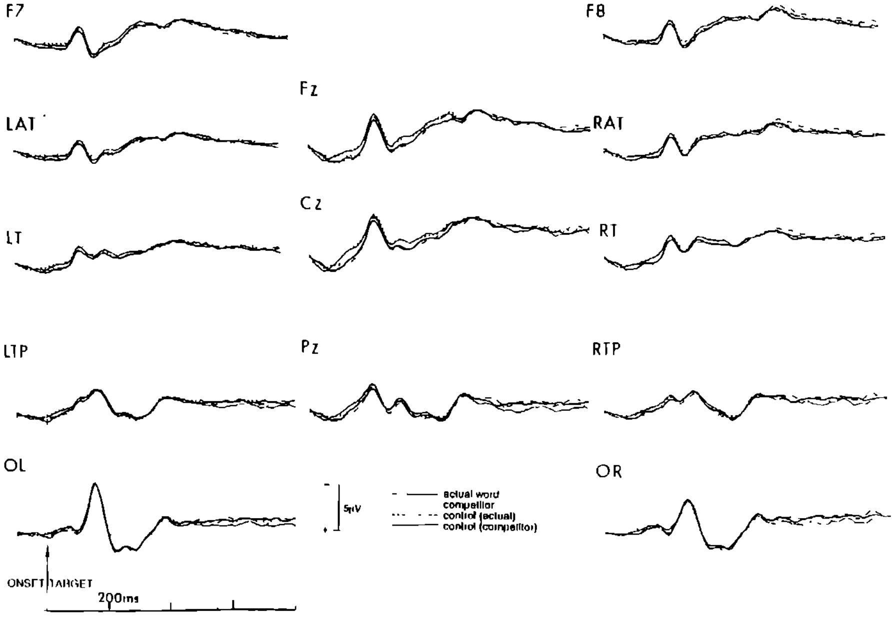

Figure 1 *Grand ERP averages (n=60) before the recognition point, time- locked to the target word, and superimposed for the four different levels of prime type (actual word: thin line; competitor word: dotted line; control actual word: dashed line; control competitor: thick line). Fz, Cz and Pz signify frontal, central and parietal midline electrodes. F7, F8, LAT, RAT, LT, RT, LTP, RTP, OL, and OR signify left and right frontal, anterior-temporal, temporal, parietal, and occipital electrodes.*

2. Figures 1 and 2 show that the waveforms for partial prime-target pairs look quite different from those for full-length prime-target pairs. The most distinguishing feature is a general increase in negativity that is observed for partial prime-target pairs. This is already reflected in a clear increase in N1 amplitude. The N1 is followed by a sustained negativity that shows maximal amplitudes at anterior sites. At posterior sites an N400 to the target word is evoked. However, no differences in N400 amplitude are observed between conditions. In contrast, the waveforms for full-length prime-target pairs are characterized by a centro-parietally distributed N400 that is modulated by the semantic relationship between the prime and the target. After the recognition point, an N400 priming effect (i.e., a reduction in N400 amplitude for related compared to unrelated word pairs) was only obtained for the semantically related actual word-target pairs (e.g., CAPTAIN - SHIP).

The results of the overall ANOVA for the N400, measured within the 300-

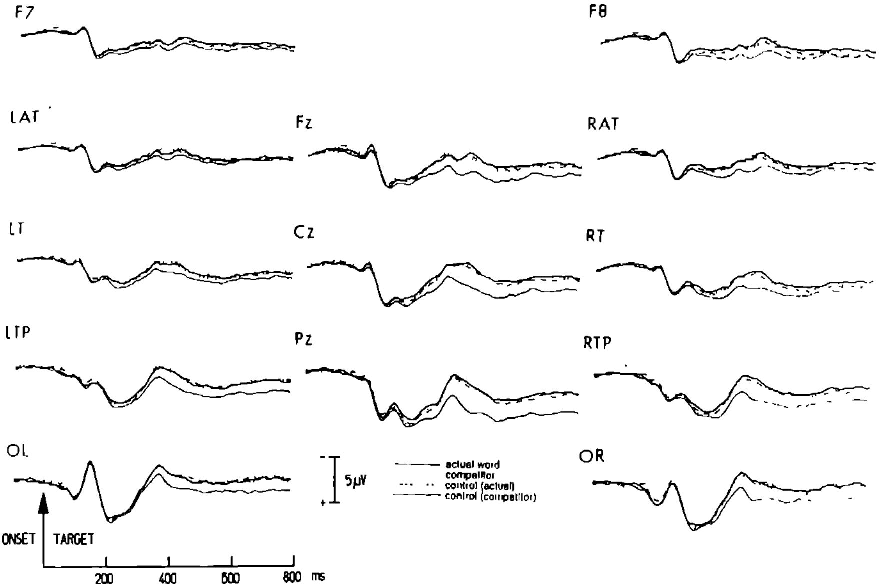

Figure 2 *Grand ERP averages (n=60) after the recognition point, time- locked to the target word, and superimposed for the four different levels of prime type (actual word. thin line; competitor word: dotted line; control actual word dashed line; control competitor: thick line). Fz, Cz and Pz signify frontal, central and parietal midline electrodes. F7, F8, LAT, RAT, LT, RT, LTP, RTP, OL, and OR signify left and right frontal, anterior-temporal, temporal, parietal, and occipital electrodes.*

450 ms post-target epoch confirmed these observations. Main effects of recognition point (F[1,59]= 294.42, p < .0001; MSe= 173.93) and prime type (F[1,59]= 13.45, p <.001; MSe= 32.61) and an interaction between both factors (F[1,59]= 7.53, p <.01; MSe= 38.09) were obtained. The main effect of recognition point reflects that the waveforms were more negative when partial primes preceded the target (-2.69 µV) than when full-length primes were presented (-1.42 µV). The effect of prime type and the interaction with recognition point indicates that modulations in N400 amplitude as a function of prime type were only observed after the recognition point. Figures 1 and 3 clearly show that there are no differences in N400 amplitude before the recognition point, whereas after the recognition point a selective reduction in N400 amplitude was observed for the actual prime-target pairs.

In addition to the overall ANOVA, analyses were performed for each level of recognition point separately. A main effect of prime type was observed after the recognition point (F[1,59]= 22.39, p <.0001; MSe= 31.59), but not before the recognition point (F[1,59]= 0.46, p =.710; MSe= 39.11). Post hoc tests

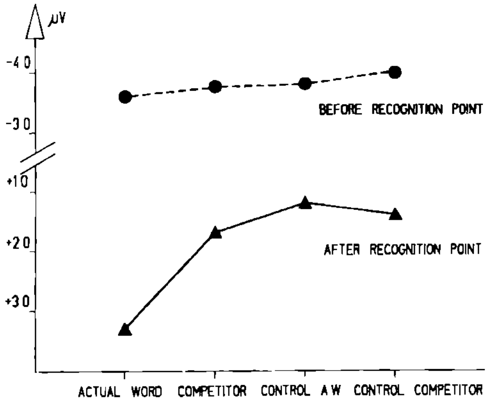

Figure 3 *Mean N400 amplitude within the 300-450 ms epoch post-target averaged across electrodes, as a function of recognition point (before, after) separately for the different prime-target combinations.*

demonstrated that the difference in N400 amplitude that was observed after the recognition point between actual full-length prime-target pairs and the three other experimental conditions (competitor, control actual word, control competitor) was significant at the 5 % level.

Early Negativity

Visual inspection of the grand averages suggests that there are differences in ERPs before the recognition point (see Figure 1). In particular, within the first 100 ms following the presentation of the target both the waveforms for the actual word and the competitor separate from those of the two control conditions This separation is most clearly visible at the fronto-central midline electrodes. To assess the reliability of this early effect an ANOVA was performed for the three midline electrodes (Fz, Cz, Pz) in the 0-60 ms epoch after target presentation. This ANOVA yielded a main effect of prime type (F[1,59]= 9.41, p < 01, MSe= 27.18) and an interaction of this factor with recognition point (F[1,59]= 8.26, p <.01 MSe= 8 78) The main effect indicates that the waveforms for actual words and competitors were more negative compared to the control conditions. The interaction disclosed that this early effect was observed before the recognition point, but not after the recognition point. Post hoc tests showed that the difference in amplitude between the actual word and the two control conditions was significant at the 5% level, and that the amplitude for the competitor differed from its control condition (p <.05).

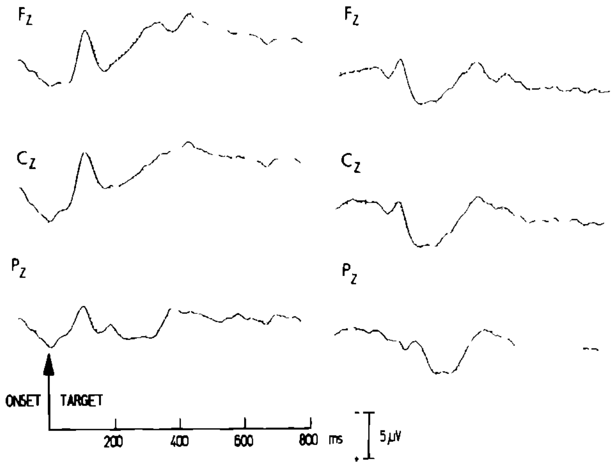

Figure 4 *Grand ERP averages (n=60) for the three midline (Fz, Cz, Pz) electrodes, time-locked to the target word, and superimposed for the backward related prime-target pairs (solid line) and the backward control pairs (dotted line), separately for the two levels of recognition point (before the recognition point see column a, after the recognition point, see column b)*

Although it is tempting to relate these early changes to the effects of multiple activation there are at least two problems with this interpretation First, notice that the differences in ERP amplitude between the experimental conditions (actual word, competitor) and the two control conditions are already present before the target has been actually presented (see Figure 1, e.g., Fz). It is unclear what underlies this difference in baseline, and therefore, we should be careful in linking this negativity to the lexical processing of the target word. The second argument for rejecting the idea that these effects might be related to lexical access or selection processes is the very early onset of the effect. It is difficult to see how the selection of the appropriate (i.e , the semantically related) candidate could precede even the N1 component, that is usually considered to mainly reflect the processing of the mere physical aspects of a stimulus. Due to the differences in baseline and the very early onset of the effect we do not attach any functional significance to these early effects.

Visual inspection of the ERP averages before the recognition point (see Figure 1) also suggests that a later negativity with an onset of about 200 ms post target might also be affected by prime type. In particular, at fronto central midline sites this negativity seems to be increased for the actual word and the competitor relative to the control conditions. To verify this apparent pattern, an ANOVA was conducted on the 200 to 300 ms epoch post target for the frontal and the central midline electrodes (Fz and Cz). This ANOVA yielded no main effect of prime type (F<1) but an interaction of recognition point with prime type (F[1,59]= 4.26, p <.05, MSe= 11 83). Separate analyses were therefore performed for the two levels of recognition point. No main effect of prime type was obtained before the recognition point (F[1,59]= 2.97, p < 10, MSe= 7.58) or after the recognition point (F[1,59]= 2.67, p < 12, MSe= 9 31). The results of the ANOVAs thus indicate that the modulation in the later negativity as a function of prime type was not reliable. Post hoc tests showed that the interaction reflected that only after the recognition point the mean amplitudes to the actual word were less negative compared to the other experimental conditions

Effects of backward associates

Figure 4 presents the grand ERP averages for the unidirectionally backward related word pairs and the control condition for the three midline electrodes as a function of recognition point Figure 4 shows that before the recognition point there were no differences in N400 amplitude between backward related pairs (-3.65 μV) and the control condition (-3.64 μV) After the recognition point N400 amplitude tended to be smaller (about 0.5 μV) for the control condition than for the full length backward related pairs To test the reliability of this effect, an ANOVA was performed on the backward and the control items, in the 300 450 ms epoch post target. The results of the ANOVA revealed that the differences in ERPs observed after the recognition point between the backward related and the control pairs were not significant Neither the main effect of prime type (F<1) nor the recognition point by prime type interaction (F<1) approached significance

DISCUSSION

The aim of this study was to assess the sensitivity of the N400 to the process of lexical access, by investigating whether the N400 reflects the initial activation of multiple word candidates during the early stages of lexical processing. The sensitivity of the N400 to the process of lexical access should be reflected in a decrease in N400 amplitude to the visual targets that are associatively related to the partial auditory primes compared to the control conditions.

