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Emotional Speech Perception: Electrophysiological Insights into the Processing of Emotional Prosody and Word Valence in Men and Women

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Dekan:
Prof. Dr. Martin Schlegel

Gutachter:
Prof. Dr. Angela D. Friederici
Dr. Mireille Besson
Prof. Dr. Erich Schröger

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CONTENTS

PREFACE

I understand a fury in your words,

But not the words.

William Shakespeare (1564 - 1616), "Othello", Act 4 scene 2

Love, friendship, but also less intimate relationships such as those between colleagues would be very difficult if not impossible without both parties being able to understand the other person's feelings. That emotional comprehension has such importance for social interaction results from its effect on how we feel and behave. First of all, it is crucial that we realize when our friends are unhappy so that we can offer support. However, being able to recognize the emotional state of others also has some personal advantage as it helps to predict their actions. For example, an angry superior might be unlikely to approve the request for a raise. If the employee is emotionally skilled he will wait with his proposal until the situation has changed for the better. Fortunately, emotional comprehension does not require intense training as even infants are able to distinguish happy from sad emotional expression on human faces and in a speaker's voice (D'Entremont & Muir, 1999; Montague & Walker-Andrews, 2001; Walker-Andrews, 1997). Such non-verbal emotional communication establishes the first form of social interaction in early infancy and is still of great importance during adulthood when words are available to express emotions.

The present work investigates the significance of a single aspect of non-verbal communication – speech melody, also referred to as prosody. Of specific interest is whether prosodic information is processed separately from word information when we listen to speech or whether both kinds of information interact. If there is indeed an interaction, which common sense would suggest, the application of the ERP method should reveal *when* during word processing prosodic information is taken into account. A second purpose of this thesis was to determine which information *dominates* emotional comprehension: the emotions that are expressed via prosody or the emotions that are put into words.

Both questions, the ‘W*hen-Question*’ and the ‘*Dominance-Question*’ were investigated with respect to the listener’s sex. The interest in the role of biological gender (which is still exceptional in cognitive neuroscience) arose from social and developmental research that suggests sex differences in the expression and perception of emotions. Females are reported to be somewhat more emotionally expressive (Manstead, 1992) and to recognize emotional expression in others somewhat better than males (Hall, 1978). To test whether men and women also differ in the processes underlying emotional comprehension, all experiments were analyzed with regard to biological gender. Interestingly, the results suggest sex differences in the processing of emotional speech. Moreover, sex was found to modify both the time course of the prosody-word interaction and the dominance of prosody and word information during emotional comprehension. As a consequence, biological gender is central for this thesis and will be discussed throughout the manuscript. To further guide the reader’s way through this work, each chapter is briefly summarized in the following paragraphs.

Chapter 1 gives a short introduction to emotions. The reader will find a description of theories concerned with the processing of emotional events and how they trigger feelings referred to as emotions. One crucial aspect that distinguishes those theories is the role of cognition for emotional processes. Furthermore, emotional valence is discussed with respect to processing differences between positive and negative stimuli. A final subsection reviews studies that investigated the expression and the perception of emotions with respect to biological gender.

The present experiments investigated word processing with regard to the role of context established by prosody. Those context effects should be compared to what has been found for other types of contextual information, for example semantics. Therefore, Chapter 2 provides an introduction to word recognition models and the role they address to context. Additionally, the term 'prosody' is introduced, followed by a description of how prosody can convey emotional information and where prosodic processes might be localized in the brain. A final subsection describes language research that investigated sex differences.

Chapter 3 provides the reader with a description of how the event related potential (ERP) is recorded, what it measures and which processes it might reflect. Particular attention is paid to ERP correlates of language and emotional processing.

Chapter 4 lists the research questions: The 'W*hen-Question*' asks whether prosody and word information interact when listening to speech and when such an interaction occurs. The '*Dominance-Question*' asks whether the emotion conveyed by prosody or the emotion conveyed by words dominate the comprehension of emotions in speech.

Chapter 5 contains the experiments concerned with the 'W*hen-Question*'. Experiment 1 and 2 revealed that emotional prosody affects word processing similar to semantic context. However, women showed an earlier interaction between prosodic and word information than men. This difference was eliminated in Experiments 4 and 5, when participants were explicitly instructed to take prosodic information into account. It was concluded that the significance of emotional prosody in a specific situation modulates the time course of prosodic context effects in men and women.

Chapter 6 presents the experiment concerned with the '*Dominance-Question*'. The results indicate that the processing of emotions in speech is more strongly affected by prosody than word valence. Although this is true for both sexes, ERPs revealed a more dominant role of prosodic information in females.

Chapter 7 discusses the findings from Chapter 5 and 6 with respect to the literature on language and emotional processing. Assumptions are formulated about the functional significance of emotional prosody during spoken word recognition in men and women. Furthermore, questions that arose from the present work and considerations for further research are suggested.

Chapter 1: Emotions

1.1 Cognition and Emotion

What emotions are and how we perceive them has been of interest to researchers for several centuries. A number of theories have been proposed to explain how the sight or the sound of an emotionally valenced stimulus leads to an emotional response. One aspect that distinguishes these theories is the role of cognition. William James (1884), for example, proposed a sensory feed-back model of emotion in which cognitive evaluation of the stimulus is unnecessary for emotional experience. He thought that sensory processing of an exciting event would trigger bodily changes (e.g., increase in heart rate). The sensory feed-back of those bodily changes and the ongoing perception of the exciting event would lead to an emotional feeling. The idea that the physiological response could precede and determine emotions was heavily criticized by Cannon (1927, 1931). He argued that bodily changes were too slow and not specific enough to account for different emotions, such as anger, happiness, disgust, or fear. In line with this criticism, cognitive emotion theories (Lazarus, 1982; Mandler, 1975; Schachter & Singer, 1962) claim that the emotionally ambiguous physiological response needs to be interpreted on the basis of the eliciting situation. Cognitive processing of the situation would enable a person to label and thus to experience emotions.

In contrast to feed-back and cognitive theories, neurological theories assume that emotions are generated by brain regions specialized for emotional processes (LeDoux, 1989; MacLean, 1949, 1952; Papez, 1937). The limbic system hypothesis, proposed by MacLean (1949, 1952), has been influential and is still one of the most frequently cited concepts of emotional processing in the brain. According to MacLean, a group of phylogenetically old structures that encircle the brain stem mediate all aspects connected with emotions, that is the processing of and the response to an emotional stimulus. He thought that structures such as the amygdala, the hippocampus, the limbic cortex, and the area septalis compose the major constituents of the limbic system. However, the limbic system concept has been challenged on both anatomic and functional grounds (LeDoux, 1991). There are ongoing discussions as to what structures should be subsumed under the term 'limbic system' (Kotter & Meyer, 1992). Moreover, regions originally labeled as limbic have been found to serve primarily cognitive functions. The hippocampus, for example, is not only important for emotional processes but is also crucial for declarative memory (Tulving & Schacter, 1990), spatial cognition (Nadel, 1991), and contextual processes (Cohen & Eichenbaum, 1993).

In spite of this criticism, LeDoux (1989, 1995) holds on to the idea that there is a key structure that mediates all aspects of emotion. However, he suggests that the amygdala as a single structure, but not the limbic system as proposed by MacLean (1949, 1952), plays such a role. Specifically, two parts of the amygdala are responsible for the perception of and the response to an emotional event. The lateral nucleus of the amygdala (LNA) receives sensory information from the thalamus, from primary sensory and association cortices, as well as from the hippocampal formation. As a sensory interface in the amygdala, the LNA modulates the output response of the central nucleus of the amygdala (CNA), which is connected to different subsystems such as the autonomic nervous system and systems that control the release of stress hormones and initiate a behavioral response. The amygdala is crucial for *affective* computations, such as a snake being potentially dangerous, which LeDoux contrasts with *cognitive* computations, such as a snake being biologically closer to an alligator than to a cow. While the former can be mediated solely by the amygdala, cortical structures have to be involved in the latter kind of computations. Furthermore, affective computations precede cognitive computations (LeDoux 1989; Zajonc, 1980).

Once they have been established both computations might interact – the cognitive evaluations might influence emotional experience and the affective computations might influence the way one evaluates an emotional event.

There is evidence that, in addition to subcortical structures, cortical regions are involved in emotional processing (Davidson, 1984; Borod, 1992; Reuter-Lorenz & Davidson, 1981). Furthermore, a study of brain damaged patients suggests that although it is crucial for the recognition of facial emotional expression, the amygdala plays a less important role in the recognition of emotional-prosodic expression (Adolphs & Tranel, 1999). This might appear to be in contrast with LeDoux's amygdala theory as he assumes the amygdala to be the key structure for affective computations. However, cognitive computations might include the retrieval of emotional associations from memory. Although not explicitly mentioned, such cognitive-emotional processing may occur independently from primary computations of the amygdala. Which cortical regions are involved in cognitive-emotional computations is still under discussion. To date, researchers are trying to determine the role of each cortical hemisphere for emotional processing. Studies investigating the perception of emotional stimuli using a visual half-field technique found superior recognition of positive stimuli presented in the right visual field as compared to the left, whereas the opposite was true for negative stimuli (Natale, Gur, & Gur, 1983; Reuter-Lorenz & Davidson, 1981; Reuter-Lorenz, Givis, & Moscovitch, 1983). Because information from a visual half-field is transferred to the contra-lateral hemisphere, it was concluded that the right hemisphere is specialized for the processing of negative information while positive information processing is lateralized to the left hemisphere. More recently, it has been suggested that this difference in lateralization for positive and negative emotions holds for the frontal lobes, but that posterior regions of the right hemisphere process both valences (Borod, 1992; Davidson, 1984). However, a large number of lesion studies (Blonder, Bowers, & Heilman, 1991; Starkstein, Federoff, Price, Leiguarda, & Robinson, 1994; Tompkins & Flowers, 1987) as well as dichotic listening experiments (Herrerro & Hillix, 1990;

Ley & Bryden, 1982) indicate a general right hemisphere dominance for the processing of positive and negative stimuli.

In sum, both cortical and subcortical structures are involved in emotional processing. Among subcortical regions, the amygdala seems to be a key structure: it receives sensory stimulus information and mediates bodily changes as well as emotional experience. In addition to the more basic stimulus analysis performed by the amygdala, cortical regions might perform cognitive emotional evaluations. At the cortical level, the right hemisphere seems to play a major role. The emotional response might result from an interaction between cortical and subcortical emotional processing.

1.2 Emotional Valence

Rolls (1999) proposed a theory of emotion that focuses on the variety of feelings an event in the environment or within a person can elicit. He argues that emotions are states caused by the presentation or omission of reinforcing stimuli. Some of these stimuli are primary (i.e., unlearned) reinforcers, such as food or pain. The majority, however, represent learned associations between a former neutral stimulus and a primary reinforcer. For example, one could imagine an association between squealing brakes on a road and pain experienced in an accident. Later on, this squealing noise itself is sufficient to elicit fear in an individual. Following this approach, Rolls classifies the different emotions with regard to their type of reinforcement. According to him, negative emotions are elicited in response to punishment (e.g., fear) as well as the omission or termination of a reward (e.g., grief). Positive emotions follow the omission or termination of a punishment (e.g., relief) as well as the presentation of a reward (e.g., elation).

Given these differences in reinforcement that lead to the experience of different emotions, it seems reasonable to assume that the neuronal processing of a stimulus differs with respect to its emotional valence (LeDoux, 1995). Öhman, Flykt, and Lundqvist (2000), for example, argue that, due to evolutionary significance, negative, but not positive stimuli automatically attract an individual's attention. In a face detection task, the authors found that an angry face in a crowd of happy faces was detected faster than vice versa. Besides the automatic capture of attention, the processing of negative stimuli also seems to depend on more attentional resources thus leaving less resources for the processing of other information. For example, responses to a target are usually slower when the target is preceded by an emotionally negative as compared to a positive stimulus (Garcia-Pereira, Volchan, Machado-Pinheiro, Oliveira, Rodrigues, Nepomuceno, & Pessoa, 2001; Hartikainen, Ogawa, & Knight, 2000). Affective priming studies often report longer reaction times for negative as compared to positive words (Musch & Klauer, 1997; Wentura, 1998). Moreover, there is evidence from event related potentials (ERPs) that negative stimuli are less expected and processed with more effort as compared to positive stimuli (Lang, Nelson, & Collins, 1990).

1.3 Emotions and Gender

Developmental investigations of emotional expression in boys and girls suggest that the stereotype that females are more emotional than males has some basis in truth (Buck, 1975, 1977; Polce-Lynch, Myers, Kilmartin, Forssmann-Falck, & Kliewer, 1998). While girls tend to increase their expression of emotions through development, boys restrict expressiveness as they get older. Some studies, however, indicate that this does not hold for all emotions. Anger, for example, has been found to be more frequently expressed by boys than girls (Hubbard, 2001). Research concerned with emotional expression in adults revealed similar findings. While some studies point to a general advantage for women in the expression of emotions (Hess, Senecal, Kirouac, Herrera, Phillippot, & Kleck, 2000; Manstead, 1992), others suggest a female advantage for certain, but not all emotions. In accordance with the developmental studies mentioned above, some investigations revealed that men express anger more effectively than women (Bonebright, Thompson, & Leger, 1996; Wallbott, 1988).

However, more than the expression of emotions seems to differ between the sexes. Women are reported to experience emotions more intensely (Grossman & Wood, 1993) and to show higher emotional contagion than men (Doherty, Orimoto, Singelis, Hatfield, & Hebb, 1995). Furthermore, there are sex differences in the perception of emotional cues in social interaction. Compared to men, women judge positive words as more positive and negative words as more negative (Grunwald, Borod, Obler, Erhan, Pick, Welkowitz, Madigan, Sliwinski, & Wahlen, 1999; Sutton & Davidson, 2000). Accordingly, a meta-analysis including 75 studies that investigated the accuracy in recognizing nonverbal emotional cues revealed a small but consistent female superiority in the recognition of emotions from voices, faces and gestures (Hall, 1978). This difference was strongest in studies that analyzed combined visual and auditory processing. Comparable to Hall (1978), a study by Rotter and Rotter (1988) on sex differences in recognizing emotionally negative facial expressions revealed an overall superiority for female subjects. However, men exceeded on a single emotion – anger. Obviously, anger seems to have an exceptional role in the general advantage of women in encoding and decoding emotions.

Theoretical explanations differ in whether they claim biological or social factors are responsible for the reported sex differences. Kimura (1999), for example, suggests an involvement of biological factors. She argues that women in their evolutionary past had to be more sensitive toward nonverbal signals in order to survive in a male-dominated world. Moreover, women with better emotional perception would be more likely to satisfy the needs of their offspring, which would help propagate their genes. However, studies investigating parental reinforcement of emotional expression in children reveal a contribution of educational factors (Brody, 1985; Malatesta & Haviland, 1982). The findings suggest that parents encourage the expression of fear and sadness in girls more than in boys. Parents, on the other hand, restrict boys less when they demonstrate anger. One form of emotional expression, namely speech, will be discussed in more detail in the following chapter.

CHAPTER 2: LANGUAGE

2.1 Models of Word Recognition

2.1.1 From Word Form to Meaning

In order to understand the emotional meaning of an utterance, we have to process every word with respect to both its semantics and its presentation context. Imagine the word 'laugh' – without any context this word might be associated with a happy emotion. However, this changes when embedded in a gloomy sentence context as in the second example below.

'When she entered the room and saw he was smiling at her –
she started to *laugh* happily.'

'When she entered the room and saw he was dead –
she started to *laugh* hysterically.'

Models of word recognition formulate assumptions about how we retrieve the meaning of a word and relate it to contextual information. They propose that each word has a corresponding entry in a so-called mental lexicon, which registers "the central abstract representation of a word's semantic, syntactic, and morphological properties" (Marslen-Wilson, 1999). Meaning, however, is also determined by the emotions associated with a word's real-world referent (e.g., gift). Moreover, Osgood, Suci and Tannenbaum (1957) suggest that emotional aspects of a word constitute primary semantic features that are accessed first among all semantic features stored in the mental lexicon.

In general, word recognition models divide the mapping from a visual or phonological word form onto meaning into different processing stages: lexical access, selection, and integration (Zwisterlood, 1989). First, the phonological or visual word form activates its corresponding entry in the mental lexicon. This stage is called lexical access and is thought to be purely stimulus driven (Frauenfelder & Floccia, 1998; Soto-Faraco, Sebastian-Galles, & Cutler, 2001). If the linguistic input is sufficient for word identification, the word together with its semantic (and emotional), syntactic, and morphologic properties gets selected from the lexicon. This stage is called lexical selection and establishes an interface between lexical form and contextual meaning (Hagoort & Brown, 2000). Lexical selection is of particular relevance in the case of lexical ambiguity. The word ‘ball’, for example, has two different meanings and might correspond to a different lexical representation when presented in a ‘dancing’ context than when presented in a ‘playing’ context. Therefore, the decision about the appropriate meaning has to be made on the basis of contextual information. Finally, after a word and its appropriate meaning have been retrieved from the mental lexicon, post-lexical processes operate. Integration is thought to be such a post-lexical process that relates a word’s properties to the context in which it has been presented.