The major finding of the present study was that N400 priming effects were only obtained after the recognition point. Before the recognition point no differences in N400 amplitude were observed between conditions i e , no N400 priming effect was obtained for the actual word and the competitor This result supports the notion that the N400 effect does not reflect the process of lexical access Because after the recognition point only one word is compatible with the sensory input, the N400 effects after this point have to be attributed to post selectional processes Since the lexical selection process is usually followed by the lexical integration process, these N400 effects very likely arise from postlexical integration processes The modulation in N400 amplitude after the recognition point is interpreted as reflecting the relative ease of integrating the semantic information of the prime with the semantic information of the target Due to the overlap in the mental representations of the meaning aspects between associatively related words, these words are easier to integrate than unrelated words Taken together, the presence of a modulation of the N400 effect after the recognition point and the absence of such a modulation before the recognition point provides further evidence that the N400 effect is especially sensitive to postlexical integration processes

However, it might be argued that the absence of multiple activation effects on the N400 as such does not provide strong evidence against the notion that the N400 might also reflect processes of lexical access, unless it has been demonstrated that our material indeed was successful in inducing effects of multiple access To address this issue a reaction time experiment was conducted on the same material

REACTION TIME STUDY

To investigate whether our material evokes reaction time multiple activation effects, a lexical decision study was conducted with a separate group of subjects A lexical decision task was used because previous studies (Marslen Wilson, 1987 and Zwitserlood, 1989) had shown that effects of multiple activation can be obtained with this task The same material (i e , 252 prime target pairs) was used as in the ERP study, but this set was complemented with 252 word prime nonword target pairs Half of the primes were word fragments and the other half were full length words The visual nonwords were constructed in accordance with the phonotactic constraints of Dutch, and were derived from real words by substituting one or two letters The proportion of related word pairs for the full length prime target combinations was 30 (when the backward related word pairs are included) Word and nonword targets were presented with an equal probability

METHOD

Subjects

Sixty-four subjects participated in this study. As in the ERP study four experimental lists were constructed Subjects were randomly assigned to one of these lists. The task was to indicate by pressing a button with the left or the right index finger whether the second word, the target, was a real dutch word or not. Subjects were instructed to respond as fast as possible, but to remain accurate.

Procedure

Besides the difference in task (lexical decision versus silent reading) and the inclusion of nonwords the procedure was the same as in the ERP study.

Data-analysis

To analyse the reaction time data ANOVAs were performed with within-subject factors Recognition Point (before, after) and Prime Type (actual word, competitor, control actual word, control competitor).

Table 3

Reaction time and standard deviation in milliseconds as a function of recognition point and prime type

	before recognition point		after recognition point	
actual word	517	(SD=54)	490	(SD=52)
control actual word	521	(SD=58)	517	(SD=56)
competitor	516	(SD=56)	513	(SD=60)
control competitor	521	(SD=61)	519	(SD=54)
backward related	532	(SD=61)	516	(SD=59)
control backward	523	(SD=69)	513	(SD=64)

RESULTS

The reaction time results are summarized in Table 3. Main effects of Recognition Point (F[1,63]= 14.45, p <.001, MSe= 699.53) and Prime Type (F[1,63]= 20.63, p <.001, MSe= 353 25) and an interaction of these factors were

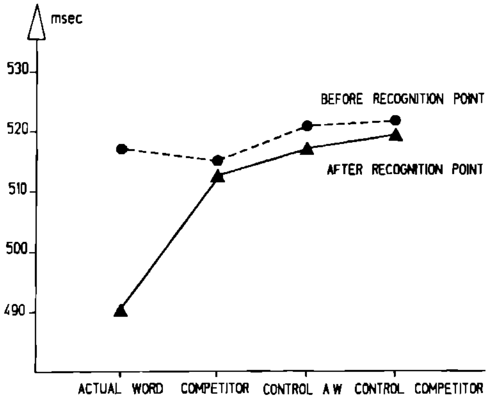

Figure 5 *Mean reaction time in milliseconds measured from target onset, as a function of recognition point (before, after) separately for the different prime-target combinations*

found (F[1,63]= 14.55, p < 001, MSe= 310 39). The main effect of Recognition Point reflects an overall increase in reaction times for partial prime-target pairs (519) compared to full-length prime-target pairs (510). The effect of Prime Type indicated that collapsed across the two levels of recognition point reaction times were faster to actual word target combinations. The interaction points to differences in priming pattern between the two levels of recognition point (see Figure 5). Figure 5 shows that modulations in reaction time as a function of semantic relatedness were only found after the recognition point. After the recognition point a selective decrease in reaction time was observed for the actual word-target pairs (e g., CAPTAIN - SHIP).

In addition to the overall ANOVA, analyses were performed for each level of recognition point separately. A main effect of prime type was observed after the recognition point (F[1,63]= 34 85, p <.001, MSe= 415 98), but not before the recognition point (F[1,63]= 1.43, p =0.24, MSe= 264.05). Post hoc Newman Keuls tests demonstrated that after the recognition point the reaction times for actual prime target pairs differed from those of the other three conditions (p <.01).

The analysis for the backward related pairs (see Table 3) yielded a main effect of recognition point (F[1,63]= 8 86, p <.01, MSe= 1239.42). Overall reaction time was longer for partial prime-target pairs than for full-length prime target pairs In addition, before the recognition point there was a trend towards shorter reaction times for control pairs compared to backward related pairs (F[1,63]= 2 86, p =.096, MSe= 962.69). No differences between backward related and control pairs were found after the recognition point.

The reaction time results provide no evidence for multiple activation Although before the recognition point reaction time tended to be a bit faster for the actual word and the competitor than for the control conditions, statistically speaking there is no evidence that multiple activation was involved In fact the reaction time data parallel the N400 data, since reaction time priming effects were only found after the recognition point.

The results are at odds with previous studies that showed effects of multiple activation under similar conditions (Marslen-Wilson, 1987, Zwitserlood, 1989) The main question is whether the differences in results have to be attributed to the specific material used in the present study or have to be attributed to other factors

Based on the strict criteria used for the selection of the experimental and control items, in particular the criterion that both the actual word and the competitor had to be produced in the gating task, it seems reasonable to assume that presentation of the partial primes resulted in the activation of the two word candidates. Since all the other criteria for the stimulus selection were identical to those used in the Zwitserlood study we suggest that the absence of multiple activation effects does not arise from the specific material sets but probably has to be ascribed to other factors

What then could be the reasons for this discrepancy between results? A comparison of the present reaction times with those of Zwitserlood (1989) reveals that the reaction times in the latter study were longer (on average about 40 ms for the actual word and the competitor, and about 70 ms for the control conditions) Therefore, it might be argued that the reaction times in the present study were too short to be modulated by the semantic relationship between the prime and the target. This possibility, however, could only hold for the partial prime-target pairs because reliable reaction time priming effects were obtained when full-length primes were presented

A related argument is that the absence of multiple activation might be due to differences in processing time between partial primes and full length primes In the case of partial primes there might just have been not enough time for differential activation to occur Therefore, if both conditions would have been equated for processing time then multiple activation might have occurred At first sight, this idea seems to be unlikely because the temporal constraints in the present study were the same as in the Zwitserlood (1989) study (Inter stimulus interval of zero milliseconds) However, a recent study of Zwitserlood and Schriefers (1995) indicates that the time available for the processing of the sensory input can play an important role in obtaining reaction time multiple activation effects Zwitserlood and Schriefers presented short and long auditory word fragments that were immediately followed by a semantically related visual target word Both the short and the long word fragments were ambiguous, in the sense that they represented points in the word at which different lexical candidates were still compatible with the sensory information To directly assess the effect of processing time a condition was added in which the same short prime fragments were presented, but an inter stimulus interval was added between the offset of the prime and the onset of the target (labelled the short+ISI condition) The duration of this interval corresponded to the difference in length between the long and the short prime fragments The most important result was that reliable multiple activation effects (i e priming effects) were found in the long and the short+ISI condition (19 and 21 ms, respectively), but not in the short condition Since the same amount of acoustic information was delivered in the short and the short+ISI condition, the results reveal that the presence versus absence of reaction time multiple activation effects for short prime fragments was dependent upon processing times Based on these results, we cannot rule out the possibility that differences in processing time between our partial and full length primes were responsible for the absence of multiple activation effects However, processing time cannot be the only relevant variable, because Zwitserlood (1989) found reaction time multiple activation effects for short word fragments that were immediately followed by the target word

A final possibility for the differences in results between the Zwisterlood (1989) and our study is that we presented the auditory word fragments in isolation In contrast, in the study of Zwitserlood (see also Zwitserlood & Schriefers, 1995) the auditory prime fragments were preceded by a carrier phrase (e g , You now listen to the word CAP) Given the scarcity of studies in which partial primes have been used, we know very little about the way in which partial primes are processed It might be argued that partial primes presented in isolation are processed in a fashion similar to nonwords, and that the addition of a carrier phrase is important to tune the system towards semantic analysis of word fragments If this idea is correct then the presence versus absence of a seemingly non informative sentence, could have had an important impact on the results In particular, the procedural difference of presenting word fragments in isolation instead of presenting word fragments following a carrier phrase might have led to an attentional bias favouring the processing of the visual stimulus over auditory word fragments This bias may be inherent to the difference between auditory and visual word recognition, namely that the sensory information for the auditory word accumulates over time, whereas the sensory information about the visual word is immediately available right from the onset of the stimulus. In contrast, in the Zwitserlood studies a bias is counteracted by the carrier phrase that explicitly directs the attention of the subject towards the auditory word fragment.

GENERAL DISCUSSION

In light of the reaction time data we have to temper the conclusion drawn from the ERP study, where we suggest that the absence of multiple activation effects on the N400 indicates that the N400 does not reflect the process of lexical access. As discussed in the previous section there are a number of alternative explanations for the absence of multiple activation effects in the present study. Nevertheless, our preliminary conclusion that the N400 is not affected by the processes of lexical access and lexical selection is consistent with the results of two recent ERP studies. Anderson and Holcomb (1995) compared N400 priming effects in the auditory and the visual modality across different Stimulus Onset Asynchronies (SOAs) (0, 200 and 800 ms). Based on the Holcomb and Neville study (1990), in which an earlier onset of the N400 priming effect was found for auditorily presented word pairs, they argued that if semantic representations are indeed available earlier in the auditory modality then this should be reflected in an earlier onset of the N400 effect at the different intervals. The results, however, did not support this notion In the visual modality reliable N400 and reaction time priming effects were obtained for all three SOAs. In contrast, in the auditory modality N400 effects were only obtained for the 800 ms SOA, whereas reaction time priming effects were found for the 200 and the 800 ms SOA. Anderson and Holcomb concluded from this that although auditory words can be primed prior to the arrival of all of their acoustic information, partial auditory words cannot serve as fully effective primes. A similar pattern of results was observed by Holcomb and Anderson (1993) when an auditory prime was paired with a visual target Reaction time priming effects were found for the three SOA conditions. For the N400, however, priming effects were only found at the 200 and the 800 ms SOA, but not when the prime and the target were presented simultaneously.

Taken together, the results of these two studies as well as the results of the present experiment suggest that lexical selection must be completed before a spoken word provides the contextual information that yields N400 priming effects Based on these results we consider it unlikely that the N400 reflects processes of lexical access and selection.

CHAPTER VI

Summary and concluding remarks

This thesis presents an electrophysiological inquiry into the field of language comprehension. Critical for the success or failure of any experimental approach are the tools the investigator has in hand to examine the questions he chooses to address. One important tool is the experimental method Within psycholinguistics the standard method is the reaction time method. A limitation of the reaction time method lies in the fact that it reflects the state of affairs at a discrete moment during comprehension. This disadvantage can be overcome by using the Event-Related Potential method. ERPs provide a continuous record of the brain activity, and therefore allow a real on line examination of the processes involved in language comprehension. The main objective of this thesis was to determine the usefulness of the ERP method in general, and of the N400 component in particular for addressing psycholinguistic issues. To assess the value of the N400 as a measure for psycholinguistic research it is of central importance to clarify how it relates to functionally distinct processes involved in language processing. In models of lexical processing a basic distinction is made between access and integration functions (e.g , Frauenfelder & Tyler, 1987, Marslen Wilson, 1989). The primary goal of the experimental programme was to elucidate whether the N400 priming effect is largely a reflection of lexical access or of lexical integration processes Therefore, the focus was not so much on the underlying theoretical issues, but on the way in which the N400 was modulated by experimental manipulations that are assumed to tap into lexical access or lexical integration functions.

In this chapter I will discuss the major findings of the experimental chapters and their repercussions with regard to the lexical processing nature of the N400 effect It will be argued that the results of the experiments are most in line with the notion that the N400 effect mainly reflects postlexical integration processes that are mediated by the mechanism of semantic matching. Finally, the chapter will be concluded by a brief discussion of different views on the N400.

The experimental chapters were aimed at a further specification of the lexical processing nature of the N400 This was accomplished by assessing the contributions of the different priming mechanisms to the N400 priming effect. The general underlying assumption was that automatic spreading of activation shares basic features with lexical access, and that semantic matching shares basic features with lexical integration processes (De Groot, 1984, Henderson, 1982, Neely, 1991). Insight into the contributions of these mechanisms to the N400 semantic priming effect therefore provides valuable information about what N400 effects reflect in relation to the normal process of language comprehension.

In the different studies the effects of the processes of lexical access and lexical integration on the N400 priming effect were distinguished, by varying (1) the level of processing, (2) the proportion of related word pairs, (3) the interval between the prime and the target, and (4) by assessing whether the N400 effect reflects effects of multiple activation.

Ad (1) Level of processing In chapter two the effects of the levels of processing were investigated by comparing ERPs and reaction times in a lexical decision task with those obtained in a nonlexical task. In the latter task the discrimination was based on purely physical features of the target word (letter-size) The general idea was that the lexical decision task is most compatible with a semantic analysis of the words, whereas the nonlexical task discourages semantic analysis, because paying attention to the word meanings does not help to perform the case discrimination It is argued, however, that the demonstration of N400 effects in shallow processing tasks as such does not necessarily imply that these effects stem from automatic spreading of activation. An alternative account for these N400 priming effects is that despite the fact that a particular task does not require semantic processing, subjects might still match the words for semantic similarity In this case the resulting priming effect has to be attributed to semantic matching. One obvious reason why subjects might look for relationships between words is that the default mode in dealing with words is to process them for their meaning. To determine whether our shallow processing task was indeed performed nonlexically the lexicality effect on reaction times was assessed, that is, the difference in overall reaction times between all word and all nonword targets. If lexical processing was involved in the task performance, the processing of words should be faster than the processing of nonwords. If, however, the task was performed nonlexically, the reaction times to word targets should not be different from the reaction times to nonword targets (cf De Groot, 1987). The results of the lexicality test confirmed that the shallow task was performed nonlexically Moreover, no reaction time priming effect was obtained in the shallow task. The critical question then becomes whether an N400 effect is obtained despite the fact that the task performance did not involve lexical processing. The results on this point were clear cut. No N400 priming effect was found in the shallow task, whereas a clear N400 effect was present in the deep processing task. Note that the results for reaction time and the N400 do not necessarily imply that even accessing word meaning in semantic memory was prevented under the shallow task conditions Indeed the results of another ERP component showed that word meanings had been accessed Under the same shallow processing conditions, differences in P300 as a function of lexical and semantic characteristics of the target words revealed that despite the shallow task requirements, subjects accessed word meanings in semantic memory. A combination of the reaction time and ERP results of chapter two, therefore, leads to the following conclusions First, the clear modulation in N400 effect as a function of the level of processing demonstrates that the N400 effect is strongly affected by the more controlled lexical processes Second, our results show that an N400 priming effect under shallow processing conditions is not obtained when the target words are processed nonlexically for task related performance. In the light of this finding, the previous demonstration of N400 priming effects in shallow processing tasks (Besson et al , 1992, Connolly, Stewart, & Philips, 1990, Mitchell et al. 1991, Kutas & Hillyard, 1989) is not compelling evidence for a spreading of activation account of these effects, unless more objective criteria are used (e.g., the computation of the lexicality effect for reaction times) to ascertain that the task in question indeed was performed nonlexically

Ad (2) Proportion of related word pairs In chapter three we separated the effects of the processes of lexical access from those of lexical integration by manipulating the relatedness proportion. More specifically, the effects of a high and a low proportion list were assessed on the ERPs in a lexical decision and a silent reading task The main result of this study was that an effect of relatedness proportion on the N400 priming effect was observed in the lexical decision, but not in the silent reading task. Typically in the reaction time literature the increase in the size of the priming effect with an increase in relatedness proportion has been attributed to attentional factors, whereas the residual priming effect has been attributed to automatic lexical semantic processes (e.g , Tweedy et al. 1977). Behavioral evidence that shows that the relatedness proportion effect reflects controlled forms of lexical semantic processing comes from the fact that these effects were usually found for long

SOAs of approximately 500 milliseconds only (Den Heyer, 1985, Den Heyer, Briand, & Dannebring, 1983, Seidenberg et al., 1984, Tweedy et al 1977, but see Stolz & Neely, 1995). In our study significant N400 priming effects were obtained in a lexical decision task as well as in a silent reading task when the proportion of related word pairs was low (i e., .20) Since a proportion effect was not observed in the silent reading task it is unlikely that this priming effect stems from expectancy induced priming In principle, therefore the residual N400 priming effect might either arise from automatic spreading of activation or semantic matching In the present study the N400 effect in the low proportion list was observed with a rather long SOA of 700 ms The effects of automatic spreading of activation, however, are assumed to be maximal at short intervals and to dissappear within about 500 ms Therefore, the results of our experiments are most consistent with a semantic matching account of the N400 priming effects observed with a low proportion of related word pairs.

The findings of chapter three provide further evidence for the notion that the N400 priming effect is modulated by the more controlled priming mechanisms In agreement with the results of Holcomb (1988) in the lexical decision task an increase in relatedness proportion was accompanied by an increase in N400 priming effect, showing that the N400 is affected by the mechanism of expectancy induced priming The data of the silent reading task suggest that N400 priming effects are also mediated by semantic matching processes but not by automatic spreading of activation

Ad (3) Interval between prime and target In chapter four the time course of backward priming effects was investigated by varying the inter-stimulus interval (ISI 0 versus 500 ms). In this study an auditory prime was paired with a visual target [1] Consistent with the results of Anderson and Holcomb (1995) and Holcomb and Anderson (1993) N400 priming effects were found at short and long intervals and the effect was not modulated by ISI. However, in contrast to these authors we interpreted the presence of an N400 priming effect at an ISI of zero milliseconds as reflecting a mandatory fast acting integrative mechanism (De Groot, 1984 and 1985, see also Coolen, Van Jaarsveld, & Schreuder, 1991) The idea that integration processes are of a mandatory nature is in line with the observation made in sentential context studies, that in normal discourse subjects cannot help but to engage in the integration of individual word meanings into a higher order representation If lexical integration indeed reflects such a mandatory process, then it could also

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[1] *Note, that in our study an ISI and not an SOA of zero milliseconds was used, which means that the prime and target were not presented simultaneously, but the target immediately followed the offset of the prime*

explain the occurrence of priming effects when prime and target are presented simultaneously. As I will outline below there is some disagreement in the reaction time semantic priming literature about the timing and the nature of integrative mechanisms such as semantic matching Clarifying this issue, therefore, has to await future research because it presupposes a better understanding of the time course and the nature of the lexical integration process than is currently available

Ad (4) The sensitivity of the N400 effect to multiple activation In chapter five the sensitivity of the N400 to the automatic process of lexical access was tested by assessing whether the N400 reflects the initial activation of multiple word candidates during the early stages of lexical processing. Auditory onset fragments of words were presented as prime. The length of these fragments was varied, such that the fragments fell either before, or after the word recognition point. In accordance with the cohort model (Marslen-Wilson, 1987) it was assumed that the processing of a partial prime activates a subset of entries in the mental lexicon, all of which are compatible with the auditory input. In the absence of contextual information, further sensory information reduces the number of word candidates (competitors) in the subset, up to a point in time at which the actual word is recognized The crucial question was whether effects of multiple activation would be obtained for the N400. The main result of this chapter was that robust N400 effects were only obtained after the recognition point Before the recognition point no N400 priming effect was obtained for either the actual word or the competitor The interaction of priming with recognition point suggests that the N400 priming effect does not reflect the automatic process of lexical access but instead reflects postlexical integration processes. A problem with interpreting these N400 findings comes from the fact that no signs of multiple activation were obtained for reaction time in a lexical decision task on the same materials Although, due to the reaction time results, alternative explanations cannot be ruled out with certainty, our preliminary conclusion that the N400 is not sensitive to multiple activation gets further support from two recent ERP studies Anderson and Holcomb (1995), and Holcomb and Anderson (1993) demonstrated that lexical selection must be completed before a spoken word provides the contextual information that is necessary for evoking N400 priming effects

In summary, the experimental findings presented in this thesis yield a quite consistent picture with regard to the lexical processing nature of the N400 priming effect None of the experiments yielded evidence that links the N400 effect to the automatic process of lexical access and its concomitant spreading of activation. Therefore, the hypothesis that the N400 effect mainly reflects automatic lexical access processes has to be rejected. In contrast, all of the N400 results are in agreement with the notion that the N400 priming effect mainly reflects the effects of the more controlled priming mechanisms. The sensitivity of the N400 priming effect to relatedness proportion in the lexical decision task indicates that the N400 under certain circumstances is affected by the mechanism of expectancy-induced priming All other results, that is, the modulation in N400 as a function of task demands, the presence of N400 effects at short and long intervals as well as the presence of N400 effects in silent reading tasks are most compatible with the notion that the N400 effect largely reflects postlexical integration processes that are mediated by the mechanism of semantic matching

To what extent these postlexical integration processes reflect controlled processes is a matter of debate. According to Neely, integrative mechanisms such as semantic matching are under strategic control and as such reflect a more or less controlled process (Neely, 1991). In contrast, De Groot (1984, 1985) claims that postlexical meaning integration processes are fast-acting, and therefore, can account for priming effects at very short stimulus-onset asynchronies A more radical position is taken by Hodgson (1991) who proposed that there has to exist an automatic extra lexical source of priming, breaking with the tradition that all automatic lexical priming arises from spreading of activation within the mental lexicon. Hodgson bases his conclusion on the asymmetries in the amount of priming he observed between the lexical decision and the naming task under stringent conditions of automaticity. Moreover, he claims that a postlexical semantic integration account of automatic priming gives an even more comprehensive account of automatic priming effects than does spreading of activation. Although I believe that postlexical integration processes are fast acting, I do not agree with Hodgson that integrative mechanisms are automatic and are the most important source of automatic priming. Despite the fact that an integrative mechanism provides a coherent account of almost all priming effects reported here, it for example cannot explain reaction time masked priming effects (e.g., Marcel, 1983).[2]

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[2] *Moreover, one basic problem for any single mechanism is to account for the differences in priming effects that are observed between tasks, in particular between lexical decision and naming*