In an effort to further specify the nature of word processing, Brown and Hagoort (1993; also see Chwilla, Kolk, & Mulder, 2000) mapped the conceptual distinction between automatic and controlled processes, derived from behavioral studies (Posner & Snyder, 1975; Shiffrin & Schneider, 1977), onto the different word recognition stages. According to the dual-process model proposed by Posner and Snyder (1975), automatic processes are of short duration, occur without attention or awareness and presuppose no or only minimal demands on a general processing capacity. In contrast, controlled processes require more time, intentional task monitoring as well as resource capacities. Furthermore, expectancy and strategies are more likely to exert an influence on controlled processes. Given this functional frame-work, Brown and Hagoort (1993) refer to lexical access as a “reflex-like and effortless behavior, which cannot be controlled by the subject." In contrast, lexical integration is assumed to be a controlled process "that can be guided by the subject's awareness of the informational content of the discourse". The authors do not refer to the processing nature of lexical selection.

2.1.2 Matters of Debate

Different positions exist regarding the independence of word recognition from other speech processing levels, such as prosody, syntax, and preceding semantic information. A further question that has been raised in this context is whether the cognitive operations that underlie language processing serve language processing only. The generative grammar theory proposed by Chomsky (1965) has been influential with respect to both questions. The term 'generative grammar' describes the assumption that an innate linguistic ability derives an infinite number of sentences from a finite set of lexical elements via combinatory rules or principles. The ability of children to acquire these principles without any effort led to the conclusion that humans possess a cognitive specialization for language. Furthermore, language processing is thought to rely on separate and independent modules specialized for different aspects of language, such as semantics, syntax, and phonology (the sound system of language, which comprises prosody).

Some models of word recognition have adopted such a modular perspective. The cohort model (Marslen-Wilson, 1984, 1987), for example, assumes that the initial auditory input (e.g., 'ca' from 'captain') activates multiple word candidates (e.g., captain, capital). Inappropriate candidates decline in activation as more auditory information becomes available. When the auditory input is sufficient to identify the appropriate word, word information is selected from the lexicon and integrated in the sentential context. The processing module that matches the acoustic input of a single word with the corresponding entry in the mental lexicon is thought to work independently from constraining semantic, syntactic, and prosodic context. Once lexical access has been established, matching context merely facilitates further processing. In a cross-modal priming experiment, Zwisterlood (1989) found support for this assumption. She presented auditory sentences that biased a particular prime word within that sentence:

With dampened spirits the men stood around the grave;
they mourned the loss of their *captain.*

At one out of four different positions concurrent with the prime word (e.g., captain), a visual probe occurred that required a lexical decision. The first (130 ms following prime word onset) and the second (199 ms) position were thought to tap lexical access of the prime word. The third position (278 ms) and the fourth position (410 ms) were believed reflect selection and post-lexical integration, respectively. The four probe positions were determined with a gating study prior to the actual experiment. Probe words were either related to the prime word (e.g., 'ship' related to captain) or to a word that shared early segmental information with the prime word (e.g., 'money' related to capital). Zwisterlood found that compared to a control condition, both types of probe words elicited a faster lexical decision at the first and the second position. A faster response to contextually related probes as compared to probes related to the prime word's initial competitor occurred for position three and four. This is in accordance with modular assumptions as it suggests that all word candidates that are still compatible with the acoustic input receive initial activation even if they do not fit into the sentence context.

However, the basic assumptions of the theory of generative grammar and modular word recognition models have been challenged. First, recent findings from functional imaging and ERP studies suggest that processes involved in language serve other cognitive functions as well. The processing of music, for example, was found to be mediated by similar brain regions as language processing (Platel, Price, Baron, Wise, Lambert, Frackowiak, Lechevalier, & Eustache, 1997; Sergent, Zuck, Terriah, & MacDonald, 1992; Zatorre, Evans, Meyer, & Gjedde, 1992). Moreover, structural violations in a musical piece elicit similar ERP effects as structural violations in language (Kölsch, Gunter, Friederici, & Schröger, 2000; Patel, Gibson, Ratner, Besson, & Holcomb, 1998; but see Besson & Schön, 2001 for an overview). Second, the assumption that separate modules process different aspects of language independently contrasts with theories that assume language processing occurs interactively[1]. One prominent representative of this interactive tradition is the TRACE model (McClelland & Elman, 1986; McClelland & Rumelhart, 1981). TRACE distinguishes feature, phoneme, and word units, which are organized hierarchically. Similar to the cohort model, the acoustic input activates several word candidates. First, feature units get excited, which then excite phonemes, so that finally words become activated. Activated units inhibit each other. The word unit that maintains highest activation will be selected from the mental lexicon. Although the model is restricted to the word level and no explicit assumptions about the role of sentential context have been made, one might draw conclusions from the role of lexical information. Activated word units are thought to influence the activation level of units lower in hierarchy. Similar effects could be assumed for contextual information derived from preceding words. This would explain the influence of sentential context on the perception of phonemes, such as ‘date’ versus ‘gate’ in a phrase like ‘check the time and the ...’ (Connine, 1987).

Further disagreement exists regarding the stages thought to underlie word recognition. In contrast to the three aforementioned stages: lexical access, selection, and integration, some researchers assume only two stages and neglect selection (e.g., Brown & Hagoort, 1993). That selection has relatively little theoretical significance for word processing may account for its occasional absence from discussion. For example, selection is necessary only for ambiguous words and if we assume that context does not affect lexical access. Unambiguous words succeed against other competitors as they receive most activation and therefore ‘light up’ as the appropriate word. Furthermore, the contextually inappropriate meaning of an ambiguous word would simply receive less activation. A later selection would be unnecessary. Beside the definition of the single word recognition stages, it is unclear whether they occur

[1] One has to keep in mind that an interaction between different processing modules does not imply that a subject can control lexical access. Both questions, the automaticity of lexical access

serially or in parallel. It might be possible that integration starts before lexical access is completed. In order to facilitate processing, incompletely accessed information might be checked for contextual feasibility (Van Petten, Coulson, Rubin, Plante, & Parks, 1999).

Finally, although word recognition models are concerned with the point in time when context comes into play, no assumptions have been made about the different types of contextual information. Specifically for word recognition, the semantic context given by preceding words or sentences has received most attention. However, in everyday communication other sources of contextual information exist, for example, syntactic and prosodic constraints. Moreover, with regard to emotional prosody one might want to draw parallels to semantic context. As suggested by Osgood and colleagues (1957), emotional information is closely linked to other forms of semantic meaning. For example, that a gift is meant to make someone happy, is usually wrapped, and comes with a ribbon is information that might be stored together in the mental lexicon. If true, then one may assume that the emotions conveyed in a speaker's voice provide contextual information similar to the semantic context established by words. Unfortunately, this non-lexical, emotional context has not been investigated with respect to word recognition. The work presented in this dissertation makes a start because it addresses the significance of emotional prosody for the processing of words. The following section introduces prosody and the kind of information it allows us to express.

2.2 Prosody

2.2.1 The Acoustical Wrapping of Language

Processes that underlie spoken language comprehension are multifaceted. Their characteristics may best be demonstrated by a comparison with written language. For example, spoken words have to be processed successively as they unfold in time,

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and the modularity of processing, are separate issues.

whereas in the visual domain words can be perceived as units. The timing of speech processing is determined by the speaker's tempo, whereas the pace of written language processing is solely determined by the recipient. Onset and offset of words in a spoken utterance are seldom marked by clear breaks in the acoustic input. In contrast, word boundaries in written language are indicated by white spaces between words. Furthermore, speech is characterized by one additional feature that makes it richer as compared to written language. This feature is prosody.

Although research on prosody is becoming more popular, there is still no consensus about what aspects of speech should be subsumed under the term prosody. Moreover, investigations of single prosodic functions such as stress, phrasing, or focus often result in definitions applied to the respective function, but they fail to contribute to a holistic understanding of prosody. To explain prosodic expression, researchers often refer to three basic parameters that describe some of the acoustic properties of speech: fundamental frequency (F0), time structure, and intensity (Schirmer, Alter, Kotz, & Friederici, 2001; Van Lancker & Sidtis, 1992). The F0 is contained in the lower portion of the frequency spectrum and is perceived as speech melody. As a marker for the tempo of spoken language production, time structure describes the length of speech units such as syllables, words, and pauses. Intensity simply measures the loudness of such speech units. As these parameters describe acoustic properties of several segments (e.g., word, phrase), they are often referred to as suprasegmental information (Friedrich, Alter, & Kotz, 2001). Suprasegmental information determines the rhythm and melody of speech. However, spectral characteristics that are tied to a segmental level (e.g., the frequency spectrum of a particular vocal) also constitute prosodic information. Taking segmental and suprasegmental information into account, one might define prosody as the phonetic and phonologic information that accompanies spoken language (see Warren, 1999).

Speech prosody serves two basic functions: the communication of linguistic content and the communication of emotion. For example, the prosodic contour of a sentence that differentiates between a question and a statement serves a linguistic function. Furthermore, linguistic content is conveyed in a word’s stress pattern, which is realized via prosody. To distinguish between the noun and the verb meaning of 'content', listeners have to pay close attention to the prominence of the first compared to the second syllable. Finally, prosody can signal syntactic phrasing to facilitate speech comprehension. Behavioral investigations demonstrated that speakers realize the syntactic structure of a sentence prosodically. Words at the end of a syntactic phrase are often lengthened and followed by a short pause (Cooper & Paccia-Cooper, 1980; Schirmer et al., 2001). Furthermore, studies on speech perception revealed that listeners use this kind of information during language processing (Marslen-Wilson, Tyler, Warren, Grenier, & Lee, 1992; Warren, Grabe, & Nolan, 1995). Sentences with ambiguous syntactic structure that are prosodically disambiguated elicit faster naming latencies for words that match the correct as compared to the incorrect interpretation of the sentence:

A: ARISE ↓

Whenever the parliament discusses Hong Kong # problems are solved instantly.

B: ARISE ↓

Whenever the parliament discusses Hong Kong problems # they are solved instantly.

The visually presented word 'ARISE' in the preceding example is spoken faster when presented with sentence A than when presented with sentence B (time point of presentation is indicated by an arrow; example taken from Warren et al., 1995). Further evidence comes from a recent ERP study by Steinhauer, Alter, and Friederici (1999). The authors found an ERP correlate for the processing of prosodic phrases: the closure positive shift. Moreover, they demonstrated that for syntactically ambiguous structures prosodic processing establishes a necessary pre-condition for successful analysis. The prosodic realization of syntactic phrasing as well as stress and the statement/question distinction is subsumed under the term linguistic prosody.

The term emotional prosody applies to a second function of prosody, namely the expression of emotions. Because of its importance for the processing of emotional speech, emotional prosody is discussed in more detail below.

2.2.2 Vocal Expression of Emotions

Humans, like most mammals, can communicate emotions via the vocal expression system. For vocalization, the lungs fill the trachea below the closed glottal folds with air. Together with laryngeal movements this subglottal air pressure initiates the vibration of the vocal folds. The pulses released into the supraglottal tract are then modulated by movements of the tongue, the lips and the jaw.

Because vocalization is closely linked to physical parameters known to differ between emotional states (e.g., muscle tension, respiration and blood pressure), it is thought to directly reflect emotions (Scherer, 1989). Scherer (1989) argues that while speech is primarily controlled by the neocortex, emotional vocal expression is highly influenced by the limbic system. Emotional responses triggered by limbic structures would affect the autonomic and the somatic nervous system which in turn influence respiration, phonation and articulation.

The acoustic parameters that Scherer (1989) uses to measure the emotional content of vocalization partially overlap with the prosodic parameters introduced in the preceding section. He lists four major classes of vocal parameters: vocal intensity, vocal frequency, vocal quality and vocal resonance. An increase in intensity is directly correlated to an increase in subglottal pressure and laryngeal tension. Vocal frequency subsumes F0 and its harmonics (multiples of F0) and is higher the more frequently the vocal folds vibrate. Frequency is also affected by changes in laryngeal tension and respiration. Because F0 is higher the shorter the vocal folds, most women speak with a higher F0 (i.e., ca. 260 Hz) than men (i.e., ca. 128 Hz; Daniloff, Schuckers, & Feth, 1980). The energy distribution (i.e., loudness) of the different frequencies in the frequency spectrum is perceived as vocal quality. For example, a voice with higher energy of frequencies in the upper portion of the spectrum is perceived as shrill. Vocal quality is determined by phonatory (e.g., laryngeal tension) and articulatory settings (e.g., lip opening, position of the tongue). Finally, vocal resonance is modulated by the articulatory setting. Modulations in resonance produce different speech sounds such as vowels and diphtongs.

Table 2.1. Means and Standard Deviations of Z-Transformed Acoustic Parameters (Banse & Scherer, 1996)

Emotion	Mean F0	Standard Deviation F0	Mean Energy	Duration of Articulation Periods	Duration of Voiced Periods
Hot Anger	1.13 (0.58)*	0.50 (0.63)	1.19 (0.53)	-0.31 (0.64)	-0.45 (0.66)
Cold Anger	0.16 (0.72)	-0.10 (0.68)	0.52 (0.58)	-0.14 (0.75)	0.15 (0.89)
Elation/Joy	1.24 (0.48)	0.21 (0.85)	1.05 (0.49)	0.12 (0.65)	-0.34 (0.57)
Happiness	-0.64 (0.41)	0.14 (0.89)	-0.48 (0.69)	-0.49 (0.63)	-0.45 (0.61)
Sadness	-0.32 (0.85)	0.43 (1.14)	-1.16 (0.47)	1.04 (1.67)	1.25 (1.86)

*(SD)

In a production and perception study of emotional prosody, Banse and Scherer (1996) collected the acoustic profiles of 14 different emotions as vocalized by 6 actresses and 6 actors. Table 2.1 summarizes some acoustical parameters found in anger, sadness, joy and happiness. Even with only a subset of parameters it becomes apparent that each emotion has a characteristic profile. Sadness, for example, is characterized by a decrease in F0, a restricted F0-variability, lower intensity and a slower speech rate. Joy, however, leads to an increase in F0, the utterance becomes louder and the speech rate faster. In a cross-cultural study, Scherer, Banse, and Wallbott (2001) demonstrated that listeners from nine different countries could infer the emotional states portrayed by German actors and actresses with a better-than-chance accuracy. This suggests that there is a high recognizability of vocal expressions across cultures. What brain regions are involved in the analysis of prosodic aspects of speech will be discussed in the following chapter.

2.2.3 Localizing Prosody in the Brain

Although researchers have been interested in the brain structures that underlie prosodic processing for more than three decades, different experimental findings prevented an unequivocal model. This might partially be due to the variety of methodological approaches used including different experimental tasks and measurement techniques. Consequently, several hypotheses have been proposed. For example, some studies stress the importance of subcortical structures, such as the caudate nucleus and the putamen, (Cancelliere & Kertesz, 1990; Kotz, Meyer, Alter, Besson, von Cramon, & Friederici, in press), whereas others suggest that prosodic processing is mediated predominantly by cortical structures. Furthermore, different assumptions concerning prosodic lateralization at a cortical level have been formulated. Various investigations in brain damaged patients (Bryan, 1989; Blonder, Bowers, & Heilman, 1991; Weintraub, Mesulam, & Kramer, 1981) as well as normal subjects (Blumstein & Cooper, 1974; Bulman-Fleming & Bryden, 1994; Shipley-Brown, Dingwall, Berlin, Yeni-Komshian, & Gordon-Salant, 1988) indicate that the right hemisphere is specialized for prosodic processing. Another hypothesis, mainly derived from patient studies (Gandour, Larsen, Dechongkit, Ponglorpisit, & Khunadorn, 1995; Gandour, Ponglorpisit, & Dardarananda, 1992; Pell & Baum, 1997), proposes a lateralization of prosody that depends on function. Whenever prosody carries linguistic information, such as stress or syntactic phrasing, it is processed in the left hemisphere, whereas when prosody has some emotional meaning its processing is lateralized to the right hemisphere. A third hypothesis, derived from a study by Van Lancker and Sidtis (1992), refers to the prosodic parameters regardless of their function. Van Lancker and Sidtis reported deficits for both left and right hemisphere damaged patients in a task that required the recognition of emotional contours. Acoustical analysis revealed that F0 provided the clearest distinction between affective categories. A discriminant analysis indicated that left, but not right hemisphere patients made use of F0 to distinguish between emotional contours. The performance deficit in left hemisphere patients was attributed to deficits in processing time structure. Consequently, the authors argued that the right hemisphere might be dominant for the processing of F0, whereas the left hemisphere might be specialized for processing temporal information. A similar dissociation for the left and the right auditory cortex has been proposed by Zatorre and Belin (2001; but see also Zatorre, Belin, & Penhune, 2002). In a study using positron emission tomography (PET), the authors found that the brain activation correlated with temporal stimulus characteristics was more pronounced for the left auditory cortex, whereas right auditory cortex activation was stronger for the discrimination of pitch information. Zatorre and Belin (2001) highlight the significance of temporal information for speech processing and that of tonal information for music perception. Furthermore, they suggest that the specialization of both auditory cortices results from a trade-off between speech and music processing demands.