What kind of lexical integration process does the N400 effect reflect? Lexical integration refers to the process of entering a lexical element into a higher-order meaning representation of the current context. Lexical integration ensures that the syntactic and semantic information associated with the lexical element is matched with the representation of the syntactic and semantic specifications as provided by the current context In this thesis evidence is provided that the N400 priming effects in lexical-semantic contexts as well as lexical sentential contexts reflect this process of lexical integration Thus the N400 priming effect is proposed to be evoked after lexical access (i e , the automatic access of the lexical information based on the speech signal or the orthographic input) has taken place The lexical integration process reflected by the N400 effect can be carried out rapidly, because it already can take place as soon as the semantic and syntactic information of the lexical element is available. The modulation in N400 amplitude is supposed to reflect the ease with which the different types of information associated with the lexical element (lexical semantic, syntactic, pragmatic, etc.) can be matched with the context, be this a single word or a sentence fragment. The better the lexical element fits into the context, the easier the lexical integration process is and the smaller the amplitude of the N400 In contrast, the increase in N400 amplitude in response to an incongruent target word is interpreted as reflecting the greater difficulty in integrating this lexical element with the representation built up by the preceding context. Further evidence for the notion that the N400 effect is closely tied to lexical integration processes comes from sentential context studies In particular, the systematic reduction in N400 amplitude toward sentence endings for open class words (Van Petten & Kutas, 1990) fits well with this view

While the importance of lexical integration processes in lexical sentential contexts is generally acknowledged, one might wonder what kind of integration process is involved during the processing of word pairs presented in isolation. The idea that the language user is commonly "searching" for meaningful relationships, however, is not surprising from the point of view that the default mode in dealing with words in everyday life is to process them for their meaning. In fact, everyday life often teaches how difficult it is to ignore words (which is equivalent to ignoring their meanings), for example to ignore headlines when sitting opposite to somebody reading a newspaper. This bias towards semantic processing is also evident from the experience that a background conversation in the mother tongue interferes with the ability to concentrate on a different subject, whereas this is not the case when the conversation is in an unknown language. Actually the only situations in which language users are requested to selectively direct their attention to particular aspects of words, such as their lexical status or physical appearance, are experimental settings. Based on these considerations it is not remarkable that in experiments in which words are presented pairwise, subjects cannot help but to search for meaningful relationships. If our view that the N400 priming effect mainly reflects postlexical integration processes is correct (see Halgren & Smith, 1987, Holcomb, 1993, Rugg, 1990, Rugg, Furda & Lorist, 1988, for similar views), then in future studies the N400 can be used as a tool to further elucidate the nature of integration processes involved in language comprehension.

PROBLEMS FOR THE POSTLEXICAL INTEGRATION VIEW

A postlexical integration view of the N400 effect can with one exception adequately deal with the N400 effects elicited by word stimuli reported in the ERP semantic priming literature. The exception refers to the demonstration of N400 priming effects at an stimulus-onset asynchrony of zero milliseconds for visual presentation (Anderson & Holcomb, 1995), and for cross modal presentation when a visual prime is paired with an auditory target (Holcomb & Anderson, 1993). Although a postlexical integration view can accommodate this finding by postulating a fast-acting mandatory integration process, we cannot rule out with certainty that these N400 effects arise from the mechanism of automatic spreading of activation between related nodes in the mental lexicon. One aspect of the data that appears to favour a postlexical integration account is the time course of the N400 effect. In contrast to reaction time the size of the N400 priming effect was not modulated by the length of the interval, ranging from zero to eight hundred milliseconds. Therefore, it is tempting to suggest that the N400 effects at short and long intervals are mediated by the same mechanism. However, differences in the waveshape and the distribution of the N400 effect between the zero and the other SOA conditions (Anderson & Holcomb, 1995) keep me from proposing that these N400 effects are qualitatively the same. Resolution of this issue, therefore, has to await future research.

The postlexical integration view of the N400 also meets difficulties in accounting for the fact that N400 effects are elicited by nonwords. The presence or absence of an N400 effect depends upon the type of nonword that is presented. In particular, orthographically legal pronounceable nonwords, called pseudowords, evoke N400 priming effects that are comparable in size or even larger than N400 effects to semantically unrelated target words (e.g., Chwilla, Brown, & Hagoort, 1995, Holcomb & Neville, 1990). In contrast, illegal unpronounceable nonwords, for example strings of consonants do not evoke an N400 (e g., Holcomb, 1988, Holcomb & Neville, 1990) It might be argued that since the postlexical integration process represented by the N400 per definition operates on the products of the lexical access function, this view cannot explain how pseudowords can yield N400 effects. Therefore, the pseudoword N400 effect seems to reveal that the postlexical integration process is not the only determinant of the N400 amplitude. An important hint with regard to the nature of the additional process lies in the fact that only word like nonwords yield an N400 effect. If we consider, however, the way in which pseudowords for lexical decision are constructed it might be less striking that these nonwords to a certain degree are handled like words and thus an attempt is undertaken to access lexical entries in the mental lexicon. Typically pseudowords are derived from real words by exchanging one or two letters. From this it follows that there exists considerable overlap between the form of real words and pseudowords. Due to this overlap in form pseudowords might initially activate those lexical entries (and the meaning aspects of these lexical entries) from which they are derived (e.g , O'Connor & Forster, 1981, McNamara & Healy, 1988)[3] The mapping of the sensory input onto the word-form representations, however, eventually fails because additional processing reveals that the pseudoword is not a real word.[4] My hypothesis is that these additional search processes in the mental lexicon generated by an appearingly meaningful stimulus are responsible for the N400 effect evoked by pseudowords.

Vis-a vis the N400 nonword findings I assume that the N400 effect in addition to postlexical integration processes (in the case of words) reflects

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[3] *O'Connor and Forster (1981) and McNamara and Healy (1988) observed an increase in reaction time and errors to semantically related word-nonword pairs such as hill mounlain , in which the first word ("hill') primed a word ('mountain") that was very similar to the nonword presented ('mounlain) These results are consistent with the view that this type of pseudoword activates those lexical items from which they are derived*

[4] *There are at least two other arguments for why word like stimuli should deserve further processing The first argument is that an efficient quick language comprehension process can only be guaranteed when some noise in the sensory input is accepted From this standpoint of efficiency, it would be disadvantageous for the lexical system if the ongoing comprehension process would be interrupted each time that a spelling mistake is encountered The second argument refers to the fact that in the lexical decision task in which the pseudoword N400 effects are observed, subjects are typically invited to adopt a conservative strategy in performing the word/nonword discrimination, namely by instructing them to respond as fast as possible but also to make as few errors as possible*

additional search processes, namely in those cases, in which an attempt is undertaken to retrieve a lexical element but a meaningful interpretation cannot be arrived at (e.g., in the case of pseudowords) (see Rosler, Putz, Friederici, & Hahne, 1993, for a similar view on the N400 in lexical sentential contexts). In the next paragraph I will briefly sketch alternative views on the N400.

ALTERNATIVE VIEWS

Fischler and Raney (1989) have linked the N400 to earlier fundamental processes in word recognition that are mediated by automatic spreading of activation (see also Van Petten & Kutas, 1990, for a similar view). In particular, these authors propose that the N400 amplitude might be modulated by the amount of resources that have to be mobilized to push a word's detector across its recognition threshold (cf. Morton, 1969). According to this view, N400 amplitude is reduced to target words because the lexical detector profits from the automatic spreading of activation from the semantically related prime to the target word. In case that the target is preceded by an unrelated word, the prime does not facilitate the processing of the target word and consequently more resources are required to push the lexical detector across its recognition threshold. The mobilization of these additional resources is reflected by the increase in N400 amplitude to unrelated words

As stated above, one piece of evidence in favour of an automatic lexical access account of the N400 is that N400 effects have been reported at very short intervals. For the remaining the results of this research programme as well as the results of the ERP priming literature, especially the absence of N400 effects to unattended stimuli in selective attention tasks (Bentin, Kutas, & Hillyard, 1995, McCarthy & Nobre, 1993) and when the prime is masked (Brown & Hagoort, 1993), contradict the view that the lexical access function underlies the N400 effect.

A somewhat different position is taken by Bentin and McCarthy (1994). Based on the finding that N400 effects are evoked by pseudowords, Bentin and McCarthy suggest that the N400 reflects the search for the meaning of a letter string, rather than the activation of its meaning. They propose that the N400 is closely tied to a process of semantic activation. More specifically, the N400 is supposed to reflect access to the semantic structure, or the meaning, which may or may not be associated with a lexical entry. According to this view, N400 amplitude is reduced to primed words because their meanings have been partially activated by the preceding word or context. One major strength of this view is that it can account for the N400 effect to pseudowords by claiming that the N400 to pseudowords represents an attempt to assign a meaning to a stimulus In particular, the authors assume that the categorization of an orthographic or phonological stimulus as word or nonword requires an active search for meaning and that this semantic activation is reflected in the N400 effect

If the hypothesis that the N400 reflects the access to semantic memory is correct then we should expect to find N400 effects whenever word meanings are activated in semantic memory However, there are at least two examples in the ERP literature in which behavioral measures (Bentin et al 1995) or other ERP components (Chwilla et al 1995 see Chapter II) revealed that there has been access to semantic memory, but this semantic activation was not reflected in the N400

FINAL CONCLUSION

This thesis illustrates how the ERP methodology can be applied to the study of human language comprehension The research programme was aimed at a further specification of the lexical characterization of one particular ERP component, the N400, that has proven to be particularly sensitive to semantic processing The experimental findings provide convincing evidence that the N400 mainly reflects postlexical integration processes that are mediated by the mechanism of semantic matching Based on this and other work it appears to be a fruitful enterprise to use the N400 in future studies as an index of lexical integration in lexical semantic and lexical sentential studies

One promising line of future research is to combine the reaction time and the N400 measure By comparing the N400, that selectively reflects lexical integration, with reaction time that reflects both spreading of activation and integration, the roles of automatic spreading of activation and integrative mechanisms in language comprehension can be independently established

A second line of research is to use the N400 measure in lexical sentential studies to elucidate how different types of information are integrated during language comprehension The fact that reliable modulations in ERPs can be obtained in the absence of additional specific task dependent processes, very likely brings us closer to a more articulate account of the integration process in normal language comprehension

POST SCRIPTUM

In a perfect world all data should fit into our models. However, the world is seldom perfect and scientific work is most comparable with making a sculpture. The process of shaping changes the details and in the long run our thinking about the nature of the object.

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APPENDICES CHAPTER 2

Related word pairs	ms	Unrelated word pairs	ms
1. ADER - BLOED	471	ZWEET - TEKST	471
2. BAKKER - BROOD	457	KACHEL - SPORT	457
3. BEEN - ARM	539	STOF - VEILIG	543
4. DONKER - LICHT	474	SJAAL - GROND	477
5. GEBOUW - FLAT	529	HONGER - STRUIK	528
6. DOL - GEK	510	WRAAK - LIP	515
7. STORM - WIND	496	TUIG - WAND	495
8. LINKS - RECHTS	488	VRETEN - POST	490
9. MATROOS SCHIP	520	DOEL - BUIK	515
10.CHEF - BAAS	566	UITVAL - SLANG	563
11.BAL - ROND	498	ACCU - JEUGD	499
12.DAG - NACHT	510	AKKER - GRIJS	514
13.KUST - ZEE	463	STRAK - PUNT	459
14.LAKEN - BED	472	AFWAS - FIETS	476
15.LANG - KORT	500	KWART - GEZIN	500
16.HAAI - VIS	523	PAKKET - DAK	525
17.FAAM - ROEM	509	PALEIS - AAP	508
18.DIER - BEEST	473	KEER - KIND	472
19.GROEN - GRAS	482	PUINHOOP WOLF	482
20.MISDAAD-MOORD	502	MONNIK - TRAP	506
21.DORP - STAD	515	NATIE - LOL	519
22.GOOIEN - WERPEN	578	KOEK TRAAG	579
23.DREMPEL - DEUR	493	PERRON - SPUIT	490
24.LEVEND - DOOD	467	ELPEE - NEUS	469
25.STER - HEMEL	530	PANIEK - BLOUSE	539
26.BEROUW - SPIJT	506	LIEFDE - HOL	508
27.ANTWOORD - VRAAG	524	KAPPER - MEER	526
28.KIL - KOUD	461	UI - SLOT	457
29.AARDIG - LIEF	530	WOORD - ZAK	530
30.HOND - KAT	492	GELEI - TAAL	489
31.BES - VRUCHT	514	SCHEDEL - TAXI	509
32.LEEG - VOL	503	BOER KREET	506
33.MAN VROUW	491	ROT - VRIJ	489
34.KOORTS - ZIEK	507	STEL - PERS	512
35.RAAK - MIS	532	ROTS PASSEN	532
36.BIJ - HONING	529	PUT - SPOT	526
37.BEVEN - TRILLEN	544	NEVEL - LEK	541
38.PREI - GROENTE	490	GELUID - JURK	487

39.PAPIER - PEN	519	VAK STEEK	515
40.VENSTER - RAAM	516	KILO - MINUUT	519
Reaction time			
M	505.6		505.9
SD	27.6		28.0
LANGUAGE FREQUENCY			
M	82.9		61.5
SD	108.5		105.9

CHAPTER 4 APPENDIX

The critical prime-target pairs for the different relatedness categories.