Schirmer and colleagues (2001) proposed a model that combines functional and parameter dependent hypotheses. In a study investigating the production of linguistic prosody in brain damaged patients, they found deficits in both left and right hemisphere patients, with a more severe impairment in the left hemisphere group. While the deficit in patients with right hemisphere lesions was attributed to difficulties in modulating fundamental frequency, left hemisphere patients had additional difficulties in timing their speech production. Given these findings, the authors suggested two distinct processing levels. One level operates with the different prosodic parameters, while the other level uses this parameter information in order to process linguistic or emotional aspects of prosody. Consequently, both hemispheres should be involved in prosodic processing with a stronger (i.e., 2-level) involvement of the left hemisphere during linguistic prosodic tasks and a stronger (i.e., 2-level) involvement of the right hemisphere in emotional prosodic tasks.

2.3 Language and Gender

Beside emotions, language skills are subject to sex differences. It is widely assumed that women have better verbal skills than men. Some evidence comes from studies in children that report differences in language acquisition between boys and girls. Girls are found to start earlier and to progress faster in speech production as compared to boys (Maccoby, 1966). Moreover, the incidence of developmental language disorders is generally higher in boys than in girls (Stein & Walsh, 1997). During further development, boys catch up on language skills. In adults, a general superiority of females in verbal tasks is no longer present (Shibley-Hyde & McKinley, 1997). Across studies, consistent gender differences in favor of women can be found only for verbal fluency and verbal memory (Halpern, 1992, Kimura, 1999). Other tasks, such as vocabulary or comprehension, that are included in the verbal assessment of the Wechsler Adult Intelligence Scale (WAIS) show either no gender differences or they slightly favor men (Hyde & Linn, 1988).

Furthermore, researchers were interested in whether the brain structures that underlie verbal functions differ with respect to gender. As there are dominant pathways from each ear and visual hemifield to the contra-lateral hemisphere, dichotic listening and visual hemifield tasks provide one approach to study language lateralization in the brain. Commonly, these studies reveal a better recognition of verbal stimuli presented to the right as compared to the left ear (Kimura, 1967) or to the right as compared to the left visual field (Levy & Reid, 1978), respectively. With regard to gender differences, however, lateralization studies reveal inconsistent findings. While some report a stronger laterlization of language function to the left hemisphere in men (Voyer & Flight, 2001; Weekes, Zaidel, & Zaidel, 1995), others suggest either no gender differences (Hiscock & MacKay, 1985) or a stronger lateralization in women (Healey, Waldstein, & Goodglass, 1985). Of the literature reviews summarizing the results of the dichotic listening and visual hemifield studies, the majority point to a slightly stronger lateralization in males than in females (Bryden, 1979; McGlone, 1980; Hiscock, Inch, Jacek, Hiscock-Kalil, & Kalil, 1994; Hiscock, Israelian, Inch, Jacek, & Hiscock-Kalil, 1995).

The question whether, in contrast to men, women process language more bilaterally has also been investigated using functional magnetic resonance imaging (fMRI). There are at least four studies that found sex differences in the activation patterns elicited during language tasks (Jaeger, Lockwood, Van Valin, Kemmerer, Murphy, & Wack, 1998; Kansaku, Yamaura, & Kitazawa, 2000; Phillips, Lowe, Lurito, Dzemidzic, & Mathews, 2001; Shaywitz, Shaywitz, Pugh, Constable, Skudlarski, Fulbright, Bronen, Fletcher, Shankwiler, Katz, & Gore, 1995). In accordance with the literature on dichotic listening and visual hemifield tasks, they report a more bilateral activation in women than in men. However, there are contradictory findings as well. Buckner, Raichle, and Petersen (1995) conducted a study in which participants performed a verb generation and a word stem completion task. Both failed to reveal sex differences. Further evidence that men and women do not differ in language lateralization comes from Frost and colleagues (1999). As in the Buckner study, they investigated language processing at a word level. However, the level of processing seems to be a critical factor that distinguishes between studies that report sex differences and those that fail to do so (Kansaku & Kitazawa, 2001). While syntactical and phonological judgment of nonsense words (Shaywitz et al., 1995; Jaeger et al., 1998) and passive listening to stories (Kansaku et al., 2000; Phillips et al., 2001) elicit a more bilateral activation in women than in men, tasks that involve isolated real words lead to a more left lateralized activation independent of sex (Buckner et al., 1995; Frost et al., 1999; Jaeger et al., 1998; Kansaku et al., 2000; Shaywitz et al., 1995). As the task may be a critical factor for the detection of sex differences in dichotic listening and hemifield studies as well (Voyer & Flight, 2001), general conclusions about sex differences in language lateralization have to be drawn cautiously. Furthermore, a high variability between participants may contribute to the diversity of findings. Sex differences in lateralization may exist, but are perhaps smaller than the variability within one sex and therefore hard to detect. Moreover, the small effect size as well as the inconstancy of its occurrence may suggest minor functional significance.

Beside sex differences in lateralization, some researchers investigated the size of certain brain structures with respect to gender. Witelson (1989), for example, found evidence for a stronger neuronal connectivity between the two hemispheres in women as compared to men. This report is in accordance with other evidence suggesting that brain structures connecting both hemispheres, such as the anterior comissure, the massa intermedia, and the splenium of the corpus callosum, are larger in women than in men (Allen & Gorski, 1991; McEwen, 1994). Given this higher interhemispheric connectivity in women, another hypothesis concerning gender differences in the processing of language arises. Beside a more bilateral organization, women could process language more interactively by integrating verbal and nonverbal stimulus information. For example, women could visualize verbal information or they could integrate prosodic and emotional aspects to a larger extent than men. The latter question, namely the interaction between verbal and non-verbal information such as prosody was of central interest for this dissertation. Moreover, the present work should reveal the time course of this interaction. As event-related potentials (ERPs) are sensitive to temporal aspects of speech processing, they were conducted for all experiments described here. The following chapter provides a short overview of methodological issues as well as relevant ERP findings from language and emotion research

CHAPTER 3: EVENT RELATED POTENTIALS

3.1 What Does ERP Stand for?

The use of scalp-recorded event-related potentials (ERPs) has enhanced our understanding of cognitive processes. ERPs can be used to document the temporal characteristics of brain functioning. For example, they might indicate when certain stimulus information becomes available during processing. Moreover, ERPs can reveal whether different information, such as the emotional prosody and the meaning of a word are processed independently or in interaction. With a sufficient number of electrodes and the right modeling, they also provide insights into the underlying neuronal sources (Grave de Peralta, Gonzalez, Morand, Michel, & Landis, 2000; Kincses, Braun, Kaiser, & Elbert, 1999; Van Dijk, Spekreijse, & Yamazaki, 1993). Consequently, the ERP constitutes an attractive tool for the online investigation of cognitive processes.

ERP recordings represent changes in voltage over time elicited by synchronously active neuron populations. Beside minor contributions of subcortical structures (e.g., thalamus), pyramidal cells in the neocortex constitute the major source of electrical activity measured at the scalp. Because of their systematic alignment vertically towards the cortical sheet, these neurons fulfill a necessary condition for producing externally detectable open fields. When excited, soma and apical dendrites of pyramidal cells develop different polarity. This difference in polarity, also called a dipole, causes intra- and extracellular current to flow. Electric potentials detected on the scalp mainly represent extracellular current (see Birbaumer & Schmidt, 1991).

The neuronal response to a stimulus is contained in the recorded electrical signal. However, spontaneous electrical activity, unrelated to stimulus processing, makes it in most cases impossible to detect stimulus-related activity from a single event. Therefore, a single event is repeated many times and corresponding epochs in the recorded electrical signal for these repetitions are averaged. This averaging procedure reduces the influence of unrelated and unsystematic activity on the measure of electrical activity and leaves an electrical potential that is event-related.

ERPs are characterized by changes in polarity. Some of these polarity changes have been labeled as specific components according to their scalp distribution, latency, polarity, and their sensitivity to experimental manipulations (Donchin, Ritter, & McCallum, 1978). Furthermore, the different waveforms in the ERP have been located on an endogenous-exogenous dimension (Rugg & Coles, 1995). More exogenous components are thought to reflect primarily sensory characteristics of stimuli and are elicited within the first 100 ms following stimulus onset. More endogenous components appear after 100 ms have passed and are associated with the interaction between the person and the stimulus. However, a clear distinction between exogenous and endogenous components on a temporal scale is not completely straight forward. Heinze, Luck, Mangun, and Hillyard (1990) reported that spatial attention modulates the amplitude of the P1 – a positivity that peaks around 100 ms. Moreover, there is evidence that the P200, which has a latency of 200 ms, has an exogenous character as it is sensitive to sensory stimulus aspects (Ritter, Simson, & Vaughan, 1983). Although there is no clear-cut distinction, early and late components may differ in how much sensory and cognitive processing they reflect. The components associated with emotional and language processing are discussed below.

3.2 ERPs and Emotional Processing

To date, there is little ERP research that deals with the processing of emotional stimuli. Moreover, existing studies differ with respect to the participants' age, the task, and the stimulus type. As a consequence, some findings are equivocal and leave several questions concerning the processing of emotional information unanswered.

There is, however, relative consensus concerning the processing differences between emotional and neutral stimuli. Kayser, Bruder, Tenke, Stewart, and Quitkin (2000), for example, presented pictures of disordered facial areas taken before and after reconstructive plastic surgery. Participants were asked to look at the pictures; no overt response was required. The authors reported that the ERP for negative (before surgery) and neutral (after surgery) pictures differed in a late positivity that peaked around 500 ms after stimulus onset, labeled as a P300. The P300 was larger in response to negative as compared to neutral pictures. This finding is in accordance with other research on the processing of emotional pictures (Johnston, Miller, & Burleson, 1986) and words (Fischler, Goldman, Besson, McKay, & Bradley, submitted; Naumann, Bartussek, Diedrich, & Laufer, 1992; Windmann & Kutas, 2001) that revealed larger P300 amplitudes for emotional as compared to neutral stimuli. Kayser and colleagues (2000) suggest that this amplitude difference might reflect the affective significance a particular stimulus has and that it might function as a somatic marker, signaling the necessity of a response.

Less conclusive are studies concerned with the processing of stimuli of different emotional valence. De Haan, Nelson, Gunnar, and Tout (1998) found that when children viewed a series of happy, fearful, and angry faces, the N400 elicited for angry faces was largest. Kerstenbaum and Nelson (1992) presented a happy, fearful, surprised, and angry faces in a probe-detection task to adults and 7-year old children. Participants had to press a button for either happy or angry faces. With this paradigm, emotional valence did not affect the N400. In children, there was a larger P300 to angry as compared to happy faces. In adults, P300 amplitudes were larger to happy as compared to angry faces. Lang and colleagues (1990) conducted a similar study in adults using only two emotional expressions: happiness and anger. In contrast to the

Kerstenbaum and Nelson study, they reported that angry faces elicited larger P300 amplitudes than happy faces. Furthermore, Kiehl, Hare, McDonald, and Brink (1999) investigated processing differences between negative and positive words in normal adults and psychopaths. Participants had to classify words as either positive or negative. The authors found a larger P300 in response to negative as compared to positive words in normal adults, but not in psychopaths. In contrast, Fischler and colleagues (submitted) failed to find processing differences between positive and negative words in two non-emotional task. Together these findings are at odds with the assumption that the P300 is a somatic marker that signals the affective significance of a stimulus (Kayser et al., 2000) as one would expect emotional valence to have the same significance across different modalities and paradigms. Therefore, the P300 might reflect an interaction of emotional processing with methodological factors, such as stimulus modality, emotional context, task, and also the participant's age.

Beside words and faces, prosody can carry emotions during communication. Although there is a growing interest in ERP research on the role of prosody during speech processing, the focus has been restricted to its linguistic function (e.g., Astesano, Alter, & Besson, submitted; Friedrich, Kotz, Alter, & Friederici, 2001; Steinhauer, Alter, & Friederici, 1999). To my knowledge, there are only two ERP studies that investigated the processing of emotional prosody to date (Kotz, Alter, Besson, Schirmer, & Friederici, 2000; Pihan, Altenmüller, Hertrich, & Ackermann, 2000). Pihan and colleagues presented sentences with happy, neutral and sad prosody. The recorded EEG was analyzed for DC-components (slow waves elicited in an interval of several seconds). The authors reported no differences between the three emotional conditions for the DC-components. No analyses of ERP components within the first 1000 ms were conducted. Kotz and colleagues (2000) also presented sentences that varied in emotional prosody. To investigate the role of attention during emotional-prosodic processing, the experiment comprised one task with prosody in focus and another task that required subjects to ignore prosody. In the prosodic task, participants had to judge the emotional prosody of a sentence as happy, neutral, or angry. In the non-prosodic task, they had to indicate whether the emotional meaning of a sentence was positive, neutral, or negative. Independent of the task, the ERPs differentiated between the three prosodic conditions as early as 200 ms following stimulus onset. Angry prosody elicited a more negative waveform than happy and neutral prosody. Furthermore, this difference was more pronounced over right-hemisphere regions. As Kotz and colleagues did not control the position of emotional words within a sentence, an analysis concerning the influence of emotional prosody on the processing of emotional words could not be performed. This later question – namely the interaction between the emotional information conveyed at a word level and the emotional information conveyed at a prosodic level was of central interest for the present work.

3.3 ERPs and Language Processing

Several ERP components have been found to reflect language processing. They have been detected by a comparison between the processing of correct and incorrect sentences. Syntactic violations, for example, modulate the amplitude of an early left anterior negativity (ELAN) that peaks around 180 ms following word onset. This negativity is larger in response to words that violate the expected word category as compared to the correct word (Friederici, Pfeifer, & Hahne, 1993; Hahne & Friederici, 1999; Hahne & Jescheniak, 2001).

A: Das Hemd wurde gebügelt. *The shirt was ironed.*

B: Das Hemd wurde am gebügelt. *The shirt was on ironed.*

The preposition 'am' in example sentence B requires a noun to follow. Therefore, the presentation of the verb 'gebügelt' does not meet the syntactic sentence constraints and elicits a larger ELAN than the same word in sentence A. In contrast, morphosyntactic errors affect a left anterior negativity with a somewhat longer latency (Coulson, King, & Kutas, 1998; Gunter, Friederici, & Schriefers, 2000; Gunter, Stowe, & Mulder 1997; Osterhout & Mobley, 1995). Syntactic violations that require a reanalysis, but also sentences with a syntactically complex structure lead to an increase in the amplitude of a late positivity – the P600. (Hagoort, Brown, & Groothusen, 1993; Kaan, Harris, Gibson, & Holcomb, 2000; Osterhout & Holcomb, 1992; Osterhout, Holcomb, & Swinney, 1994).

Next to components related to syntactic processing, there is also a component that seems to reflect semantic processing. The presentation of visual as well as auditory words elicits a negativity in the ERP with a peak latency of about 400 ms, called the N400. The N400 was first reported in an experiment manipulating the semantic congruency of sentence final words (Kutas and Hilyard, 1980). In a sentence like 'He spread the warm bread with...', congruent words (e.g., butter) elicited a smaller N400 amplitude as compared to incongruent words (e.g., socks). Follow-up experiments revealed a negative correlation between the N400 amplitude and word frequency (Rugg, 1990) as well as cloze probability (Kutas & Hillyard, 1984). Furthermore, the N400 is sensitive to the abstract-concrete word distinction, with abstract words eliciting smaller amplitudes than concrete words (Holcomb, Kounios, Anderson, & West, 1999; Kounios & Holcomb, 1994). Additionally, different forms of priming have been found to affect the N400. In a word priming experiment a critical word, called the target, is preceded by another word, called the prime. If the prime shares certain characteristics with the target then processing of the target is facilitated. This facilitation is reflected in smaller N400 amplitudes and faster responses to related as compared to unrelated targets. The relation between prime and target can be orthographic, morphologic, phonologic, or semantic (see Kutas & Federmeier, 2000).

Although an N400 effect has been found for visual as well as auditory presentation modes, its timing and spatial distribution differs with respect to modality (Holcomb & Neville, 1990; Holcomb & Anderson, 1993). In the visual domain, the N400 effect has its maximum over right posterior sites whereas the auditory N400 effect is distributed more bilaterally and has an onset that is about 100 ms earlier.

The question, what aspect of word recognition the N400 reflects, is still not completely answered. Results from studies investigating semantic priming with a level of processing approach suggest that early processes such as lexical access might contribute to the N400 semantic priming effect. There were reliable N400 differences between congruent and incongruent prime-target pairs in tasks (e.g., letter detection) that required only a shallow level of processing (Besson, Fischler, Boaz, & Raney, 1992; Kutas & Hillyard, 1989). Although letter detection may not induce a semantic analysis of the target, one cannot exclude the possibility that participants nevertheless process the target to a semantic level. Therefore, processing may not have been as automatic as the task suggests and the N400 effect may not, or not only, reflect lexical access. In accordance with such an explanation is a study by Chwilla, Brown, and Hagoort (1995) in which they reported an absence of N400 semantic priming effects when subjects merely had to discriminate the letter case. The authors concluded that the N400 reflects lexical integration rather than access. To date, most researchers agree with this latter interpretation (Brown & Hagoort, 1993; Friederici, Steinhauer, & Frisch, 1999; Hinojosa, Martin-Loeches, & Rubia, 2001; Holcomb, 1993; Van Petten, et al., 1999).

Despite this debate, there is relative consensus regarding the idea that semantic context can modulate the N400 elicited by a word. This dissertation aimed at specifying the role of context provided by emotional prosody, which has been proposed to carry primary semantic information. If true, then emotional-prosodic context should exert a similar influence on word processing as does the semantic context established by words. As the N400 should reflect such an influence this component was taken as a tool for the investigation of emotional speech. In an attempt to prevent conceptual confusion, I will refer to the context established by words as semantic context and to the context established by emotional prosody as emotional-prosodic context.

CHAPTER 4: RESEARCH QUESTIONS

The major objective of this dissertation was to contribute to the understanding of how the brain processes emotional speech. More specifically, the focus was on the interaction between emotional prosody and the emotional information that is conveyed at a semantic level. Emotional comprehension in everyday communication makes it necessary for listeners to refer to both the prosodic and the semantic level. For example, a phrase like “Thank you!” changes dramatically in meaning if it is spoken in an angry tone. Then it indicates that one is not satisfied with the service provided. As we all understand the implicit meaning that prosody can add, it seems obvious that at some point during speech comprehension we must make a connection between emotional-prosodic and semantic information. For the present experiments, two aspects of this interaction were of particular interest: the time course and the dominance of both sources of information.

The first series of experiments, reported under the heading *‘When-Question’*, investigated the temporal structure of the prosody-semantics interaction. Insights into temporal characteristics should allow conclusions about the functional significance of emotional prosody during word processing. Moreover, the experiments should determine whether the role of prosody resembles that of semantic context established by the words in a sentence. As the functional role of semantic context is still not completely understood, this question could only be answered by comparing emotional-prosodic context effects and the effects of semantic context reported in the literature. It was assumed that if congruity between a word and its emotional-prosodic context exerts a similar influence on the N400 amplitude as semantic congruity, then the functional significance and the time course of emotional-prosodic effects on word processing are similar to the effects of semantic context.

A further study, described under the heading *'Dominance-Question'*, analyzed the relative significance of emotional prosody and word meaning for the comprehension of emotions in speech. As mentioned above, sometimes the precise meaning of an utterance is determined by its emotional prosody. This suggests that we weigh prosodic information more than semantics when we listen to emotional speech. Therefore, it was hypothesized thatIf true then influences of emotional prosody on an emotional judgment should be stronger than influences of word valence.

Both the *'When-Question'* and the *'Dominance-Question'* were also investigated with respect to the listener's sex. As sex differences have been reported for a variety of emotional tasks as well as for certain language skills and language lateralization, it seemed likely that men and women would differ in the processes underlying emotional speech comprehension. Moreover, the inclusion of gender in the data analysis should determine whether sex differences in the performance of emotional tasks result from quantitative or qualitative processing differences. In other words, are women simply more emotional and process emotional aspects of stimuli more intensely than men do – or does the processing of emotional aspects involve different mechanisms in men and women?

CHAPTER 5: THE WHEN-QUESTION

5.1 Introduction

In everyday speech, we not only listen to *what* people say but also to *how* they say it. The integration of both levels of communication is particularly relevant when they carry conflictive information, as in the case of sarcasm and irony. To understand sarcastic and ironic speech, we have to make a connection between the verbal meaning of an utterance and its prosody. The experiments presented in Chapter 5 investigated *when* during word processing prosody comes into play. Moreover, they determined whether the context established by the emotional prosody of a sentence affects word processing at a similar point in time as semantic context. The N400, which reflects the interaction between a word and preceding semantic context (Besson, Kutas, & Van Petten, 1992; Kutas & Hillyard, 1980; Van Petten & Kutas, 1987), was taken as a candidate for measuring the interaction between a word and preceding prosodic context. Furthermore, an N400 effect was predicted that resembles the N400 effect for semantic violations reported in the literature. More specifically, we expected incongruence between the emotional valence of a word and the emotion conveyed by prosody to enhance the N400 amplitude as compared to congruence. Such a result permits two conclusions. First, word processing is susceptible to emotional prosody around 400 ms following word onset. Second, emotional prosody and semantic context may have a similar effect on the processing of words.

A cross-modal priming paradigm was employed to compare prosodic with semantic context effects (Schirmer, Kotz, & Friederici, in press). An auditory (prosodic) prime preceded a visual target word. The switch from auditory to visual modality had the advantage that processing differences between congruous and incongruous target words were not affected by differences in the acoustic stimulus properties. Nevertheless, context effects were expected. As Holcomb and Anderson (1993) demonstrated by showing a reliable N400 effect for cross-modal priming, semantic relatedness carries over into a different modality.

In the present study, sentences with either happy or sad prosody served as auditory primes. All sentences contained an emotionally ambiguous word in the sentence final position, which could have a positive or a negative meaning depending on the prosodic context. The sentence context was neutral and non-predictive (e.g., 'Gestern hatte sie ihre *Abschlussprüfung*.' / 'Yesterday she had her *final exam*.'). Two-hundred milliseconds following sentence offset, a visual target appeared in the center of the computer screen in front of the subject. The target was either a German word or a pseudoword. Legal target words were semantically related to the sentence final word. To minimize prime repetitions, no semantically unrelated target words were presented. For half of the words, word valence and prime prosody matched (e.g., 'success' following a happy intonation) whereas for the remaining words, word valence and prime prosody did not match (e.g., 'failure' following a happy intonation). Participants indicated whether the target was a word or a pseudoword by pressing one of two buttons. Furthermore, subjects were told that the auditory primes were not relevant to the task and that they should just listen to them.

If listeners use emotional prosody to guide word processing in a similar way as they use semantic context, congruent prime-target pairs should elicit a smaller N400 amplitude as compared to incongruent pairs. However, semantic relatedness has been found to also affect the speed of lexical decisions (Neely, 1991). Therefore, emotionally congruous words were expected to elicit faster responses as compared to incongruous words. Furthermore, as women are reported to be more emotionally expressive than men (Manstead, 1992; Polce-Lynch et al., 1998), as well as better able to understand emotional expression from faces, gestures and voices (Hall, 1978), they might differ from men in their reliance on emotional-prosodic cues. To address this question, sex was included as a factor in the data analyses.

5.2 Experiment 1

5.2.1 Methods

Participants. Thirty-two volunteers (16 female) participated in Experiment 1. The female participants had a mean age of 23.81 (sd 3.01) and the males had a mean age of 24 (sd 2.03). All subjects were right-handed, native speakers of German, had normal or corrected to normal vision and no hearing impairment.

Materials. The stimulus material consisted of 99 sentences, of which 49 were experimentally relevant and 50 were fillers. A female native speaker of standard German produced all sentences with happy and sad intonation resulting in a total of 198 sentences. Sentences were taped with a DAT recorder and digitized at a 16-bit/44.1-kHz sampling rate. For all experimentally relevant sentences, two corresponding words were selected on the basis of a prior association study (see Appendix 1). One word had a positive meaning and the other word had a negative meaning. Both groups of target words did not differ in word frequency (Celex, 1995) or word length. In a prior study with a different group of subjects, target words were rated for emotional valence on a 5 point scale ranging from –2 for very negative to +2 for very positive. This rating was used to ensure that although positive (mean 0.61, sd 0.77) and negative (mean –0.59, sd 0.82) words differed significantly in valence their absolute valence strength was identical (i.e., positive words were rated as positive as negative words were rated negative). In addition to target words, pseudowords were presented. Pseudowords were invented for the lexical decision task only and were not of interest for further analysis. Every pseudoword was preceded by a filler sentence. As all filler and experimental sentences were presented twice (i.e., once with happy and once with sad prosody) to each subject, sentence repetition might have predicted the occurrence of pseudowords and words, respectively. To prevent an expectancy based task strategy, 20 out of 50 filler sentences were paired with a pseudoword and an affectively valenced real word. Ten of those filler sentences were followed by a pseudoword at first presentation and a real word at second presentation. For the remaining 10 filler sentences the order was reversed. Thus, sentence repetition was not an accurate predictor of the occurrence of words and pseudowords.

In sum, there were four experimental conditions (see Table 5.1): match and mismatch condition for positive target words as well as match and mismatch condition for negative target words. Happy and sad filler sentences were also presented twice followed by either a positive or a negative word or a pseudoword, respectively. To minimize repetition effects, the stimulus material was divided so that a given target was presented only once to each subject. Consequently, every subject saw 98 experimentally relevant target words and 100 fillers (20 words and 80 pseudowords). Trials were pseudo-randomized and distributed over 4 blocks.

Table 5.1. Stimulus Material Presented in an Experimental Session

49 Experimental Sentences				50 Filler Sentences					
Happy Prosody		Sad Prosody		Happy Prosody			Sad Prosody		
24 (25) Positive Words	25 (24) Negative words	24 (25) Positive Words	25 (24) Negative words	5 Positive Words	5 Negative words	40 Pseudo -words	5 Positive Words	5 Negative words	40 Pseudo -words

Procedure. Testing was carried out in a sound proof and electrically shielded chamber. Subjects were seated in a comfortable chair facing a computer monitor at a distance of 1.15 meters. Sentences were presented over speakers positioned to the left and right side of the monitor. Visual targets appeared 200 ms following sentence offset on the computer screen in front of the subject. Visual targets were presented for 300 ms. Participants were asked to decide as quickly and as accurately as possible whether the target was a word or a pseudoword. Responses were given by pressing one of two buttons on a response box. Half the subjects responded to words with their right hand and to pseudo-words with their left hand. For the remaining subjects the response pattern was reversed. In order to familiarize participants with the task, each experimental session started with a block of 8 practice trials.

Because there was a chance that men and women might differ in how they experience the emotional match and mismatch conditions, an expectancy judgement followed every experimental session. In the expectancy judgement, all experimental sentence-word pairs were presented a second time. Subjects were asked to judge on a 5-point scale how expected or unexpected the target word following a sentence was.

ERP Recording and Data Analysis. The EEG was recorded (250 Hz sampling rate) from 58 electrodes, which were placed on the head according to the modified expanded 10-20 system. The reference electrode was placed on the tip of the nose. In order to control for horizontal and vertical eye movements, a bipolar electrooculogram was recorded using four electrodes. Electrode resistance was kept below 5 kOhm. ERP averages were computed with a 150 ms prestimulus baseline and a 1000 ms ERP time window. Trials containing eye blinks or movement artifacts were omitted from the ERP analysis.

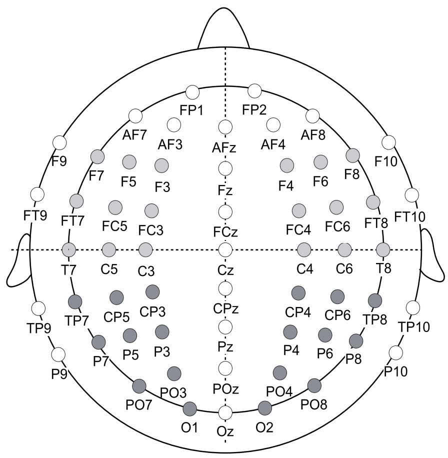

Figure 5.1. Open circles indicate electrodes that were recorded but did not enter statistical analysis. Circles filled with light grey indicate electrodes that entered right and left anterior regions of interest. Circles filled with dark grey indicate electrodes that entered right and left posterior regions of interest.

For statistical analysis, electrodes were grouped into 4 Regions Of Interest[2] (ROIs; Fig. 5.1): left anterior (F7, F5, F3, FT7, FC5, FC3, T7, C5, C3), right anterior (F8, F6, F4, FT8, FC6, FC4, T8, C6, C4), left posterior (TP7, CP5, CP3, P7, P5, P3, PO7, PO3, O1), and right posterior (TP8, CP6, CP4, P8, P6, P4, PO8, PO4, O2). ERPs measured at anterior and posterior ROIs established the factor AP in the statistical analysis and ERPs measured at right and left hemisphere ROIs established the factor HEMISPHERE. ERPs were quantified as mean amplitudes in three different time windows in each of the ROIs. Time windows were defined according to visual inspection and in close resemblance to a prior ERP study on cross modal priming (Holcomb & Anderson, 1993). Separate ANOVAs were conducted for the P200 (150-300 ms), the N400 (300-550 ms), and the P300 (550-700 ms) time windows. MATCH (match/mismatch), TARGET (positive/negative), AP (anterior/ posterior) and HEMISPHERE (left/right) were repeated measures factors and SEX was a between subjects factor. The null-hypothesis was rejected for p-values smaller than 0.05. If main effects or interactions required a higher number of post-hoc comparisons than the degrees of freedom would permit, respective p-values were corrected using a modified Bonferroni procedure (see Keppel, 1991). Significant interactions are reported only when post hoc comparisons revealed significant effects. For illustration only, grand averages were smoothed with an 8-Hz low pass filter.

5.2.2 Results

Behavioral Results. Reaction times and accuracy were entered into separate ANOVAs treating MATCH (match/mismatch) and TARGET (positive/negative) as repeated measures factors and SEX as a between subjects factor. Statistical analysis of the reaction times revealed a significant SEX*MATCH interaction ($F_{1,30} = 4.65$, $p < .05$). Post hoc comparisons indicated that women responded faster to target words preceded by emotionally congruent prosody as compared to incongruent prosody ($F_{1,15} = 6.45$, p

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[2] To keep the number of electrodes constant for each ROI, midline electrodes were excluded from this analysis. However, a seperate analysis of the midline electrodes revealed similar effects as reported for the other ROIs. To avoid redundancy, the result section does not include this seperate analysis.

< .05; Fig. 5.2). This effect was absent in men ($p > .1$). A significant SEX*TARGET interaction ($F_{1,30} = 10.37$, $p < .01$) indicated that the main effect of TARGET reached significance in men ($F_{1,15} = 25.27$, $p < .001$; Fig. 5.2), but not in women ($p > .1$). Male participants showed faster reaction times to positive as compared to negative target words independent of the prime's prosody.

As the lexical decisions were fairly easy, no differences were obtained for the accuracy data ($p > .1$). Participants performed well above 97% correct across conditions.

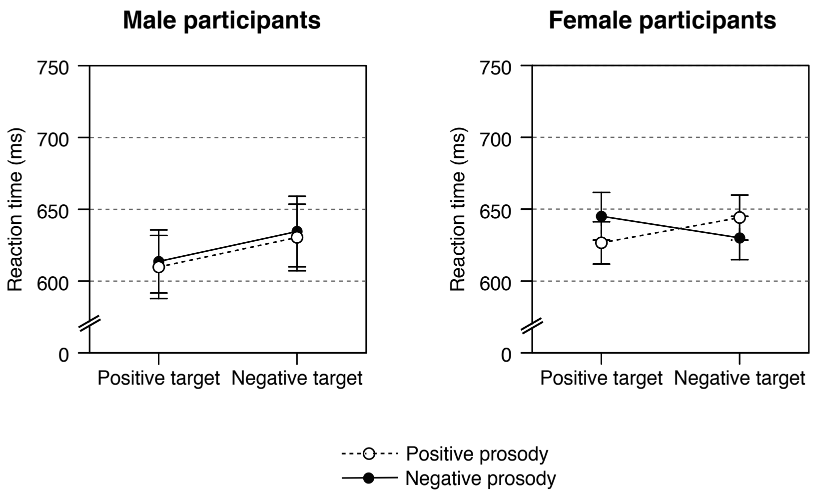

Figure 5.2. Mean reaction times (±1 s.e.) for lexical decisions in Experiment 1 plotted as a function of target valence.

Electrophysiological Results. As for the reaction times, there was a SEX*MATCH interaction in the ERPs. Moreover, the interaction was significant for the time window of the P200 ($F_{1,30} = 4.18$, $p < .05$), the N400 ($F_{1,30} = 4.27$, $p < .05$) and the P300 ($F_{1,30} = 8.0$, $p < .01$). Post hoc comparisons revealed a significant N400 effect in female participants ($F_{1,15} = 19.42$, $p < .001$; Fig. 5.3). Smaller N400 amplitudes were elicited for the match as compared to the mismatch condition. This emotional-prosodic priming effect already started to differentiate in a preceding ERP component, the P200 ($F_{1,15} = 7.25$, $p < .05$), and was still present in the later P300 ($F_{1,15} = 7.64$, $p < .05$).

Furthermore, this effect was broadly distributed over the scalp because the MATCH*SEX interaction was not modified by either HEMISPHERE or AP ($p > .1$). Male subjects failed to demonstrate electrophysiological indices of emotional-prosodic priming ($p > .1$).

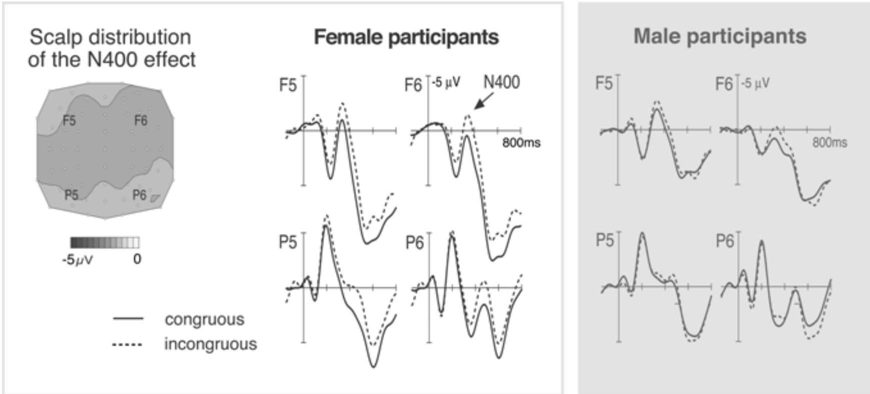

Figure 5.3. ERPs time locked to target onset for Experiment 1. A mismatch between prime and target (dotted line) elicited a larger N400 response as compared to a match (solid line) in female, but not in male participants. This priming effect started to differentiate in the P200 and was also present in the P300. A topographical map illustrates that the N400 effect in women had a broad distribution.