Forward related word pairs

1	GROOT	HANDEL
2	DOOF	STOM
3	BLIK	VELD
4	KERST	FEEST
5	THUIS	ADRES
6	ENGELEN	GEDULD
7	AS	BAK
8	DUIK	BOOT
9	POST	BUS
10	PROEF	WERK
11	MOORD	PLEGEN
12	DOOP	KLEED
13	DOL	BLIJ
14	KLEREN	KAST
15	BREEDTE	GRAAD
16	KNOT	WILG
17	ZWART	RIJDEN
18	WERELD	BOL
19	ZET	PIL
20	SCHERP	ZINNIG
21	ZONDE	BOK
22	KLUIF	HOND
23	SCHRIK	ANGST
24	BOEZEM	BORST
25	MOSTERD	MAALTIJD
26	KIST	HOUT
27	HAGEL	SNEEUW
28	MAJOOR	LEGER
29	SMELTEN	IJS
30	DRAAK	VUUR
31	RUG	BUIK
32	SLAAP	BED
33	TANG	HAMER
34	KWARK	TAART
35	CONTACT	LENS
36	DANS	VLOER

Backward related word pairs

1	KETTING	HALS
2	DOEK	BLIND
3	WIT	EI
4	EILAND	BOOR
5	ORKEST	KAMER
6	MERG	BEEN
7	TOON	KLEM
8	STELSEL	ZENUW
9	VERBAND	MAAND
10	LIED	KLAAG
11	ZORG	KRAAM
12	EZEL	LAST
13	KWAAL	HART
14	VLEK	OLIE
15	GRAF	MASSA
16	VERMAAK	LEED
17	PARK	PRET
18	ZIEN	SCHEEL
19	HAAK	TREK
20	SCHERM	VAL
21	STUUR	AUTO
22	VOGEL	LIJSTER
23	ZEE	DUIN
24	HARD	STEEN
25	LEEG	HOL
26	DIER	PELS
27	BOEK	SCHRIJVER
28	JAS	KRAAG
29	VRUCHT	BES
30	MUZIEK	FLUIT
31	HOOI	GRAS
32	OORLOG	VERZET
33	BIER	HERBERG
34	DEKSEL	DOOS
35	SLAPEN	SNURKEN
36	DARM	SLOK

37	GOLF	LENGTE
38	OCHTEND	KRANT
39	AKKER	BOUW
40	BAD	MUTS
41	BEELD	BUIS
42	ROTS	WAND
43	KAS	PLANT
44	BLAD	LUIS
45	BLAUW	ZUUR
46	BEET	NEMEN
47	BLOED	GROEP
48	BOM	MELDING
49	POEDER	SUIKER
50	BOOS	WICHT
51	BRAND	SLANG
52	BRUG	KLAS
53	FOTO	MODEL
54	DIENST	MAAGD
55	DOEL	PUNT
56	HAVEN	SCHIP
57	BROK	KEEL
58	KRAAN	WATER
59	BOER	LAND
60	PALM	BOOM
61	VLIEGTUIG	LUCHT
62	WEI	KOE
63	ADDER	GRAS
64	BEK	MOND
65	KLAP	PIJN
66	STAL	PAARD

37	RIT	ROND
38	LAK	NAGEL
39	RIJP	VROEG
40	GAT	NEUS
41	KIND	SCHOOT
42	SCHRIFT	TIJD
43	MIDDEL	LAP
44	KONT	DRAAI
45	STREEK	MAAG
46	TROMMEL	KOEK
47	KOP	STIJF
48	SNEDE	KEIZER
49	GEVAL	NOOD
50	TEKEN	KRUIS
51	WACHT	LIJF
52	GEEST	PLAAG
53	VAST	KLEUR
54	ROOS	KLIM
55	STOEL	MEUBEL
56	BROOD	BAKKER
57	DEUR	POORT
58	VARKEN	ZWIJN
59	NOOT	AAP
60	KUST	KAPER
61	AARDE	KLUIT
62	PAN	VEEG
63	VIS	ZALM
64	MACHT	DWANG
65	GROENTE	KOOL
66	KERK	KAPEL

Bidirectional unrelated word pairs

1	ZWEET	TEKST
2	KACHEL	GEEL
3	STOF	VEILIG
4	HONGER	STRUIK
5	ACCU	JEUGD
6	AFWAS	FIETS

Bidirectional related word pairs

1	TEEN	VOET
2	WONEN	HUIS
3	VRAAG	ANTWOORD
4	ARTS	DOKTER
5	BAARD	SNOR
6	HAVER	GORT

7	PAKKET	DAK
8	OEVER	LATEN
9	KEER	BOTER
10	PUINHOOP	VLAM
11	NATIE	LOL
12	PLAS	TRAAG
13	PERRON	SPUIT
14	ELPEE	TRUI
15	KAPPER	MEER
16	UIL	KANS
17	GELEI	GETAL
18	SCHEDEL	TAXI
19	ORGEL	KEURIG
20	VLOED	PASSEN
21	PUT	SPOT
22	NEVEL	LEK
23	VAK	STEEK
24	KILO	MINUUT
25	DUEL	TAAL
26	GEDICHT	KNOP
27	HALF	BABY
28	HOTEL	RAS
29	LIFT	DROGEN
30	OERWOUD	OBER
31	VRETEN	KNECHT
32	LADEN	PRINS
33	TROUW	HALTE
34	OMZET	ZWEER
35	DOM	TILLEN
36	HUUR	SPELEN
37	ZEEF	TRAM
38	ZIEL	GLAS
39	APRIL	KRAP
40	SPEER	HOF
41	OVEN	BESTAAN
42	STRAND	KAAS
43	PLAFOND	GLOED
44	RUZIE	GIDS
45	STRIK	OPA
46	TUBE	NOTA

7	HEUVEL	BERG
8	BOOG	PIJL
9	BROER	ZUS
10	DAME	HEER
11	DOCHTER	ZOON
12	DONDER	BLIKSEM
13	DORP	STAD
14	DRAAD	NAALD
15	GOUD	ZILVER
16	TOUW	BINDEN
17	HAAS	KONIJN
18	GRIJPEN	PAKKEN
19	APPEL	PEER
20	IJZER	STAAL
21	ZOUT	PEPER
22	KAT	POES
23	HAND	VINGER
24	TAND	KIES
25	TOR	KEVER
26	KORF	MAND
27	KRENT	ROZIJN
28	LEEUW	TIJGER
29	HAASTIG	VLUG
30	MES	VORK
31	MEISJE	JONGEN
32	OOM	TANTE
33	OORLOG	VREDE
34	ROK	JURK
35	SCHAAP	WOL
36	DIK	DUN
37	NAUW	ENG
38	WEB	SPIN
39	WIND	STORM
40	WEG	STRAAT
41	STREEP	LIJN
42	RIEM	BROEK
43	KWAST	VERF
44	BAAS	CHEF
45	VENSTER	RAAM
46	MOEDER	VADER

47	METAAL	SEKS
48	HEKS	DEEL
49	SLIJM	ZITTEN
50	SAUS	RENTE
51	SMOEL	PAAL
52	PARTIJ	MATROOS
53	STIER	VERS
54	PIANO	TEHUIS
55	HAAN	MAKEN
56	GELUK	PREI
57	RIVIER	AAIEN
58	STELLIG	ZOEN
59	GENOT	TELLEN
60	OCEAAN	KUNST
61	PRIL	RUS
62	PRIKKEL	KWIJT
63	RAND	VIRUS
64	ZALF	TUNNEL
65	PUKKEL	AKTE
66	STANK	ZALIG

47	WIMPEL	VLAG
48	HUMOR	LACHEN
49	HUID	VEL
50	KOGEL	GEWEER
51	INSEKT	VLIEG
52	LINKS	RECHTS
53	POTLOOD	PEN
54	LAAG	HOOG
55	DAL	VALLEI
56	LAWAAI	HERRIE
57	NAAKT	BLOOT
58	GOOIEN	WERPEN
59	DOOD	LEVEND
60	HEMEL	STER
61	BEROUW	SPIJT
62	PLAN	IDEE
63	RAAK	MIS
64	NICHT	NEEF
65	BEVEN	TRILLEN
66	VREEMD	RAAR

The lexical decision reaction times and standard deviations for the target words presented in isolation, i.e., without a prime.

	Mean reaction time in ms	*Standard deviation in ms*
Forward related	504	44
Backward related	513	39
Bidirectionally related	511	37
Unrelated [baseline]	511	39

Chapter 5, Appendix 1

Presents the experimental sets and the control sets. Column 1 and 2 present the actual word and the competitor comprising the experimental stimuli (auditory primes first row), together with their associates (visual targets second row). Column 3 and 4 present the auditory control stimuli for the actual word and the competitor (first row), together with an unrelated visual target word (second row). The number preceding the actual word, respectively the competitor, corresponds with the number of subjects that before the recognition point produced the actual word, respectively the competitor. The percentages preceding the visual target words represent the associative strength between the prime and the target word (for details, see Methods)

	Experimental sets		**Control sets**	
	actual	competitor	actual	competitor
1)	8 strijden	4 strijken	9 kostuum	4 kosten
	48% vechten	24% wassen	vechten	wassen
2)	6 vrede	5 vreemd	8 waarde	5 warm
	44% oorlog	62% raar	oorlog	raar
3)	14 kakkerlak	4 kaketoe	11 populair	4 populier
	27% vies	27% papegaai	vies	papagaai
4)	3 portie	7 porselein	4 file	12 fiets
	21% friet	21% servies	friet	servies
5)	7 korps	4 korf	6 smal	4 smak
	34% politie	52% mand	politie	mand
6)	6 gravure	7 gravin	7 reiger	8 rijgen
	40% ets	17% kasteel	ets	kasteel
7)	4 smoes	11 smoel	5 draak	11 draad
	34% leugen	31% gezicht	leugen	gezicht
8)	6 kreunen	8 kreupel	6 passaat	11 passage
	41% pijn	38% mank	pijn	mank

9)	7 pech	7 pek	7 festijn	9 vest
	24% ongeluk	17% teer	ongeluk	teer
10)	4 kaas	4 kaal	10 zwaan	8 zwaluw
	24% schaaf	24% hoofd	schaaf	hoofd
11)	8 scheef	3 schepen	7 goot	3 goden
	27% recht	19% zee	recht	zee
12)	7 smeden	11 smeken	4 tuig	10 tuin
	34% ijzer	24% bidden	ijzer	bidden
13)	11 plat	4 plan	11 record	4 ruk
	27% vlak	58% idee	vlak	idee
14)	10 virus	7 vieren	10 straf	5 strak
	17% griep	24% feesten	griep	feesten
15)	6 stop	6 stok	6 zaal	8 zaad
	24% halt	21% hout	halt	hout
16)	11 barok	7 baron	11 poot	7 pool
	17% stijl	38% adel	stijl	adel
17)	6 excuses	4 exclusief	6 kracht	4 kramp
	41% sorry	24% duur	sorry	duur
18)	11 portret	3 portaal	12 krant	3 kramp
	34% schilderij	31% deur	schilderij	deur
19)	8 contrast	10 contract	7 sleuf	10 sleutel
	17% tegenstelling	17% werk	tegenstelling	werk
20)	11 dwalen	7 dwaas	11 lichaam	7 licht
	21% zwerven	69% gek	zwerven	gek
21)	14 rand	3 rang	14 brutaal	3 bruut
	23% afgrond	24% leger	afgrond	leger