Expectancy judgment. The subjects' judgments entered an ANOVA with TARGET (positive/negative) and MATCH (match/mismatch) as repeated factors and SEX as between subjects factor. The analysis indicated no difference between male and female subjects ($p > .1$). However, there was a significant TARGET main effect indicating that target expectancy was higher for positive as compared to negative targets ($F_{1,30}$ = 48.25, $p < .0001$; Fig. 5.4). This valence effect is in accordance with earlier findings that showed that negative events are less expected and capture more attention (Bradley, Mogg, & Millar, 2000; Lang, Nelson, & Collins, 1990). Additionally, a significant main effect of MATCH indicated a match between target valence and prime prosody was experienced as more expected than a mismatch ($F_{1,30}$ = 68.55, $p < .0001$).

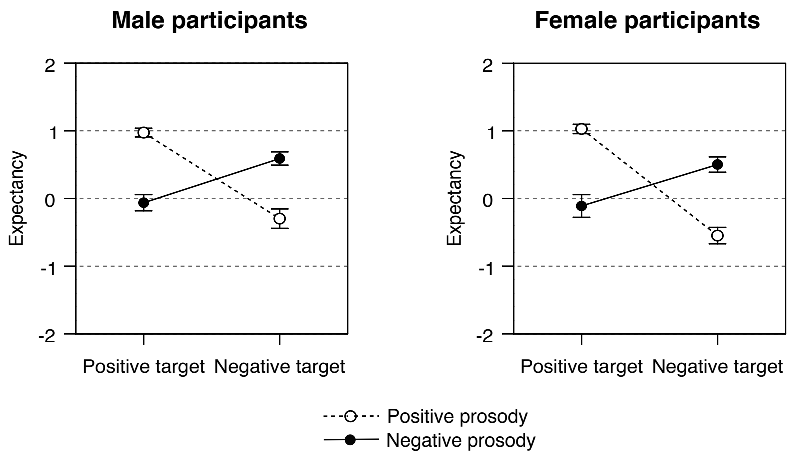

Figure 5.4. Mean congruence (±1 s.e.) for the congruence judgement in Experiment 1 plotted as a function of target valence.

5.2.3 Discussion

In sum, these results suggest that shortly after the prime, women and men process the target word in very different ways. While women clearly use the prosodic context during the processing of the target word, men process the target word with regard to word valence, but do not use prosodic information. One can conclude from these findings that emotional-prosodic context effects in women are comparable to the time course and functional significance of semantic context effects.

Similar to findings for semantic priming, women responded faster to emotionally congruent words as compared to emotionally incongruent words. Three mechanisms have been proposed to account for the variety of behavioral priming effects found in the literature (Chwilla, Brown, & Hagoort, 1995; Chwilla, Hagoort, & Brown, 1998; Neely, 1991): spreading activation, expectancy-induced priming, and semantic matching. The first mechanism, spreading activation, is based on the assumption that every entry in the mental lexicon is represented as a node that connects to words that are closely related in meaning. If one word becomes activated, activation automatically spreads to nearby connected nodes. Thus, processing of related target words in a priming experiment is facilitated because they had received some activation already.

As spreading activation is fast-acting, of short duration, and does not require attention or awareness (Posner & Snyder, 1975; Shiffrin & Schneider, 1977), it has been linked to lexical access (Brown & Hagoort, 1993; Chwilla, Brown, & Hagoort, 1995). In contrast, expectancy-induced priming results from controlled processes. The subject generates a set of words which are likely to occur in combination with the prime. Responses to target words are faster, if they are included in the subject's expectancy set (Keefe & Neely, 1990). Semantic matching is also a controlled process and has been linked to lexical integration. When participants encounter a word, they presumably check whether the word's meaning matches preceding semantic information. Detection of semantic congruity biases the subject to respond 'yes' in a lexical decision task, whereas unrelated words bias a 'no'-response. For the present results it is impossible to determine which mechanism caused the reported behavioral priming in women as all three could plausibly have contributed.

In addition to the reaction times, emotional-prosodic context modulated the N400 amplitude in female participants. Similar to auditory priming (Holcomb & Neville, 1990, 1991), the N400 effect started relatively early at around 150 ms following word onset. If the N400 reflects contextual integration, then an earlier onset of the N400 effect might suggest an earlier onset of integrative processes. Van Petten and colleagues (1999) reported findings from spoken word recognition that support such a hypothesis. They found that with sentence context, an N400 effect can be elicited before the acoustic input is sufficient for correct word identification. Therefore, the authors concluded that the integration process already operates with incomplete lexical information. However, one could argue that an earlier onset of the N400 effect results from an influence of context information on word processing stages that precede integration. With respect to the present findings, women might use emotional prosody before the integration of a word. However, as one can not distinguish whether the reaction times and ERP effects result from automatic and/or controlled processes, assumptions about the functional significance of emotional prosody during word processing in women remain speculative.

Further questions arise from the failure of men to show emotional-prosodic priming. Given that the male inferiority in emotional tasks is reported to be relatively small (Hall, 1978), one might expect the priming effect in men to be somewhat smaller or morphologically different from the priming effect in women. In any case, such an effect should exist. The failure to find priming in men is even more surprising, as they did not differ from women in the emotional congruity judgment. Both rated a mismatch between the emotional prosody of a sentence and the valence of the following target word as less expected than a match. Consequently, men must use the emotional prosody at some point during processing. To determine when, a second experiment with a longer interstimulus interval (ISI) was conducted.

5.3 Experiment 2

The idea to conduct a second experiment with a longer interval between prime and target was derived from a study by Swinney (1979). He presented sentences auditorily that contained an ambiguous prime word such as ‘ball’. The sentence context biased one meaning of the prime word (e.g., ‘As she was all dressed-up for the *ball*, the carriage was already waiting.’). Following the prime word a visual target appeared on a computer screen in front of the participant. The target was either a word or a pseudo-word. Target words were semantically related to the contextually biased meaning of the ambiguous prime word (e.g., dance), to the unbiased meaning (e.g., game), or they were unrelated. Participants were asked to decide whether the target was a word or a pseudo-word. Swinney found that when the target followed the prime word immediately, both kinds of related targets (i.e., ‘dance’ and ‘game’ in the given example) were responded to faster than unrelated targets. However, with an interval of approximately 750 ms between prime and target word, only responses to contextually biased target words (i.e., ‘dance’ in the given example) were facilitated. Given these findings, Swinney argued that, regardless of contextual information, the presentation of ambiguous words leads to the activation of both meanings. Context does not exert its influence until lexical access has been completed.

In men, prosody might have a similar effect on the processing of emotionally ambiguous words. Following a happily spoken word like ‘exam’ they might activate both positive and negative words related to the event. Consequently, the target words ‘success’ and ‘failure’ may be processed with similar effort. However, with a longer delay between prime and target, men might interpret the meaning of ‘exam’ with respect to the happy sentence prosody and semantically related words with negative valence might lose in activation as they are emotionally unrelated. Then the target word ‘failure’ might require a higher processing effort than the target word ‘success’. To test this possibility, the ISI used in Experiment 2 was 750 ms.

5.3.1 Methods

Stimulus material, ERP recording, data analysis, and procedure were comparable to Experiment 1, with the exception that the interval between prime and target was now 750 ms.

Participants. Sixteen males and 16 females that did not participate in Experiment 1 were recruited for Experiment 2. Female participants had a mean age of 21.87 (sd 1.92) and male participants had a mean age of 23.37 (sd 3.03). All subjects were right-handed, native speakers of German, had normal or corrected to normal vision and no hearing impairment.

5.3.2 Results

Behavioral Results. With the longer ISI the MATCH*SEX interaction was non-significant ($F_{1,30} = 2.59$, $p = 0.117$) and the MATCH main effect showed only as a tendency ($F_{1,30} = 3.29$, $p = .079$). However, there was a significant SEX*TARGET interaction ($F_{1,30} = 6.81$, $p < .05$). Post hoc comparisons revealed a significant TARGET main effect in female ($F_{1,15} = 16.84$, $p < .001$) but not in male participants ($p > .1$). Women’s behavioral response to positive targets was faster as compared to negative targets independent of the prime's prosody (Fig. 5.5). Again, no differences were obtained for accuracy ($p > .1$).

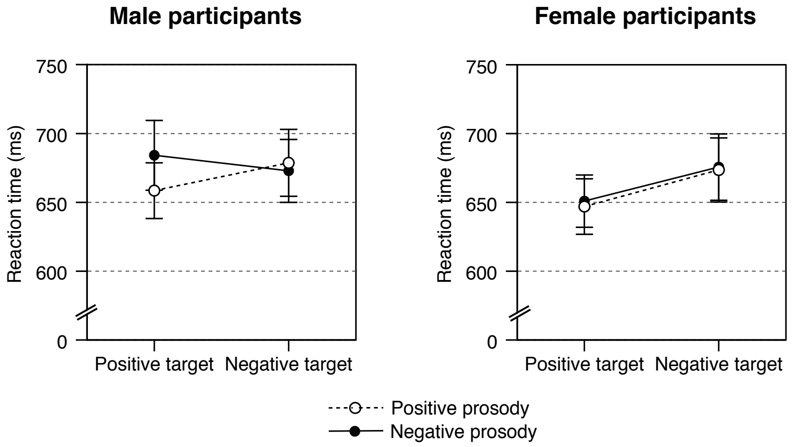

Figure 5.5. Mean reaction times (±1 s.e.) for lexical decisions in Experiment 2 plotted as a function of target valence.

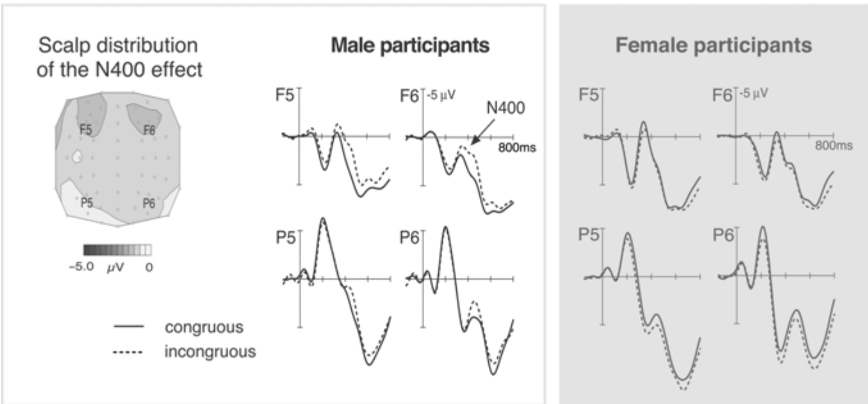

Figure 5.6. ERPs time locked to target onset for Experiment 2. A mismatch between prime and target (dotted line) elicited a larger N400 response as compared to a match (solid line) in male, but not in female participants. A topographical map suggests that the N400 effect in men was stronger at frontal electrodes. However, the SEX by MATCH by AP interaction did not reach significance.

Electrophysiological Results. In contrast to the behavioral data, ERPs revealed a significant SEX*MATCH interaction in the N400 time window ($F_{1,30} = 7.87$, $p < .01$). Post hoc comparisons indicated that women failed to show emotional-prosodic priming ($p > .1$), whereas men did show significant emotional-prosodic priming. Emotional congruence between prime and target elicited a smaller N400 as compared to incongruence ($F_{1,15}$ = 6.07, p < .05; Fig. 5.6). In contrast to the priming effect reported for women in the previous experiment, the priming effect in men was restricted to the N400 time range between 300 and 550 ms following word onset. No effects were obtained for the P200 or the P300 time ranges. The lack of an interaction with the factors AP and HEMISPHERE (p > .1) indicated that the N400 effect was broadly distributed over the scalp.

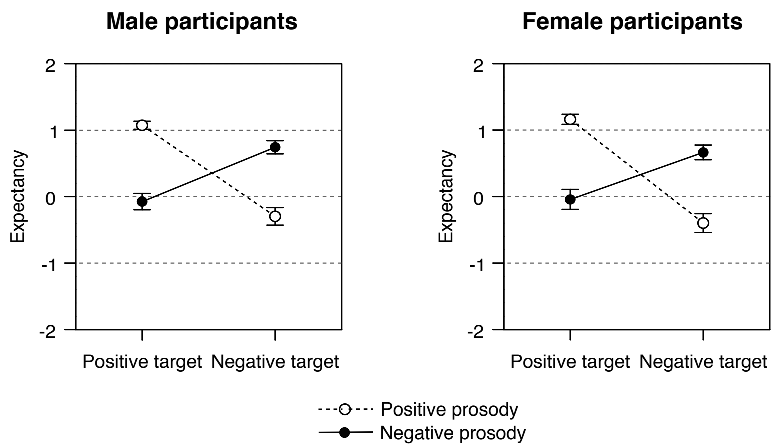

Figure 5.7. Mean congruence (±1 s.e.) for the congruence judgement in Experiment 2 plotted as a function of target valence.

Expectancy Judgment. Again, there was a significant TARGET main effect indicating that target expectancy was higher for positive as compared to negative targets ($F_{1,30}$ = 81.76, p < .0001; Fig. 5.7). There is a suggestion that this TARGET effect was slightly larger in women than in men because the TARGET*SEX interaction approached significance ($F_{1,30}$ = 3.79, p = .061). However, men and women did not differ in the MATCH effect (p > .1). Both rated a match between target valence and prime prosody as more expected than a mismatch ($F_{1,30}$ = 79.01, p < .0001).

5.3.3 Discussion

Taken together, the results of Experiment 2 support the notion of processing differences between men and women. With the longer ISI, word processing in male subjects profits to some extent from the given emotional-prosodic context. However, there was no reliable behavioral priming and the priming effect in the ERP was restricted to the N400 time range.

That effects of emotional prosody on word processing in men occur later than in women may suggest sex differences in the functional significance of emotional prosody. As the present two experiments closely resemble the cross-modal priming study conducted by Swinney (1979), one might want to draw parallels with respect to the interpretation of the reported findings. In women, emotional prosody might activate words that are congruent in valence. Thereby, emotional prosody would affect processes related to lexical access. For example, the word 'exam' embedded in a happily spoken sentence might lead to positive associations, such as 'success'. As a consequence, positive words following 'exam' show facilitated processing in comparison to negative words. Men, on the other hand, might activate positive as well as negative words regardless of the emotional-prosodic context. Therefore, the processing of positive and negative words following shortly after 'exam' does not differ. Later, however, men might use the sentence prosody to interpret the emotional meaning of 'exam' in the given context. Therefore, with a longer delay, the processing of negative words following 'exam' runs less smoothly as compared to positive words.
Studies that revealed sex differences in the lateralization of language processing might encourage this interpretation. There is evidence that women, in contrast to men, process language more bilaterally (Jaeger et al., 1998; Kansaku et al., 2000; Phillips et al., 2001; Shaywitz et al., 1995). If true then this would bring language closer to emotional prosody, which is thought be lateralized to the right hemisphere (Pell & Baum, 1997). Although speculative, this might be correlated with a faster use of emotional prosody during language processing. To test this possibility, the participants from Experiments 1 and 2 were re-invited to the lab and examined for language lateralization using a dichotic listening procedure[3]. This, however, failed to reveal sex

[3] Fifty-five of the 64 ERP participants returned for the dichotic listening study. One woman and 3 men were missing from Experiment 1; 2 women and 3 men were missing from Experiment 2. The subjects listened over headphones, first monaurally and then binaurally, to a series of rhyme words (e.g., bank and tank). Their task was to chose from a set of 4 words presented on

differences. Although somewhat disappointing, the finding was not completely unexpected. As discussed in Chapter 2, the literature on language lateralization is equivocal. Beside studies that find sex differences, there are several investigations that report negative findings. Although similar language lateralization in men and women does not rule out sex differences in the function of emotional prosody during word processing, methodological considerations concerning both experiments further restrict such an interpretation.

The ISI in Experiment 1 may not have been short enough to reflect early word activation. Moreover, it might be the case that both ISIs tap the same processing stage, for example, contextual integration. Women might simply enter this processing stage earlier than men. A further point that raises some doubt is that women failed to show emotional-prosodic priming in Experiment 2. If the longer interval really taps lexical integration, it seems a bit odd that women should be insensitive to prosodic information during that stage. However, this is what Experiment 2 may suggest. Alternatively, the absence of a priming effect in females may be due to behavioral strategies used in completing the task. Women may still have access to emotional prosody with a longer delay, but they may simply chose to ignore it. The question whether the short ISI taps automatic processing and the question whether the long ISI prevents women from a prosody-word interaction were addressed in Experiments 3 and 4, respectively.