22)	6 komeet	8 commune	7 idioot	11 ideaal
	38% heelal	17% gemeenschap	heelal	gemeenschap
23)	5 stal	7 stad	5 tocht	7 tor
	6% dier	24% land	dier	land
24)	9 stroom	6 stroop	8 vloek	9 vloed
	34% electriciteit	31% pannekoek	electriciteit	pannekoek
25)	3 slap	9 slak	5 strik	9 strip
	17% vaatdoek	24% langzaam	vaatdoek	langzaam
26)	7 artiest	11 artikel	11 schans	6 schande
	24% zanger	41% krant	zanger	krant
27)	10 dader	4 dadel	9 donder	5 donker
	17% dief	21% vijg	dief	vijg
28)	6 buidel	9 buiten	7 kader	9 kade
	38% kangoeroe	27% binnen	kangoeroe	binnen
29)	9 lelie	9 lelijk	parkiet	5 parket
	48% bloem	20 % mooi	bloem	mooi
30)	4 mentor	7 mentaal	4 sluis	7 sluipen
	21% leraar	38% geestelijk	leraar	geestelijk
31)	9 florijn	4 flora	3 nul	5 neus
	38% gulden	45% fauna	gulden	fauna
32)	5 kluif	7 kluis	5 maan	7 maat
	59% hond	66% geld	hond	geld
33)	7 bordes	10 bordeel	8 bloed	10 bloem
	34% koningin	38% hoeren	koningin	hoeren
34)	14 broek	4 broer	14 relatie	4 relaas
	11% jas	56% zus	jas	zus

35)	10 stadion	7 stadium	7 staaf	5 staan
	76% voetbal	62% fase	voetbal	fase
36)	9 kraan	6 kraal	10 blaag	8 blaar
	24% water	90% ketting	water	ketting
37)	9 meute	8 meubel	6 partij	9 part
	24% massa	24% stoel	massa	stoel
38)	6 praal	10 praten	7 troebel	10 troep
	52% pracht	21% kletsen	pracht	kletsen
39)	5 montuur	8 mond	9 beurt	8 beurs
	93% bril	34% lippen	bril	lippen
40)	7 dorst	7 dorp	7 formeel	6 formule
	20 % drinken	37 % stad	drinken	stad
41)	11 stiksel	5 stikstof	13 sloot	3 sloop
	35% naaien	41% scheikunde	naaien	scheikunde
42)	5 fractuur	7 fraktie	4 loket	6 lokaal
	62% breuk	41% deel	breuk	deel
43)	4 stel	4 stem	4 schop	3 schok
	56% paar	41% geluid	paar	geluid
44)	8 kompas	9 compact	7 slurf	7 slurpen
	36% noorden	27% klein	noorden	klein
45)	12 haven	4 haver	10 traan	6 tralie
	40% schip	29% gort	schip	gort
46)	5 keuze	8 keuken	6 college	11 collega
	17% twijfel	17% eten	twijfel	eten
47)	7 limiet	5 limoen	7 corrupt	4 kort
	52% grens	27% citroen	grens	citroen

48)	8 masker	9 mascotte	7 spanning	10 spat
	27% carnaval	21% beertje	carnaval	beertje
49)	7 koffer	11 koffie	6 banaal	12 banaan
	24% reis	19% thee	reis	thee
50)	6 salaris	9 salade	5 domein	8 dominant
	35% loon	21% gezond	loon	gezond
51)	10 dreumes	5 dreun	9 wedloop	6 wettelijk
	31% kind	45% klap	kind	klap
52)	12 lepel	3 lepra	7 antiek	3 antenne
	24% soep	55% ziekte	soep	ziekte
53)	5 wervel	7 werpen	4 agressie	6 agrarier
	19% rug	69% gooien	rug	gooien
54)	9 klas	5 klap	7 uniform	6 uniek
	38% school	21% slag	school	slag
55)	5 vlag	6 vlam	4 gids	6 gips
	23% wimpel	56% vuur	wimpel	vuur
56)	9 hark	7 harp	9 aspirine	5 aspirant
	48% tuin	18% instrument	tuin	instrument
57)	6 nerf	5 nerts	6 macaroni	5 macaber
	40% blad	29% bond	blad	bond
58)	8 tempo	9 tempel	5 primus	5 priemen
	62% snel	21% geloof	snel	geloof
59)	3 ruig	6 ruiken	4 tiran	6 tieren
	31% stoer	59% geur	stoer	geur
60)	4 absurd	4 abstract	3 pastei	14 pastoor
	17 % belachelijk	21 % kunst	belachelijk	kunst

61)	5 orkaan	12 orkest	4 metaal	11 meteen
	32% wind	19% viool	wind	viool
62)	15 proces	3 procent	15 kapitein	3kapitaal
	21% rechtbank	17% percentage	rechtbank	percentage
63)	8 stapel	7 staal	7 kolom	6 kolonie
	25% papier	17% hard	papier	hard
64)	3 knul	3 knuppel	3 storten	3 storm
	63% jongen	17% hoenderhok	jongen	hoenderhok
65)	10 dominee	4 dominant	10 componist	4 component
	41% kerk	52% heersen	heersen	kerk
66)	8 grijpen	6 grijns	5 diesel	5 distel
	48% pakken	34% lach	pakken	lach
67)	4 vork	3 vorm	4 knokkel	3 knop
	34% mes	17% rond	mes	rond
68)	14 dressuur	3 dressoir	13 latijn	4 latent
	96% paard	34% kast	paard	kast
69)	7 scherven	5 scherm	7 dialekt	5 dialoog
	12% kapot	21% televisie	kapot	televisie
70)	10 saldo	3 salto	8 stoot	5 stoof
	24% rekening	31% circus	rekening	circus
71)	8 berk	10 berg	8 gratis	3 graan
	59% boom	19% hoog	boom	hoog
72)	7 bloesem	11 bloes	12 kelner	6 kelder
	24% lente	17% knopen	knopen	lente
73)	14 rozijn	4 rozen	13 algebra	4 algemeen
	41% krent	17% rood	krent	rood

74)	12 kalf	3 kalk	7 schaken	3 schakel
	76% koe	45% wit	koe	wit
75)	7 schijf	4 schijn	7 kruis	3 kruid
	21% computer	17% zon	computer	zon
76)	7 dogma	7 dochter	12 poedel	6 poeder
	17% leer	24% meisje	leer	meisje
77)	6 schedel	5 schepen	4 robot	5 robijn
	14% dak	18% boot	dak	boot
78)	9 glas	9 glad	5 formulier	3 formuleren
	17% wijn	34% ijs	wijn	ijs
79)	7 kuit	5 kuip	5 kennel	3 kennis
	55% been	72% bad	been	bad
80)	7 fles	8 fluit	7 impuls	4 impasse
	14% melk	11% spelen	melk	spelen
81)	8 satijn	6 sate	3 gordel	14 gordijn
	45% zacht	24% vlees	zacht	vlees
82)	4 vuist	14 vuil	3 spurt	11 speuren
	19% slaan	9% smerig	slaan	smerig
83)	11 heuvel	6 heupen	6 commune	11 communie
	14 % dal	28% breed	dal	breed
84)	12 atleet	5 atlas	8 wreken	4 wreed
	72% sport	38% wereld	werelds	port
85)	9 grap	5 graf	9 radijs	3 radar
	52% lachen	34% dood	lachen	dood
86)	8 spies	6 spiegel	9 schoon	9 school
	45% barbecue	17% kijken	barbecue	kijken

87)	5 tabak	9 taboe	4 complex	10 compleet
	62% roken	24% sex	roken	sex
88)	7 centraal	5 ceintuur	5 pleister	4 pleiten
	45% midden	72% riem	midden	riem
89)	7 braaf	9 braam	5 japon	10 japan
	21% lief	14% struik	lief	struik
90)	5 klimaat	5 climax	3 zuipen	5 zuigen
	41% weer	48% hoogtepunt	weer	hoogtepunt
91)	11 magie	4 maagd	11 druppel	5 druk
	52% tovenaar	31% sterrebeeld	tovenaar	sterrebeeld
92)	4 spinazie	6 spier	6 kamer	6 kaper
	31% groente	17% sterk	groente	sterk
93)	9 champagne	4 shampoo	9 hormoon	4 horloge
	17% nieuwjaar	59% haren	nieuwjaar	haren
94)	8 drang	10 drank	5 zwijgen	11 zwijn
	17% wil	24% bier	wil	bier
95)	9 boter	6 boot	9 roet	4 roepen
	24% brood	38% varen	brood	varen
96)	11 symbool	6 simpel	11 buffel	4 buffer
	62% teken	34% eenvoudig	teken	eenvoudig
97)	7 band	7 bandiet	3 casette	4 kassa
	17% fiets	41% boef	fiets	boef
98)	7 slim	7 slip	6 tijger	11 tijd
	38% intelligent	55% onderbroek	intelligent	onderbroek
99)	5 huis	8 huilen	4 specie	8 speciaal
	24% wonen	48% verdriet	wonen	verdriet
100)	4 bidon	5 bieden	11 kroket	4 krokant
	21% wielrennen	17% geven	wielrennen	geven

To summarize, the mean number of subjects that before the recognition point produced the actual word or the competitor word

	Experimental sets		Control sets	
Actual word	M	7 59	M	7.31
	SD	2.84	SD	2.93
Competitor	M	6.49	M	6.43
	SD	2.53	SD	2.78

CHAPTER 5 APPENDIX 2

Presents the backward sets and the control sets Column 1 and 2 present the actual word and the competitor comprising the backward stimuli (auditory primes first row), together with the unidirectionally backward related visual target words (second row) Column 3 and 4 present the auditory control stimuli for the actual word and the competitor (first row), together with an unrelated visual target word (second row) The number preceding the actual word, respectively the competitor, corresponds to the number of subjects that before the recognition point produced the actual word, respectively the competitor

	Backward related sets		**Control sets**	
	actual	competitor	actual	competitor
1)	6 maat	4 maand	7 geest	5 geeft
	schoen	schoen	schoen	schoen
2)	6 gat	3 gans	6 hemel	3 hekel
	neus	neus	neus	neus
3)	3 muziek	6 muur	4 palm	5 pap
	fluit	fluit	fluit	fluit
4)	12 snede	6 sneeuw	12 schrift	4 schreeuw
	keizer	keizer	keizer	keizer

5)	7 keel brok	4 ketel brok	8 debat brok	5 dubbel brok
6)	4 kabel kink	7 kaper kink	5 modaal kink	8 model kink
7)	4 rijden zwart	11 rijpen zwart	5 kapel zwart	6 kapot zwart
8)	10 feest kerst	6 feeks kerst	9 kwart kerst	6 kwark kerst
9)	6 darm slok	4 dal slok	6 fobie slok	3 vocaal slok
10)	7 zien scheel	3 ziel scheel	7 lens scheel	7 lente scheel
11)	12 middel lap	3 middag lap	9 regen lap	3 regel lap
12)	12 stuur auto	4 studie auto	13 kleuter auto	5 kleur auto
13)	8 rijp vroeg	9 rijden vroeg	7 dieet vroeg	9 dier vroeg
14)	14 aarde kluit	4 aardig kluit	7 dorp kluit	4 dop kluit
15)	5 handel groot	12 handen groot	6 aula groot	11 auto groot
16)	3 nemen beet	3 nevel beet	3 tarbot beet	6 tarwe beet
17)	7 vrucht bes	11 vreugde bes	6 moedig bes	12 moeder bes

18)	13 punt doel	4 punaise doel	10 comfort doel	3 computer doel
19)	7 melding bom	11 melk bom	5 profeet bom	8 professor bom
20)	11 kwaal hart	7 kwaad hart	10 zinnig hart	5 zinnen hart
21)	6 slang brand	8 slak brand	11 extreem brand	3 extra brand
22)	11 model foto	6 modern foto	8 drama foto	4 draad foto
23)	12 vogel lijster	6 voogd lijster	11 broos lijster	7 brood lijster
24)	6 toestand nood	10 toestel nood	7 samba nood	11 sambal nood
25)	5 maaltijd mosterd	8 maand mosterd	8 visum mosterd	4 visioen mosterd
26)	9 hanger sleutel	4 hangar sleutel	7 drank sleutel	11 drang sleutel

To summarize, the mean number of subjects that before the recognition point produced the actual word or the competitor word

	Backward sets		Control sets	
Actual word	M	7.92	M	7.58
	SD	3.23	SD	2.44
Competitor	M	6.31	M	6.08
	SD	2.83	SD	2.74

SAMENVATTING

Centraal in dit proefschrift staat het proces van visuele woordherkenning Een fundamentele vraagstelling binnen de taalpsychologie is hoe een lezer in staat is om op snelle en efficiente wijze taal te begrijpen Het probleem wordt duidelijk als men zich realiseert dat een taalgebruiker over een passieve kennis van 50 000 woorden of meer beschikt Uit taalpsychologisch onderzoek is bekend dat gemiddeld drie woorden per seconde worden herkend d w z begrepen Een wezenlijke vraag is hoe wij ogenschijnlijk zonder enige moeite in staat zijn om uit dit enorme databestand de juiste woorden te selecteren en toegang verkrijgen tot hun betekenissen

De binnen de taalpsychologie meest gebruikte methode om kennis omtrent (de werkwijze van) het taalverwerkingssysteem te verkrijgen is de reactietijdmethode In dit proefschrift wordt een andere methode gebruikt, namelijk het registreren van hersenpotentialen, de zogenaamde 'Event Related Brain Potential' (ERP) methode Een belangrijk voordeel van de ERP methode ten opzichte van de traditionele reactietijdmethode is dat deze een continue weergave verschaft van de hersenactiviteit tijdens taalverwerking Hierdoor is het mogelijk om de processen die betrokken zijn bij het taalverwerkingsproces direct in de tijd te volgen Een ander voordeel van de ERP-methode is dat betrouwbare ERP effecten kunnen worden gemeten in afwezigheid van een additionele taak, zoals bijvoorbeeld lexicale beslissing[1] Binnen de taalpsychologische literatuur is vaak zorg geuit over de mogelijke neveneffecten van het gebruik van experimentele taken ten aanzien van het bestuderen van normale taalbegripsprocessen Door ERPs tijdens het uitvoeren van een taak te vergelijken met een situatie waarin het aangeboden taalmateriaal alleen gelezen hoeft te worden, is het mogelijk de effecten van normale taalverwerking en de effecten van taak specifieke factoren van elkaar te onderscheiden

Het onderzoek gepresenteerd in dit proefschrift heeft als doel de bruikbaarheid van een bepaalde ERP component de N400 - te onderzoeken voor het bestuderen van taalpsychologische vraagstukken De N400 is een in polariteit negatieve component, die gemiddeld 400 milliseconden na presentatie van een woord zijn piekwaarde bereikt Een modulatie in N400 amplitude wordt waargenomen als de N400 op in betekenis gerelateerde woorden (APPEL PEER) vergeleken wordt met de N400 op ongerelateerde woorden (TAFEL PEER) De N400 amplitude is groter voor ongerelateerde woorden dan voor gerelateerde woorden Dit verschil in N400 amplitude wordt

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[1] *In deze taak wordt een letterreeks aangeboden en geeft de proefpersoon middels het indrukken van een knop aan of de letterreeks een bestaand nederlands woord is of niet De tijd vanaf aanbieding wordt gemeten (reactietijd)*

het 'N400 priming effect' genoemd Om de waarde van de N400 als een maat voor taalpsychologisch onderzoek nader te bepalen, is het van groot belang om te onderzoeken hoe het N400 priming effect gerelateerd is aan de verschillende taalverwerkingsprocessen

Ik zal in het kort het taalpsychologische kader schetsen waarbinnen dit onderzoeksprogramma werd uitgevoerd In theorieen over taalbegrip wordt een centrale rol toegekend aan het mentale lexicon. Het mentale lexicon speelt een beslissende rol in het bemiddelen tussen de sensorische input (spraak of tekst) en de interpretatie die aan deze input wordt toegekend. Het mentale lexicon wordt beschouwd als een woordenboek waarin alle kennis omtrent de woorden in onze moedertaal ligt opgeslagen Deze kennis bevat minstens drie soorten van informatie de woordvorm (hoe wordt het woord geschreven of gesproken), de betekenis (eigenschappen behorende bij het woord, bijvoorbeeld een hond is een viervoeter, heeft een vacht, hij blaft en kan bijten) en syntactische eigenschappen (bijvoorbeeld de woordsoort zelfstandig naamwoord, werkwoord, adjectief). In deze dissertatie richt ik mij op het betekenisgedeelte van het mentale lexicon.

In taalpsychologische theorieen worden lexicale processen grofweg onderverdeeld in drie processen lexicale toegang, lexicale selectie en lexicale integratie. Lexicale toegang verwijst naar het contact tussen de sensorische informatie (het geschreven of gesproken woord) en de representaties opgeslagen in het mentale lexicon. Zo leidt bijvoorbeeld aanbieding van een auditief woord tot de activatie van die woorden in het mentale lexicon die qua woordvorm overeenstemmen met het aangeboden woord. Dit leidt tot de activatie van de semantische en syntactische eigenschappen van deze woordvormen. Naarmate meer sensorische informatie beschikbaar komt, neemt het aantal geactiveerde woordvormen af totdat een woord wordt geselecteerd en uiteindelijk wordt herkend. Dit proces wordt aangeduid als lexicale selectie. Tenslotte wordt de geactiveerde woordbetekenis (het herkende woord) geinterpreteerd binnen zijn samenhang, die meestal uit de voorafgaande woorden uit de zin bestaat. Het voegen van de geactiveerde woordbetekenis in een hogere orde representatie van een gegeven context wordt het lexicaal integratieproces genoemd.

De doelstelling van dit onderzoeksprogramma was om de lexicale verwerkingsaard van de N400 binnen een taalpsychologisch kader nader te specificeren. De fundamentele vraag die aan de verschillende experimenten ten grondslag lag was of het N400 priming effect primair processen van lexicale toegang, dan wel processen van lexicale integratie weerspiegelt Als hulpmiddel bij het beantwoorden van deze vraag werd gebruik gemaakt van het semantische priming paradigma. In dit paradigma wordt een woord (de prime) snel gevolgd door een tweede woord (de target). Een van de meest robuuste bevindingen in de taalpsychologische literatuur is dat een woord sneller wordt herkend als dit wordt voorafgegaan door een in betekenis gerelateerd woord, dan door een in betekenis ongerelateerd woord Dit effect wordt het reactietijd priming effect genoemd Het semantische priming paradigma heeft een belangrijke rol gespeeld bij de toetsing van modellen van context effecten en woordherkenning. De keuze voor dit paradigma was dan ook gebaseerd op de grondige kennis die aanwezig is met betrekking tot de mechanismen die bijdragen aan semantische reactietijd priming effecten. Op basis van de reactietijdliteratuur kan worden geconcludeerd dat tenminste drie mechanismen bijdragen aan het reactietijd priming effect. Een van deze mechanismen is automatisch en de andere twee zijn min of meer gecontroleerd, dat wil zeggen dat deze een groter beroep doen op de verwerkingscapaciteit dan een automatisch proces. Het eerste mechanisme is automatische spreiding van activatie (ASA). Verondersteld wordt dat verbindingen bestaan tussen semantisch en/of associatief gerelateerde woorden in het mentale lexicon. Presentatie van een woord leidt tot de activatie van de bij dit woord behorende knoop in het mentale lexicon. Deze activatie breidt zich langs de paden van het netwerk uit over knopen van woorden met een gerelateerde betekenis Deze spreiding van activatie bezit alle kenmerken van een automatisch proces het is snel, van korte duur, onbewust en heeft een vrijwel onbeperkte capaciteit Het tweede mechanisme is "expectancy induced priming" De proefpersoon gebruikt de informatie die door het prime woord wordt verstrekt voor het voorspellen van mogelijke targetwoorden. De aard van de reactietijd priming effecten hangt af van de grootte van de verwachtingsset. Is deze klein zoals bij associatief gerelateerde woorden en hoort het targetwoord tot deze set, dan vindt men een versnelling van het herkenningsproces Hoort het targetwoord echter niet tot de verwachtingsset dan wordt het herkenningsproces vertraagd. Is de verwachtingsset daarentegen groot, dan is de winst in herkenningstijd voor de woorden uit deze set veel kleiner omdat de zoektijd toeneemt. Dit mechanisme kan worden beinvloed via instructie of door de proportie van gerelateerde versus ongerelateerde woordparen te manipuleren (zie hoofdstuk III). Het derde mechanisme is "semantic matching". Verondersteld wordt dat de proefpersoon in de lexicale beslissingstaak de prime en de target met elkaar vergelijkt en dat de woord/niet-woord beslissing op de target wordt beinvloed door het resultaat van dit vergelijkingsproces. Het ontdekken van een relatie tussen prime en target leidt tot een neiging om "Woord" in te drukken, terwijl het ontbreken van een relatie leidt tot een neiging om "Niet Woord" in te drukken.

In de meeste onderzoeken naar semantische priming werden experimentele taken, zoals de lexicale beslissingstaak en de benoemingstaak, gebruikt. Hierbij werd aangenomen dat deze priming mechanismen samenhangen met taalverwerkingsprocessen die ook een rol spelen tijdens het normale taalbegripsproces. In dit proefschrift wordt verondersteld dat twee van deze mechanismen fundamentele kenmerken gemeenschappelijk hebben met processen die betrokken zijn bij normale taalverwerking. Op de eerste plaats deelt ASA belangrijke kenmerken met het automatische lexicale toegangsproces. In de tweede plaats deelt semantic matching belangrijke kenmerken met het meer gecontroleerde lexicale integratieproces. Inzicht in de bijdrage van deze mechanismen aan het N400 semantische priming effect is daarom van groot belang voor het koppelen van het N400 effect aan de processen van lexicale toegang en lexicale integratie.

In de vier experimentele hoofdstukken werden de effecten van het automatische lexicale toegangsproces en het meer gecontroleerde lexicale integratieproces op het N400 priming effect vastgesteld, door het veranderen van (1) de diepte van verwerking (diep versus oppervlakkig), (2) de proportie van in betekenis gerelateerde woordparen (80% versus 20%), (3) het tijdsinterval tussen prime en target (0 versus 500 milliseconden), en (4) door te onderzoeken of het N400 effect gevoelig is voor de activatie van meerdere woordkandidaten tijdens de vroege stadia van gesproken woordherkenning.