5.4 Experiment 3

Together, Experiments 1 and 2 suggest sex differences in the role of emotional prosody during word processing. It has been argued that in women emotional prosody might influence the activation of lexical candidates, whereas in men prosody might

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the computer screen the one they thought they had just heard. In the case of binaural presentation, they had to report the more dominant word. For each subject a Lambda coefficient was computed, which entered an ANOVA with SEX and EXPERIMENT (ISI 200/ISI 750) as between subject factors. The results indicate that male and female subjects did not differ in language lateralization ($p = .93$).

affect the integration of a word in the preceding context. This interpretation is based on the assumption that the short ISI in Experiment 1 was sensitive to lexical access and the long ISI in Experiment 2 reflected integration. However, it is possible that both experiments tapped the same process, for instance, post-lexical integration. Moreover, the time course of integration may depend on the significance or priority that a certain kind of context has. Women might regard emotional prosody as more significant than men and, therefore, rank emotional prosody just as high or perhaps higher than semantics in contextual priority. Sex differences in Experiments 1 and 2 may simply reflect differences in contextual priority rather than in the function prosody has during word processing. Findings of higher emotional contagion (Doherty et al., 1995) and better recognition of emotional cues (Rotter & Rotter, 1988) in women provide tentative support for this assumption. Alternatively, sex differences might be due to men and women approaching the lexical task differently. Sex differences in task strategies have already been reported for a variety of tasks, such as dichotic listening (Welsh & Elliott, 2001), reaction time tests, visuospatial tasks (Adam, Paas, Buekers, Wuyts, Spijkers, & Wallmeyer, 1999; Klinteberg, Levander, & Schalling, 1987), and memory tasks (Turner, 1993; Waters & Schreiber, 1991). Frequently, they have been attributed to a more reflective and accuracy oriented performance in females (Klinteberg et al., 1987; Welsh & Elliott, 2001). As the task in the present study was fairly easy, women might have allocated some attention to the prime as they might have questioned its being of no significance for the experiment. Both alternative explanations would result in a different level of prime processing for men and women.

That the level of processing modulates priming has already been reported (for a review see Maxfield, 1997). While behavioral priming studies find reliable priming effects when participants read a prime word silently, a more shallow processing of the prime can reduce or prevent such effects. The letter search task, for example, requires the detection of a particular letter in the prime word. If the subject is engaged in this task prior to the lexical decision for a target, priming between semantically related prime-target pairs is eliminated (Smith, Theodor, & Franklin, 1983; Stolz & Besner, 1998). Furthermore, Smith, Bentin, and Spalek (2001) found that the processing level affected the temporal structure of priming. With a task (i.e., vowel-consonant discrimination for the first letter of the prime) that differed less in prime processing depth from reading than the letter search task, they found priming for a short but not for a longer stimulus onset asynchrony (SOA). They concluded that automatic spreading activation might be preserved if a certain depth of prime processing is ensured, whereas strategic priming responsible for priming at longer SOAs can be prevented.

The careful reader might notice that the conclusion from Smith and colleagues (2001) seems to be in contrast with the present finding of prosodic priming in men with a long but not with a short prime-target interval. However, the exact nature of prime-target processing, the ISI, and the type of context might modify the observed priming mechanisms. Moreover, the present study may not have been sensitive to a fast, automatic form of priming. Therefore, early processes may well be preserved within the current paradigm and only later priming mechanisms, such as expectancy based priming and semantic matching, might have been affected by the level of prime processing. Moreover, these slower forms of priming might have been accelerated or slowed down depending on the level of prime processing. Although no direct comparison between the reported experiments and the present study can be drawn, they support the idea that occurrence and temporal structure of prosodic priming can be influenced by how deeply participants process the prime's prosody. As strategies that affect prime processing should play a role only during integration but not during lexical access (Brown & Hagoort, 1993; Chwilla et al., 1995), putting the prime's prosody into the focus of the task should affect the former but not the later. Therefore, if the 200 ms ISI taps integration rather than lexical access, the induction of a prosodic matching strategy should affect target processing. Moreover, forcing men to give prosody a high contextual priority should elicit emotional-prosodic priming. If, however, a prosodic matching strategy does not elicit priming in men, then women use emotional prosody earlier than men. Furthermore, this would strengthen the interpretation that lexical access is susceptible to emotional prosody in women, but not in men.

5.4.1 Methods

Stimulus material, ERP recording, and data analysis were comparable to Experiment 1 and 2.

Participants. Twenty subjects were invited to participate in the experiment. Half of them were female and had a mean age of 23.3 (sd 1.8). Male participants had a mean age of 24.7 (sd 2.4). All subjects were right-handed, native speakers of German, had normal or corrected to normal vision and no hearing impairment.

Procedure. As in the first experiment, participants listened to sentences with happy and sad prosody that were followed by a visual target. The interval between sentence offset and target onset was 200 ms. Participants were asked to decide as quickly and as accurately as possible if the target was a word or a pseudoword. Pseudoword responses were given by pressing the middle button of the response box. If the emotional valence of a word was congruent with the emotional prosody of the preceding sentence, a left button press was appropriate and if incongruent a right button press was appropriate. For half the participants the assignment of congruency judgment to response button was reversed. As task difficulty was higher than in the first experiment, accuracy was expected to drop. The concern that an insufficient number of trials would remain for the ERP analysis actuated the decision to present the complete set of stimuli to each subject. As a consequence, each subject saw each target twice: once preceded by a happily spoken sentence and once preceded by a sadly spoken sentence. The remaining experimental parameters were the same as in Experiment 1.

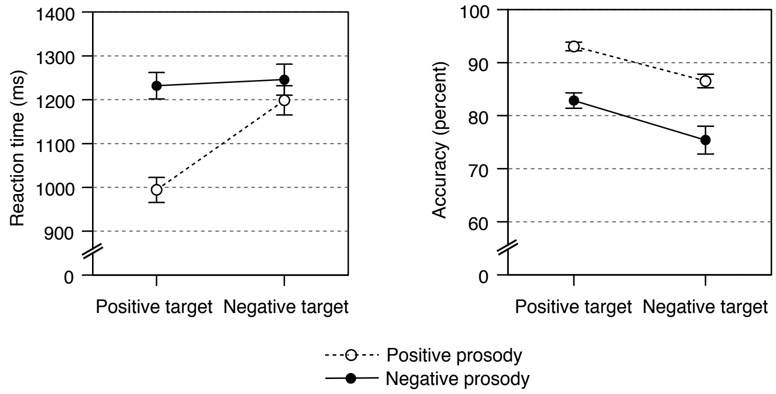

Figure 5.8. Mean reaction times and accuracy (±1 s.e.) for congruency judgement in Experiment 3 plotted as a function of target valence.

5.4.2 Results

Behavioral Results. Repeated measures ANOVAs were conducted for reaction times and accuracy separately with MATCH (match/mismatch) and TARGET (positive/negative) as repeated measures factors and SEX as a between subjects factor. In the reaction time data, there was a significant MATCH*TARGET interaction ($F_{1,18}$ = 79.23, p < .0001). Post hoc comparisons revealed a significant MATCH effect for the positive target ($F_{1,18}$ = 155.36, p < .0001). Positive target words were responded to faster when preceded by a prime with happy prosody as compared to a prime with sad prosody. The prime prosody had no significant effect on the negative target ($F_{1,18}$ = 3.31, p = .085; Fig. 5.8). Additionally, there was a MATCH*TARGET interaction ($F_{1,18}$ = 27.77, p < .0001) in the accuracy data. Post hoc comparisons revealed a significant MATCH effect for both the positive ($F_{1,18}$ = 44.09, p < .0001) and the negative target ($F_{1,18}$ = 18.48, p < .0001). However, the MATCH effect for the negative target was reversed in that participants responded more accurately when the preceding prime had a happy as compared to a sad prosody. In other words, both negative and positive targets elicited higher accuracy scores when the preceding sentence had a happy prosody as compared to a sad prosody (Fig. 5.8). There was no significant effect involving the factor SEX.

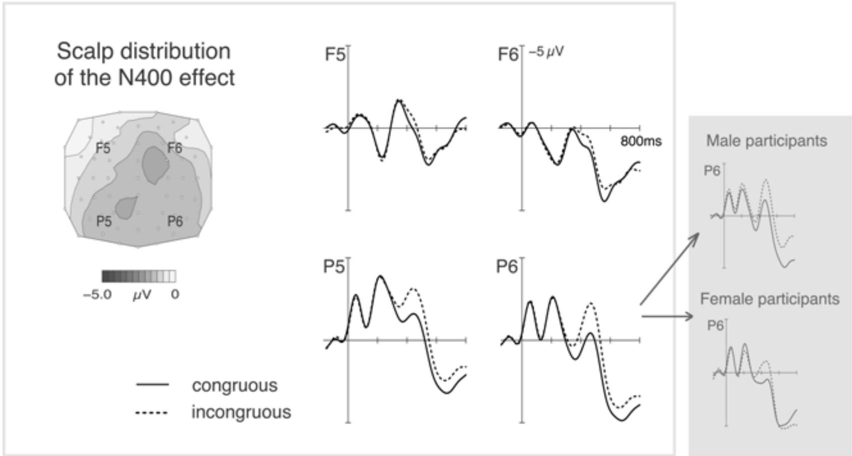

Figure 5.9. ERPs time locked to target onset for Experiment 3. A mismatch between prime and target (dotted line) elicited a larger N400 response as compared to a match (solid line) in both men and women. A topographical map illustrates that the N400 effect was strongest at right and posterior electrodes.

Electrophysiological Results. Statistical analysis for the N400 time window revealed a main effect for MATCH ($F_{1,18}$ = 9.49, p < .01) and a MATCH*HEMISPHERE*AP interaction ($F_{1,18}$ = 11.94, p < .01). At anterior electrodes, there was a significant interaction involving MATCH and HEMISPHERE ($F_{1,18}$ = 5.04, p < .05). Although the MATCH effect was significant for both hemispheres (left, $F_{1,18}$ = 4.43, p < .05; right, $F_{1,18}$ = 14.03, p < .01) it was more pronounced at right-anterior regions (Fig. 5.9). At posterior regions, the MATCH*HEMISPHERE interaction did not reach significance (p > .1). Rather, there was a main effect of MATCH ($F_{1,18}$ = 7.65, p < .05) indicating that it was evenly distributed across hemispheres. Furthermore, the N400 was sensitive to target valence as there was a main effect of TARGET ($F_{1,18}$ = 11.60, p < .01). Positive words elicited a larger N400 than negative words. The MATCH and the TARGET effect occurred independently and were not affected by SEX.

However, this was no longer true for the time window of the P300. A MATCH*TARGET interaction ($F_{1,18}$ = 8.52, p < .01; Fig. 5.10) indicated that prime-target congruence influenced the P300 amplitude only for positive ($F_{1,18}$ = 11.60, p < .01), but not for negative target words (p > .1). The P300 for positive words was larger when the preceding prime had a happy as compared to a sad prosody. Furthermore, a MATCH*SEX interaction ($F_{1,18}$ = 5.87, p < .05) revealed that men ($F_{1,9}$ = 8.61, p < .05), but not women (p > .1), showed a main effect of MATCH. In men, congruence between prime prosody and target valence elicited a larger positivity than incongruence.

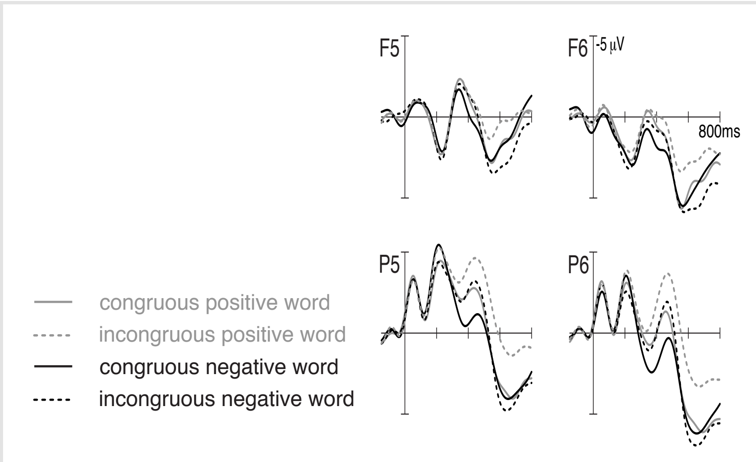

Figure 5.10. ERPs time locked to target onset for Experiment 3. Positive target words (grey lines) elicited a larger N400 as compared to negative target words (black lines). In the time window of the P300 the target effect was modified by the prime's prosody.

5.4.3 Discussion

In contrast to the lexical decision task, the congruency judgment revealed only little evidence for processing differences between men and women. Moreover, the N400 priming effect in the ERP was comparable between sexes. Both men and women showed a smaller N400 to words that matched the emotional valence of the preceding prime's prosody as compared words that did not match. Consequently, the sex differences reported for the lexical decision task may not result from differences in early stages of word processing, but rather from different levels of prime processing. If the instruction puts emotional prosody into focus, men use this information in a similar way to women. However, with a 200 ms ISI, women use emotional prosody regardless of instruction.

Although there was an N400 priming effect, it differed in some respects from the N400 effect reported for Experiment 1 in female participants. First of all, there were differences in scalp distribution. While in Experiment 1 the N400 effect was evenly distributed across hemispheres, the N400 effect in Experiment 3 was somewhat stronger over right hemisphere regions. Second, the ERP difference between match and mismatch conditions had a different temporal structure. While the N400 effect in Experiment 1 started at about 150 ms following word onset and was still present in the P300, the N400 effect in Experiment 3 was temporally more restricted. It started approximately 300 ms following word onset and ended after 500 ms in women. In men, the effect extended into the P300. Finally, Experiment 3 failed to elicit clear behavioral priming effects. The effects of the emotional valence of the prime seem to have overwritten any effects of prime-target congruence. Positive and negative words were responded to more slowly and less accurately when the preceding sentence was spoken with a sad as compared to a happy voice. Furthermore, accuracy was lower and response latencies were higher than for Experiment 1. Taken together, these differences suggest that a different kind of processing was involved in the two tasks. Perhaps, the priming effect for women in Experiment 1 reflects a default mechanism that makes emotional information from prosody and word meaning accessible to the word processor. In contrast, Experiment 3 required a higher level of cognitive control as participants had to consciously retrieve the emotional valence of prosody and word meaning and check it for congruence. Although the N400 priming effect in the ERP for Experiments 1 and 3 may in each case arise from the detection of an emotional mismatch, the detection processes themselves may differ. Whatever the reason for the reported task differences, they restrict the conclusions that can be drawn from a comparison between both experiments.

That men show an N400 effect for the congruence judgment does not mean that they use emotional prosody in the same way as women do. Men and women fail to differ in emotional-prosodic context effects when both are forced to pay close attention to emotional prosody. However, there may still be processing differences if there is no need to consciously retrieve the emotional-prosodic information.

Furthermore, the results from Experiment 3 indicate that with a 200 ms interval between prime and target, target processing can be facilitated in both men and women if it is congruent with the emotional prosody of the prime. However, this does not allow the conclusion that men and women use prosodic information at the same time during word processing. Perhaps with a smaller or with no delay between prime and target, women would still show emotional-prosodic priming, whereas men, even if they are told to take prosody into account, would not.

In sum, Experiment 3 demonstrated that the cross-modal priming task with a 200 ms interval between prime and target was sensitive to a slow strategic priming mechanism that is thought to underlie contextual integration: semantic – or in this case – prosodic matching. Consequently, the findings from Experiment 1 are unlikely to reflect fast-acting automatic processes.

5.5 Experiment 4

The purpose of Experiment 4 derives from the results of Experiments 1 and 2. Surprisingly, emotional prosody influenced word processing in women with a 200 ms interval between prime and target but not with a longer interval of 750 ms. This is in contrast to semantic priming, which has been reported for ISIs that exceed even a second (Deacon, Uhm, Ritter, Hewitt, & Dynowska, 1999). Moreover, long intervals profit from two controlled priming mechanisms: expectancy based priming and semantic matching (Neely, 1991). Therefore, the question arises whether prosodic context is no longer accessible to word processing in women so that both priming mechanisms do not apply. Alternatively, women may choose to ignore prosodic information when given more time. As Experiments 1 and 3 demonstrated, women accomplish the integration of the sentence final word in the prosodic context within 200 ms following word offset. Given more time, they may prepare for the lexical task, which does not profit from sentence prosody. In contrast, ignoring emotional prosody would render both positive and negative words as expected and potentially facilitate lexical decisions. This assumption is not necessarily in contrast to the idea that women processed the emotional prosody of the prime at a higher processing level than men in Experiment 1 and 2. Women could have tried both: attend to the prosodic prime and perform the lexical task efficiently. The longer interval in Experiment 2 might have permitted women to complete prime processing before the target appeared.

The question whether priming at a longer ISI could be induced via a prosodic matching strategy was tested by repeating Experiment 2 with a change in instructions. In addition to a lexical decision, participants performed a congruity judgment. If prosodic information is not accessible to word processing in women when there is a longer delay between prime and target, then this should still be true if they are asked to attend to the prime's prosody and compare its emotional valence with the target valence. However, if a change in instructions elicits emotional-prosodic priming, then the absence of a female priming effect in Experiment 2 might have had strategic reasons.

5.5.1 Methods

Stimulus material, ERP recording, data analysis, and procedure were comparable to Experiment 3, with the exception that the stimulus interval between prime and target was now 750 ms.

Participants. Twenty subjects were invited to participate in the experiment. Half of them were female and had a mean age of 24.2 (sd 3.2). Male participants had a mean age of 23.7 (sd 3.4). All subjects were right-handed, native speakers of German, had normal or corrected to normal vision and no hearing impairment.