Ad (1) De diepte van verwerking In hoofdstuk II wordt het effect van de diepte van verwerking onderzocht door ERPs en reactietijden in een lexicale beslissingstaak en een niet-lexicale taak met elkaar te vergelijken In de niet-lexicale taak was de targetdiscriminatie gebaseerd op louter fysieke kenmerken van het targetwoord (lettergrootte). Het algemene idee was dat de lexicale beslissingstaak het meest verenigbaar is met een semantische analyse van de woorden, terwijl de niet lexicale taak semantische analyse ontmoedigt aandacht besteden aan woordbetekenissen bevordert in dit geval niet het uitvoeren van de taak. In de ERP literatuur wordt de aanwezigheid van N400 priming effecten in niet-lexicale taken beschouwd als een bewijs voor de gevoeligheid van het N400 effect voor het automatische lexicale toegangsproces. Een alternatieve verklaring is echter dat deze N400 effecten voortkomen uit het feit dat proefpersonen ondanks het niet-lexicale karakter van de taak, nagaan of de betekenissen van de prime en het targetwoord aan elkaar gerelateerd zijn. In dit geval moeten de effecten dus toegeschreven worden aan het mechanisme van semantic matching. Om tussen deze twee verklaringen te kunnen kiezen zijn meer objectieve criteria vereist aan de hand waarvan bepaald kan worden of een zogenaamde "oppervlakkige" taak al dan niet lexicaal werd uitgevoerd. Om dit vast te stellen werd het lexicaliteitseffect bepaald het verschil in reactietijden tussen alle woord en alle niet-woord targets. Als bij de taakuitvoering van de niet lexicale taak lexicale verwerking betrokken was, dan zouden de reactietijden op de woord targets sneller moeten zijn dan de reactietijden op de niet-woord targets. De resultaten van de lexicaliteitstest lieten zien dat bij de uitvoering van de oppervlakkige taak geen lexicale verwerking betrokken was. In overeenstemming hiermee werd in deze taak geen reactietijd priming effect gevonden De kritische vraag was nu of een N400 priming effect optreedt als de taak in kwestie niet-lexicaal wordt uitgevoerd. Het belangrijkste resultaat van deze studie was dat in dit geval geen N400 priming effect werd gevonden, terwijl duidelijke N400 priming effecten werden gevonden in de lexicale beslissingstaak. Een combinatie van de reactietijd en ERP resultaten uit hoofdstuk II leidt tot de volgende conclusies Ten eerste, de duidelijke modulatie in N400 effect als een functie van de diepte van verwerking wijst erop dat het N400 effect in sterke mate wordt beinvloed door meer gecontroleerde lexicale processen. Ten tweede, deze studie toont aan dat N400 priming effecten onder oppervlakkige verwerkingscondities niet worden gevonden als de targetwoorden voor de taakuitvoering niet-lexicaal worden verwerkt.

Ad (2) De proportie van in betekenis gerelateerde woordparen In het derde hoofdstuk werden de effecten van de processen van lexicale toegang en lexicale integratie gescheiden door het veranderen van de proportie van in betekenis gerelateerde woordparen In het bijzonder werd het effect van een hoge versus lage proportie gerelateerde paren (.80 versus .20) op de ERPs in een lexicale beslissings- en een stille leestaak onderzocht. Het voornaamste resultaat was dat een N400 proportie effect (d.w.z. een toename in het N400 priming effect bij een toename in de proportie gerelateerde paren) wel in de lexicale beslissingstaak, maar niet in de leestaak werd gevonden Dit resultaat geeft aan dat het proportie effect (tot stand gebracht via het mechanisme van expectancy induced priming) geen deel uitmaakt van het normale taalverwerkingsproces maar schijnbaar wordt geinduceerd door de taakvereisten van de lexicale beslissingstaak. In de reactietijdliteratuur wordt het proportie-effect toegeschreven aan aandachtsfaktoren, terwijl het priming effect bij een lage proportie toegeschreven wordt aan automatische lexicaal semantische processen. In deze studie werden zowel in de lexicale beslissingstaak als in de leestaak solide N400 priming effecten gevonden bij een lage proportie van gerelateerde woordparen Omdat in de leestaak de N400 modulatie niet afhankelijk was van de proportie manipulatie, is het onwaarschijnlijk dat deze N400 effecten tot stand komen door expectancy-induced priming. De N400 priming effecten bij een lage proportie zouden daarom effecten van ASA ofwel effecten van semantic matching kunnen reflecteren De aanwezigheid van een N400 priming effect bij een vrij lang interval (Stimulus Onset Asynchronie van 700 ms) is strijdig met een snel verval van het automatische spreiding van activatie proces en pleit daarom voor het toeschrijven van de lage proportie priming effecten aan het mechanisme van semantic matching De uitkomsten van deze studie leveren verdere aanwijzingen voor de stelling dat het N400 effect wordt beinvloed door meer gecontroleerde priming mechanismen In het bijzonder laat het N400 proportie effect in de lexicale beslissingstaak zien dat de N400 wordt beinvloed door het mechanisme van expectancy induced priming Verder duidt de aanwezigheid van N400 effecten in de leestaak op een bijdrage van het mechanisme van semantic matching aan het N400 priming effect

Ad (3) Het interval tussen prime en target In hoofdstuk IV wordt het temporele verloop van achterwaartse priming effecten (d w z een versnelling in reactietijd op basis van een unidirectionele relatie van het targetwoord naar het primewoord) in de lexicale beslissingstaak onderzocht Dit was gedaan door het inter stimulus interval te varieren (ISI 0 versus 500 msec) Twee woorden werden cross modaal aangeboden, d w z een auditieve prime werd gecombineerd met een visuele target Er werden achterwaartse N400 priming effecten gevonden voor beide intervallen Bovendien bleek de grootte van het effect niet te varieren met de lengte van het interval De aanwezigheid van achterwaartse N400 priming effecten bij een ISI van nul milliseconden werd geinterpreteerd als aanwijzing voor een snel werkend integratiemechanisme In de reactietijdliteratuur bestaat onenigheid over het temporele verloop en de aard van integratieprocessen Neely (1991) stelt dat semantic matching tijd kost terwijl De Groot (1994) en Hodgson (1991) van mening zijn dat semantische integratieprocessen een eerder onvermijdelijk, snel werkend mechanisme weerspiegelen De resultaten van dit hoofdstuk, met name de gevoeligheid van het N400 effect voor achterwaartse relaties en in combinatie met het ontbreken van een interactie met tijdsinterval, pleiten voor de aanname dat deze effecten tot stand komen via een snel werkend integratief mechanisme

Ad (4) De gevoeligheid van het N400 effect voor de initiele activatie van meerdere woordkandidaten (multiple activatie) In hoofdstuk V wordt de lexicale verwerkingsaard van het N400 effect verder gespecificeerd door de

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Bijvoorbeeld in het geval van het woordpaar VUUR DRAAK is er sprake van een unidirectionele achterwaartse relatie omdat presentatie van het woord DRAAK in een associatietest het woord VUUR als associaat oproept terwijl dit in de omgekeerde volgorde (VUUR DRAAK) niet het geval is gevoeligheid van de N400 te testen voor processen van multiple activatie. Het theoretische kader is het cohort model van Marslen-Wilson (1987) Verondersteld wordt dat de aanbieding van een auditief woordfragment leidt tot de activatie van al die woordvormen die overeenkomen met de sensorische informatie. Als prime werden auditieve woordfragmenten aangeboden waarvan de lengte met betrekking tot het woordherkenningspunt werd veranderd (voor/na het herkenningspunt). De effecten van multiple activatie werden vastgesteld door de partiele auditieve prime te combineren met een visueel targetwoord dat of (i) in betekenis gerelateerd was aan het auditieve primewoord waarvan het fragment was afgeleid (het feiteijke woord bijvoorbeeld "KAPI-SCHIP"), (ii) gerelateerd was aan een van de "rivaliserende" woorden bijvoorbeeld "KAPI GELD", of (iii) ongerelateerd was aan het primewoord (bijvoorbeeld "KAPI-DEUR") Als het N400 priming effect processen van lexicale toegang weerspiegelt, dan zou dit moeten blijken uit een reductie in N400 amplitude voorafgaande aan het herkenningspunt voor het feitelijke en het rivaliserende woord (i c."KAPI SCHIP" en "KAPI-GELD), terwijl na het herkenningspunt een selectieve afname in N400 amplitude voor het feitelijke woord gevonden zou moeten worden (i c. "KAPITEIN-SCHIP en niet voor "KAPITEIN-GELD"). Het belangrijkste resultaat van hoofdstuk V was dat robuuste N400 priming effecten alleen na het herkenningspunt werden gevonden. Dit resultaat is in overeenstemming met recente resultaten van Holcomb en collega's (1993, 1995) die laten zien dat het lexicale selectieproces voltooid moet zijn voordat het gesproken woord de contextuele informatie verschaft die nodig is om een N400 priming effect op te roepen.

Samenvattend leveren de onderzoeken beschreven in dit proefschrift een vrij consistent beeld met betrekking tot de lexicale verwerkingsaard van het N400 priming effect. In geen van de studies werd evidentie gevonden voor de aanname dat het N400 priming effect verband houdt met het automatische lexicale toegangsproces dat tot stand wordt gebracht via spreiding van activatie Daarom dient de hypothese dat het N400 priming effect primair automatische lexicale toegangsprocessen weerspiegelt, te worden verworpen. Daarentegen wordt de stelling dat het N400 priming effect hoofdzakelijk de effecten van de meer gecontroleerde priming mechanismen weerspiegelt door alle N400 resultaten gesteund De gevoeligheid van het N400 effect voor gerelateerdheidsproportie in de lexicale beslissingstaak laat zien dat de N400 onder bepaalde omstandigheden wordt beinvloed door het mechanisme van expectancy induced priming. Alle andere resultaten, met name de modulatie in N400 amplitude als functie van de diepte van verwerking, de aanwezigheid van N400 effecten voor korte en lange intervallen, als ook de aanwezigheid van N400 priming effecten in leestaken, zijn het meest in overeenstemming met de aanname dat het N400 effect primair postlexicale integratieprocessen weerspiegelt, die tot stand komen via het mechanisme van semantic matching.

Welk soort lexicaal integratieproces reflecteert het N400 priming effect? Het lexicale integratieproces verwijst naar het samenvoegen van een lexicaal element in een hogere-orde betekenisrepresentatie van een gegeven context. Lexicale integratie zorgt ervoor dat de syntactische en semantische informatie behorende bij het lexicale element wordt vergeleken met de syntactische en semantische specificaties aangereikt door de actuele context. Op grond van de onderzoeksresultaten gepresenteerd in dit proefschrift kom ik tot de stelling dat het N400 priming effect in woordcontext dit proces van lexicale integratie reflecteert. De modulatie in N400 amplitude weerspiegelt het gemak waarmee de verschillende soorten van informatie behorende bij het lexicale element samengevoegd kunnen worden in de betekenisrepresentatie van de context. Hoe beter het lexicale element past in een bepaalde context, hoe makkelijker het lexicale integratieproces en dus hoe kleiner de amplitude van de N400. In tegenstelling hiermee, wordt de toename in N400 amplitude op semantisch incongruente woorden gezien als een reflectie van de grotere moeilijkheid om het lexicale element te assimileren in een bepaalde context.

Dit proefschrift illustreert hoe de ERP methode gebruikt kan worden om taalbegripsprocessen te bestuderen. Het onderzoeksprogramma beoogde een beter inzicht te verschaffen in de lexicale correlaten van een bepaalde ERP component, de N400, waarvan bekend was dat deze bijzonder gevoelig is voor semantische processen. De experimentele bevindingen leveren overtuigende evidentie dat het N400 effect hoofdzakelijk postlexicale integratieprocessen reflecteert, die tot stand komen via het mechanisme van semantic matching. Op basis van deze uitkomsten en recente bevindingen uit de ERP literatuur lijkt het een vruchtbare onderneming om de N400 in toekomstige studies te gebruiken als een index van lexicale integratie in woord- en zinscontext.

CURRICULUM VITAE

Dorothee Derix werd geboren te Waldniel Reeds op vroege leeftijd ontvoerde Uli Chwilla haar naar Nederland waar zij van naam en nationaliteit ging veranderen Zij studeerde Klinische Psychologie aan de Universiteit van Tilburg en studeerde in 1984 cum laude af. Van 1984 tot 1986 werkte zij als projektmedewerker op het Tilburgse Instituut voor Akademische Studies Van 1987 tot de zomer 1990 werkte zij als assistent in opleiding op het projekt "Een Electrofysiologische studie naar stimulus anticipatie" In 1990 kon zij de verleiding niet weerstaan om een NWO projekt op het Max Planck Institut fur Psycholinguistik met als onderwerp Electrophysiological correlates of semantic processing' te aanvaarden, waarvan in dit proefschrift verslag wordt gedaan Sinds 1994 is zij werkzaam op het Nijmeegse Instituut voor Cognitie en Informatie