5.5.2 Results

Behavioral Results. Statistical analysis of the reaction times revealed a significant MATCH*TARGET interaction ($F_{1,18}$ = 83.36, p < .0001; Fig. 5.11). While the MATCH effect for the positive target reached significance ($F_{1,18}$ = 139.56, p < .0001), it was non-significant for the negative target (p > .1). There was also a MATCH*TARGET interaction in the accuracy data ($F_{1,18}$ = 95.1, p < .0001; Fig. 5.11). Post hoc comparisons revealed a significant MATCH effect for the positive ($F_{1,18}$ = 33.47, p < .0001) and the negative target ($F_{1,18}$ = 6.9, p < .05). However, the effects were reversed. While positive words were responded to more accurately when preceded by a congruent (i.e., happily spoken) prime, negative words elicited higher accuracy scores when preceded by an incongruent (i.e., happily spoken) prime.

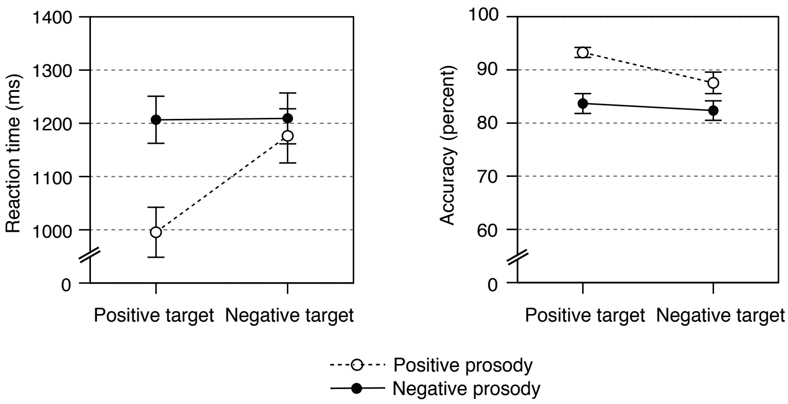

Figure 5.11. Mean reaction time and accuracy (±1 s.e.) for the congruence judgement in Experiment 4 plotted as a function of target valence.

Electrophysiological Results. As in the behavioral data, there was also a MATCH*TARGET interaction in the ERPs (Fig. 5.12). This interaction reached significance for the time window of the P200 ($F_{1,18}$ = 6.73, p < .05) and the P300 ($F_{1,18}$ = 5.29, p < .05). Positive words elicited a larger P200 when the preceding sentence was spoken with happy prosody as compared to sad prosody ($F_{1,18}$ = 10.66, p < .01). There was no difference in the P200 amplitude between the match and the mismatch condition for the negative target (p > .1). The MATCH*TARGET interaction for the P300 was modified by the factor AP ($F_{1,18}$ = 6.40, p < .05) as it was significant at posterior ($F_{1,18}$ = 6.42, p < .05), but not at anterior electrodes ($F_{1,18}$ = 3.37, p = .083).

Again, post hoc comparisons for the MATCH*TARGET interaction at posterior electrodes revealed a significant MATCH effect only for the positive ($F_{1,18} = 14.21$, $p < .01$), but not for the negative target (p > .1). Positive words elicited a larger P300 when the prime's prosody was happy as compared to sad.

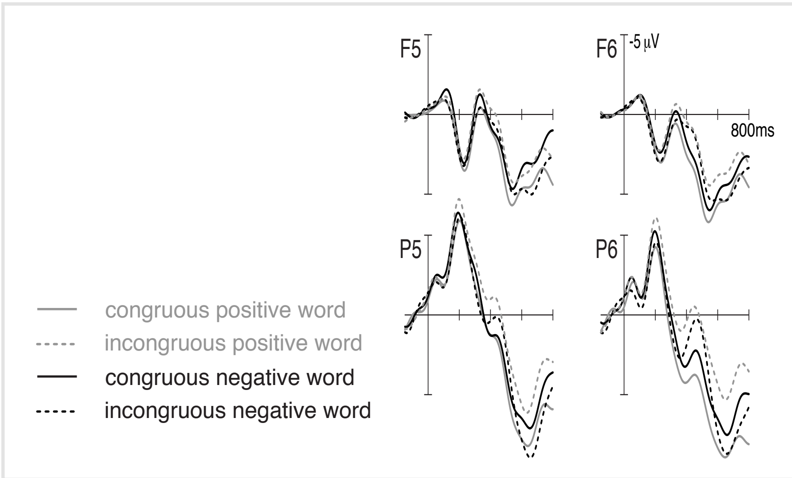

Figure 5.12. ERPs time locked to target onset for Experiment 4. Positive target words (grey lines) elicited a larger P200 and a larger P300 when the preceding prime was congruous (solid line) as compared to incongruous (dotted line). There was no such effect for negative target words (black lines). Regardless of valence, congruous words elicited a smaller N400 than incongruous words.

Statistical analysis of the N400 time window revealed a significant MATCH*HEMISPHERE interaction ($F_{1,18} = 6.49$, $p < .05$; Fig. 5.13). Post hoc comparisons indicated that the MATCH effect reached significance for both the right ($F_{1,18} = 18.43$, $p < .001$) and the left hemisphere ($F_{1,18} = 6.71$, $p < .05$). However, as illustrated in Figure 5.13, the effect was somewhat stronger at right hemisphere electrodes. Targets that matched the preceding prime in emotional valence elicited smaller N400 amplitudes than targets that did not match. Furthermore, N400 amplitudes in men were larger than in women ($F_{1,18} = 6.86$, $p < .05$).

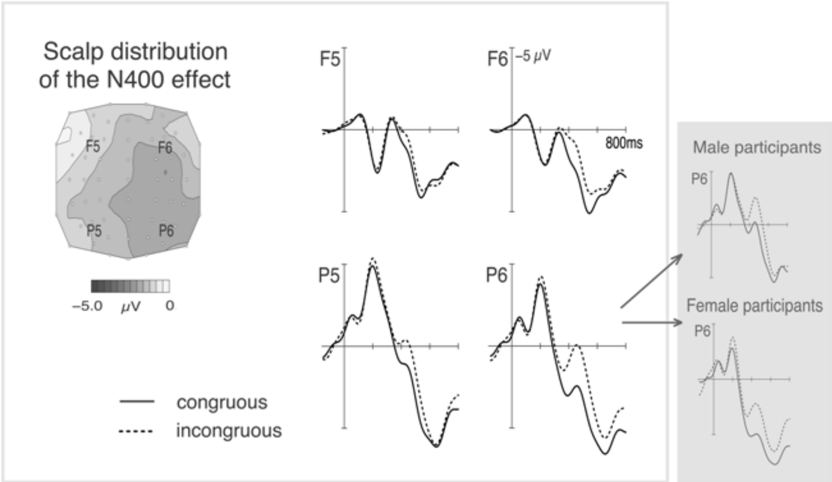

Figure 5.13. ERPs time locked to target onset for Experiment 4. A mismatch between prime and target (dotted line) elicited a larger N400 as compared to a match (solid line) in both men and women. A topographical map illustrates that the N400 effect was strongest at right-posterior electrodes.

5.5.3 Discussion

As in Experiment 3, the congruence judgment eliminated sex differences in emotional-prosodic priming. Both men and women showed a smaller N400 to words that matched the prosodic prime in emotional valence as compared to words that did not match. Consequently, emotional-prosodic information is still accessible to word processing in women with a delay of 750 ms between prime prosody offset and target word onset. The absence of a difference between prosodically related and unrelated targets in Experiment 2 might be explained by expectancy based priming (Neely, 1991). Female participants may have realized that emotional prosody was not predicting the occurrence of words and pseudowords and that all words were semantically related to the sentence final word. As a consequence, women may have tried to recover emotional associations that were not biased by the prime prosody. This slow strategic priming as described by Neely (1991) would have increased the expectancy set. Consequently, positive and negative words would be expected and therefore facilitated in response independently of emotional prosody.

However, this interpretation does not account for the women's priming effect in Experiment 1 and the men's priming effect in Experiment 2. Why would they process the emotional prosody if it were of no use? If true and women perform experimental tasks in a more reflective and accuracy oriented fashion than men (Klinteberg et al., 1987; Welsh & Elliott, 2000), they might be motivated to do both – process the prime and perform the target task efficiently. In contrast, men might put the lexical task more in focus than women. Nevertheless, they process the prime to some extent (as they can not shut their ears) so that it carries over to the target. The relatively low level of prime processing elicits later prosodic effects in men than in women. As the lexical decision for the target is fairly easy, men might not entertain a particular motivation to prevent the carry over. As this is only a post-hoc interpretation, it requires confirmation in further research.

The behavioral and electrophysiological results from Experiment 4 were very similar to the results from Experiment 3. Again, there was a strong influence of the emotional prosody on the behavioral response. Words that followed a sentence with sad prosody were responded to more slowly and less accurately than words that followed a sentence with happy prosody. Similar findings have been reported by Hartikainen and colleagues (2000). In their study, participants responded slower to visual targets that were preceded by an emotional as compared to a neutral picture. Moreover, reaction times were even slower if the preceding picture had a negative valence. Together, these results suggest that emotional, and especially negative, stimuli can interfere with the processing of subsequent stimuli. Inducing a strategy that made it necessary to consciously retrieve the emotional information of the prime may have triggered such interference in the present study. That emotional prosody interfered with the expected priming effect, was also clearly visible in the ERPs. Only positive words showed a significant difference between congruent and incongruent trials for the P200 and the P300. There was no such effect for negative words. This pattern as well as the reaction time priming effect that was found for positive but not for negative targets may result from the co-occurrence of a priming effect and the interference effect of sad prosody. Both may summate in the ERPs as well as in the behavioral data. Interestingly, sad prosody interference did not affect the N400 priming effect.

Again, differences in the scalp distribution of the N400 effect elicited for the congruence judgment as compared to the lexical decision task suggest that different processing was involved in the two tasks. As illustrated in Figure 5.13, the congruence judgment elicited an N400 effect that was more pronounced over right hemisphere than over left hemisphere regions. In contrast, the N400 effect found for the lexical decision task was evenly distributed across the scalp. One should note that the topographical distribution found in the congruence judgment more closely resembles the N400 effect reported for visual language processing (Kutas & Van Petten, 1994).

5.6 Conclusions Derived from Experiments 1 to 4

To answer the question whether effects of prosodic and semantic context on word processing are comparable in time course as well as morphology, a series of cross-modal priming experiments was conducted. In resemblance to semantic priming studies (Onifer & Swinney, 1981; Swinney, 1979; Van Petten & Kutas, 1987), positive and negative words followed a prime of either the same or a different emotional valence. However, crucial contextual information was carried by the emotional prosody of the prime and not by its semantic meaning. As reported for semantic context effects, target words that were congruous in emotional valence to the preceding prime elicited smaller N400 amplitudes and shorter reaction times than incongruous words (Kutas & Hillyard, 1980; Van Petten & Kutas, 1987). The fact that target words were always semantically related to the prime and that only prosody determined whether target words were congruous or incongruous can be taken as evidence that prosody and not semantics determined the reported priming effects. Consequently, word processing can be facilitated not only by congruous semantic information, but also by congruous emotional-prosodic information. Moreover, the influence of emotional prosody on word processing occurs in a time window known for semantic context effects, namely around 400 ms following word onset.

However, the present findings also suggest differences between semantic and emotional-prosodic priming. For example, there seems to be a sex difference in the time course of emotional-prosodic context effects. If not specifically instructed to take prosody into account, women show emotional-prosodic priming with a shorter interval between prime and target than men. This sex difference is no longer present when participants are asked to judge the congruence between prime prosody and target valence. Then, both men and women show an N400 priming effect with a short and a long interval between prime and target. That the congruence judgment could elicit prosodic priming in both sexes regardless of the inter-stimulus interval suggests that the behavioral as well as the ERP priming effect reflect processes that are susceptible to cognitive control. Moreover, they reflect the integration of a word in its emotional-prosodic context rather than the automatic access of a word in the mental lexicon. However, there may be qualitative differences between the integration process elicited by the lexical decision task and the integration process elicited by the congruence judgment. For the congruence judgment, behavioral as well as ERP responses were strongly affected by the emotional valence of the prime. Negative prime prosody influenced the P200 and the P300 amplitudes and led to an increase in reaction times as well as error rates. No such effect occurred for the lexical decision task. Furthermore, the temporal and topographical distribution of the N400 effect differed between tasks. While the lexical decision task elicited a very early onset of an N400 effect in women as well as a symmetrical scalp distribution, the N400 effect elicited for the congruence judgment more closely resembled the influence of semantic context on visual word processing as its onset was about 300 ms following word onset and its maximum was over right hemisphere regions.

That both tasks resulted in somewhat different emotional-prosodic priming effects might be taken as evidence that the underlying processes were different. During the lexical decision task, participants were not specifically asked to pay attention to emotional prosody. Therefore, prosodic context effects may reflect little cognitive control. Moreover, context information might have entered some kind of default mechanism that qualitatively differs from the mechanism that executes a congruence judgment. Differences between such mechanisms could influence the onset of integration and the susceptibility to emotional interference. For example, contextual integration in women could start earlier and operate with incomplete word information during the lexical decision task. Furthermore, a context with negative valence may not interfere with word processing other than in a case of incongruence. During the congruence judgment, contextual integration may operate at a higher level of cognitive control. Retrieving the emotional valence of the prime prosody and the target word may be completed before integration starts. Furthermore, the conscious retrieval of emotional valence may trigger interference between a negative prime and the processing of a subsequent target regardless of contextual congruence.

That the level of processing induced by a lexical decision task as compared to a congruence judgment has an influence on the time course and morphology of emotional-prosodic context effects in men and women is surprising. In contrast, lexicality (Brown, Hagoort, & Chwilla, 2000) and congruence judgments (Holcomb, Kounios, Anderson, & West, 1999) elicit semantic context effects reflected in the N400 that do not differ in temporal structure and topographical distribution. Furthermore, semantic priming has been reported for short as well as for long ISIs (Deacon et al., 1999) and even when masking permitted only subliminal processing of the prime (Deacon, Hewitt, Yang, & Nagata, 2000; Kiefer, 2002). Therefore, the present findings suggest that the integration of a word in its emotional-prosodic context is a flexible process that listeners adapt to the significance of emotional prosody in a given situation.

5.7 Digression: Single Word Processing

5.7.1 Introduction

A control experiment was conducted to investigate processing differences between negative and positive words. Several studies suggest that emotional stimuli elicit a larger P300 than neutral stimuli (Fischler et al., submitted; Johnston et al., 1986; Kayser et al., 2000; Naumann et al., 1992; Windmann & Kutas, 2001). However, there is some inconsistency regarding the effect of different emotional valences on the P300. So far, the comparison between positive and negative stimuli revealed a diversity of findings. For example, Fischler and colleages (submitted) report processing difference only for neutral and emotional words, but not for emotional words with different valence. In contrast, other researchers found that negative stimuli elicited either a larger P300 (Kiehl, Hare, McDonald, & Brink, 1999; Lang et al. 1990) or a smaller P300 than positive stimuli in adult participants (Kerstenbaum & Nelson, 1992). The Lang (1990) and the Kerstenbaum and Nelson studies (1992) differ only with respect to the stimulus material. In contrast to Lang who used only one happy and one angry face, Kerstenbaum and Nelson used several different positive and negative facial expressions. Although it seems straightforward to conclude that the stimulus material caused the divergent results, the authors offer no suggestion why this should be the case.

Additionally, the cross-modal priming paradigm in the present study indicated a word valence effect for the P300 and preceding components. Its occurrence and time course was influenced by the task and the ISI. While the lexical decision task revealed an effect of target valence only in the reaction times, the congruence judgment revealed additional effects in the ERP. Moreover, valence differences started at the N400 component with a short ISI and at the P200 with a longer delay between prime and target. This suggests that word valence more strongly affects processing when a task is emotional rather than lexical and that such effects occur earlier the more time participants have to employ strategies. However, the majority of word valence effects reported for the cross-modal priming experiments occurred not independently but were modified by the prosody of the prime.

Therefore, the present experiment investigated time course and morphology of target effects independently from prime information. Furthermore, as the preceding cross-modal priming studies suggest that the processing of emotional valence can be influenced by the task, a second purpose was to further specify the task effect on word valence processing by comparing an emotional with a lexical instruction. An additional question concerned potential sex differences. From the preceding experiments we learned that male and female participants differ in the influence of emotional prosody on word processing when the task does not put emotional information in focus. Additionally, there are behavioral sex differences in the recognition of emotions from words (Grundwald et al., 1999; Sutton & Davidson, 2000). Therefore, a third purpose of this study was to test whether men and women differ in the processing of visually presented emotional words without prosodic information and whether potential sex differences would be modified by the task.

5.7.2 Methods

Participants. Fifty-five participants were invited for the experiment. The ERP of 4 participants was distorted by excessive eye movements. Three participants made too many errors so that not enough trials were left for the analysis of the ERP. Therefore, only 48 participants were included in the data analyses. Of those participants, 12 females with a mean age of 22.3 years (sd 2.1) and 12 males with a mean age of 23.3 years (sd 3.3) performed a lexical decision task. The remaining participants, that is 12 females with a mean age of 22.4 (sd 2.9) and 12 males with a mean age of 24.3 (2.4), performed an emotional judgment task. All had normal or corrected to normal vision and were native speakers of German.

Material. The target words and pseudowords from Experiment 1 to 4 served as stimulus material.

Procedure. Participants were seated inside a sound proof, electrically shielded chamber facing a computer monitor at a distance of 1.15m. Targets were presented for 300 ms with an intertrial interval of 2000 ms. Half the participants performed a simple lexical decision task. The remaining participants were asked to decide whether words had positive or negative valence, no response was required for pseudowords. Participants responded by pressing the left or the right button on a response box. Left and right hand responses were counterbalanced.

ERP Recording and Data Analysis. As one purpose of this experiment was to determine the onset of target valence effects in the ERP, the data analysis was modified. Instead of using time windows that describe ERP components, statistical analysis was conducted for 100 ms time frames: 100-200 ms, 200-300 ms, .., 700-800 ms. Furthermore, the latency of the P300 amplitude was determined for each subject and each electrode. Mean voltage per time frame and P300 latency entered separate ANOVAs with TASK (lexical/emotional) and SEX as between subjects factors and TARGET (positive/negative), HEMISPHERE (left/right), and AP (anterior/ posterior) as repeated measures factors. Data acquisition and the electrodes that were included in the data analyses were equivalent to Experiments 1 through 4.

5.7.3 Results

Behavioral Results. A three factor ANOVA with SEX and TASK (lexical/emotional) as between subjects factors and TARGET (positive/negative) as a repeated measures factor was conducted for reaction times and accuracy separately. Both reaction times and accuracy elicited a main effect for TARGET (rt, $F_{1,44} = 30.5$, $p < .0001$; ac, $F_{1,44} = 20.12$, $p < .0001$) and TASK (rt, $F_{1,44} = 83.71$, $p < .0001$; ac, $F_{1,44} = 89.16$, $p < .0001$) as well as a TARGET*TASK interaction (rt, $F_{1,44} = 6.79$, $p < .05$; ac, $F_{1,44} = 25.95$, $p < .0001$; Fig. 5.14). Post hoc comparisons were conducted for each task separately. During the lexical task, participants responded faster to positive than to negative words ($F_{1,22} = 14.9$, $p < .001$) while accuracy was comparable ($p > .1$). The emotional task also elicited faster responses to positive as compared to negative words ($F_{1,22} = 19.27$, $p < .001$). However, this difference in response latency was larger than in the lexical

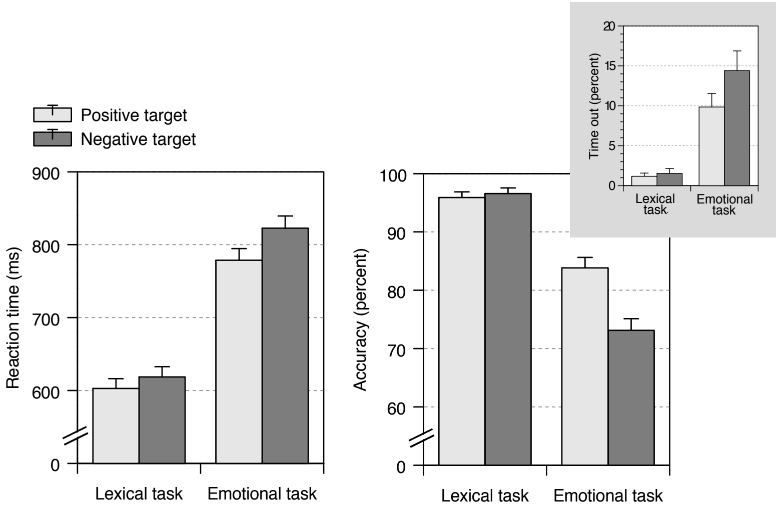

Figure 5.14. Mean reaction times and accuracy (±1 s.e.) for the single word processing plotted as a function of target valence. The light columns indicate positive targets, the dark columns indicate negative targets. The diagram in the top right corner illustrates that the low accuracy scores for the emotional task as compared to the lexical task mainly result from an increase in response latency.

task. Additionally, positive words were responded to more accurately than negative words ($F_{1,44}$ = 26.61, p < .0001). The TARGET effect in accuracy was mainly due to the fact that responses to negative words often exceeded the recording time (Fig. 5.14).

Electrophysiological Results. Statistical analysis of mean voltages within the 100 ms time frames revealed a significant TARGET*TASK interaction between 400 and 700 ms (400-500, $F_{1,44}$ = 11.32, p < .01; 500-600, $F_{1,44}$ = 11.07, p < .01; 600-700, $F_{1,44}$ = 17.45, p < .0001). This interaction was modified by the factor AP between 600 and 700 ms ($F_{1,44}$ = 7.66, p < .01). There was no main effect for TARGET nor an interaction involving TARGET for the remaining time frames. Post hoc comparisons were conducted for each task separately. During the lexical task, negative words elicited a more positive ERP between 400 and 700 ms (400-500, $F_{1,22}$ = 7.99, p < .01; 500-600, $F_{1,22}$ = 6.66, p < .05; 600-700, $F_{1,22}$ = 12.88, p < .01). This effect was not modified by AP. During the emotional task, a significant difference between positive and negative words appeared somewhat later as the TARGET effect between 400-500

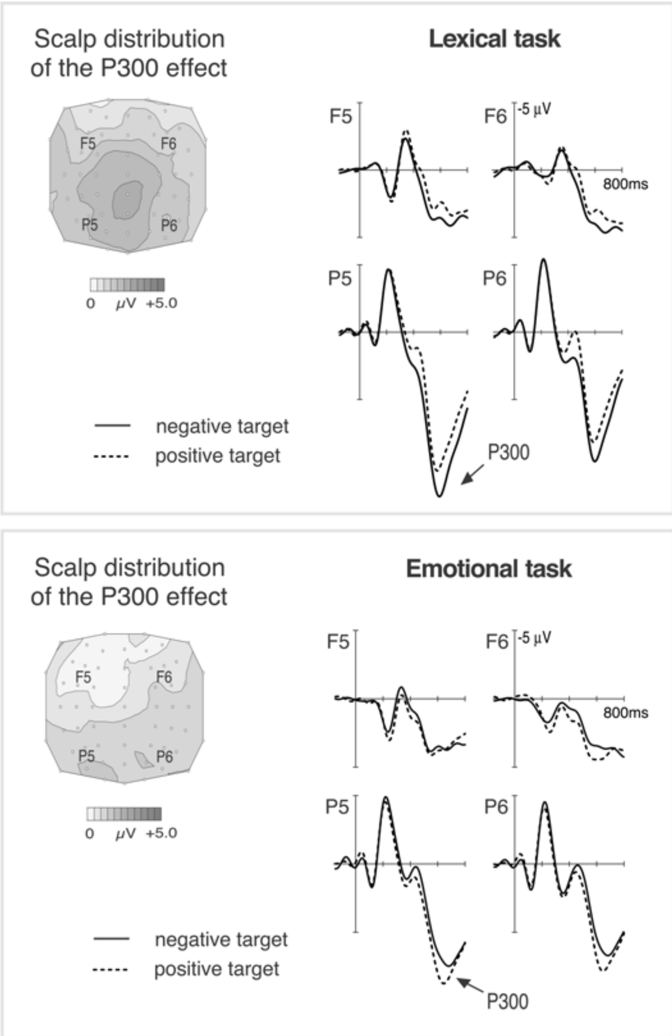

Figure 5.15. ERPs time locked to target onset for the single word processing. During the lexical task (top of the figure) negative targets elicited a larger P300 than positive targets. During the emotional task (bottom of the figure) the target effect was reversed. The topographical maps illustrate that the target effect in both tasks was strongest at posterior electrodes.

ms was marginally significant (400-500, $F_{1,22} = 3.42$, $p = .077$; 500-600, $F_{1,22} = 4.43$, $p < .05$; 600-700, $F_{1,22} = 5.31$, $p < .05$). Furthermore, a TARGET*AP interaction ($F_{1,22} = 6.65$, $p < .05$) indicated that between 600 and 700 ms the TARGET effect was significant only at posterior ($F_{1,22}$ = 8.60, $p < .01$), but not at anterior electrodes ($p > .1$). In contrast to the lexical task, the emotional task elicited a more positive ERP for positive as compared to negative words (Fig. 5.15).

Additionally, a P300 latency analysis indicated that at posterior electrodes, the P300 reached its maximum earlier in the lexical task than in the emotional task (TASK*AP, $F_{1,44}$ = 9.96, $p < .01$; posterior, $F_{1,44}$ = 8.6, $p < .01$; anterior, $p > .1$). No significant differences in P300 latency were observed between positive and negative words ($p > .1$).

5.7.4 Discussion

As men and women did not differ in the reported effects, there seems to be no sex difference in the processing of emotional words presented without prosodic information. Both men and women responded slower to negative than to positive words. However, different processing was elicited for the two tasks. First, the reaction time difference for positive and negative words was more pronounced during the emotional as compared to the lexical task. Second, reaction times were slower and accuracy was lower for the emotional than for the lexical task. Furthermore, there were processing differences reflected in the ERP. While the lexical task elicited a larger P300 in response to negative words, the emotional task elicited a larger P300 to positive words. Moreover, the valence effect in the lexical task started 100 ms earlier (i.e., 400 ms following word onset) than the valence effect in the emotional task.

The comparison between the single word study and the cross modal priming suggests that the occurrence of emotional valence effects in the ERP can be modified by the presence or absence of contextual information (e.g., emotional prosody). Moreover, from the present data one could conclude that task and context interact in their influence on emotional word processing. Earlier ERP effects of word valence processing occurred (a) when context was present and the task was emotional or (b) when no context was present and the task was non-emotional. However, later or no differences between positive and negative words in the ERP were obtained when (a) there was no context, but the task was emotional or (b) context was present and the task was non-emotional.

The present data do not clarify the nature of this task by context interaction nor do they allow for any general conclusions concerning the processing of negative and positive words. However, these findings nicely demonstrate the complexity of emotional processing and that an emotionally valenced stimulus can trigger different kinds of processing depending on the situation it is presented in. More striking than the temporal differences, however, is the result of qualitatively different P300 effects for the lexical and the emotional task. The P300 has been linked to emotional processing (e.g., Kayser et al., 2000) but also to several cognitive aspects, such as working memory, event categorization, attention, and task difficulty (for a review see Kok, 2001). Therefore, it is difficult to infer the significance of the present P300 effect from the literature. However, a previous study with a similar design does provide some insights. Kiehl and colleagues (1999) compared semantic and affective processing in normals and psychopaths. In one task, they presented positive and negative words and asked participants to indicate emotional valence by pressing one of two buttons. They found that both groups responded faster and more accurately to positive than to negative words. Furthermore, normals, but not psychopaths showed a larger P300 to negative as compared to positive words. Moreover, this effect started to differentiate in a preceding negativity which the authors labeled as an N350. The P300 effect in normals closely resembles the word valence effect reported for the lexical task here, but it differs from the emotional task findings. As the only difference between the emotional task in the Kiehl study and the emotional task in the present study is the occurrence of pseudowords, they might be responsible for the inverted P300 effect.

Usually, negative stimuli, because of their potential threatening character, are more surprising and attract more attention than neutral and positive stimuli (Oehmann et al., 2000). This difference in emotional significance might modulate the P300 amplitude (Kayser et al., 2000). However, since the P300 is sensitive to other cognitive processes as well, it may indicate emotional processing only indirectly. This becomes apparent from the emotional task in the present study. The presentation of pseudowords forced participants to make two decisions for each target: first, is it a word or pseudoword and second, if it is a word – what is its emotional valence. Presumably, pseudowords received a negative tag because they were not real words and did not require a response. This tag might have been similar to that of negative words. Perhaps, such an association between pseudowords and negative words lowered the subjective probability of positive words, which would result in a larger P300 (Johnson, 1986). The higher rate of time outs for negative words supports this interpretation as it suggests that negative words were more often classified as pseudowords than positive words. In contrast, the lexical task required a 'yes' response for both positive and negative words. This may have prevented an association between negative words and pseudowords.

However, other explanations are possible as well. One can be derived from Garcia-Larrea & Cezanne-Bert (1998) who conducted an auditory oddball experiment in which subjects had to count rare stimuli. A more difficult counting procedure (e.g., forward counting vs. backward counting in steps of 3) reduced the P300 amplitude and elicited a slow positive wave. With respect to the present experiment, it is possible that the difficulty to respond to a certain stimulus modulated the P300 effect for the emotional but not for the lexical task. While accuracy was comparable for positive and negative words during the lexical task, it was harder for participants to recognize negative targets as compared to positive targets when they had to be classified for emotional valence. This might have reduced the P300 amplitude for negative words during the emotional task. Furthermore, this interpretation may apply to the Kerstenbaum and Nelson (1992) study. Similar to the emotional task in the present study, they found that adults produce a larger P300 in response to happy as compared to angry faces. While happy faces were detected almost without any mistakes, angry faces were more frequently misclassified as expressing fear. In contrast, Lang and colleagues (1990), who found a larger P300 for angry as compared to happy faces, presented only one happy face and one angry face that had to be discriminated. There, mistakes were almost impossible. With respect to the present study, words with stronger emotional valence that are easier to classify might have resulted in similar effects for the lexical and the emotional task. However, as the single word presentation needed to closely match the cross-modal priming paradigm in order to investigate prime independent effects within the material, it was necessary to use pseudowords and only moderately emotional words.

Of further interest to the present experiment were effects on P300 latency. In a probe-response task, McCarthy and Donchin (1981) presented the words ‘left’ and ‘right’ in randomized order on a computer screen in front of the participants. Participants responded with their right hand to the word ‘right’ and with their left hand to the word ‘left’. The latency of the P300 increased when stimulus discrimination became more difficult. However, a reversed response pattern (i.e., the word ‘right’ required a left-hand response) led to an increase in reaction times, but not in P300 latency. Given these findings it has been concluded that the P300 latency reflects the time necessary for stimulus evaluation, but not for response preparation (Friedman, Kazmerski, & Fabiani, 1997; Kutas, McCarthy, & Donchin, 1977; McCarthy & Donchin, 1981). If true, than the difference between the emotional and the lexical task in P300 latency may suggest that stimulus evaluation required more time during the emotional than during the lexical task. This is indeed very likely because the emotional task required two instead of only one decision (i.e., lexical plus emotional).

Furthermore, the latency analysis revealed insights into the processing of emotional words. That positive and negative words did not differ significantly in P300 latency indicates that stimulus processing time was comparable. Additionally, it suggests that the reaction time differences reflect response related processes rather than the time to evaluate the emotional meaning of a word (McCarthy & Donchin, 1981). That there are indeed different response tendencies to positive and negative stimuli was proposed by Lewin in 1935. He suggested that positive objects are linked to an attraction motive, whereas negative objects are linked to an avoidance motive. More recently, Lang, Bradley and Cuthbert (1998) presented a similar motivational account of emotion. They argued for the existence of two motivational systems: an appetitive system and a defense system. Positive and negative stimuli activate the appetitive and the defense system, respectively and thereby trigger emotions and modify physical and behavioral parameters. For example, negative pictures elicit an increase in corrugator (‘frown’) electromyographic activity and a deceleration in heart rate as compared to positive pictures (Lang, Greenwald, Bradley, & Hamm, 1993). Furthermore, responses such as memory associations but also actions (e.g., flight) that are linked to the activated motivational system are primed. The startle response, for example, elicited by an abrupt sensory event, can be amplified or attenuated by the prior presentation of a negative or positive picture, respectively (Lang, Bradley, & Cuthbert, 1990). Further evidence that positive and negative stimuli trigger different response tendencies comes from studies by Solarz (1960) and Chen and Bargh (1999). They presented positive and negative words to participants and asked them to either pull a lever or push it away in response to those words. When participants had to pull the lever they were faster when the word was positive as compared to negative. In contrast, pushing the lever was performed faster when the word was negative as compared to positive. Furthermore, Williams, Mathews, and MacLeod (1996) review a series of experiments where they presented emotional words printed in different color ink. They report that, for example, anxious patients were slower in naming the ink color of threatening words as compared to words with neutral valence. Taken together, these findings suggest that the response latency to a given stimulus can vary as a function of its emotional valence. If a stimulus or object is evaluated as positive, responses associated with approach are facilitated and avoidance is inhibited. However, if a stimulus has a negative meaning, then approaching behavior is inhibited and avoidance facilitated. If a button press is experienced as approach, then the longer reaction times to negative words in the present experiment may result from a response conflict.

In sum, the single word experiment failed to reveal an ERP correlate that directly reflects processing of emotional valence. Rather the observed ERP results varied as a function of task. Moreover, in the context of cross-modal priming, ERP effects of emotional valence were additionally modulated by the ISI and the emotional valence of the prime. Therefore it seems that processes that detect the emotional valence of a stimulus strongly interact with the processing of context information and general task demands. Furthermore, the present experiment failed to reveal sex differences for the processing of visually presented emotional words. This may suggests that the sex differences reported for cross-modal priming are restricted to the interaction of emotional information from word meaning and prosody. Finally, the present study indicates that the frequently reported reaction time differences between negative and positive words (Kiehl et al., 1999; Schirmer et al., 2001; Wentura, 1998) may arise from different response tendencies rather than from differences in stimulus evaluation time.

CHAPTER 6: THE DOMINANCE-QUESTION

6.1 Introduction

How someone feels often shows in the way he or she behaves, for example, through a smile. Additionally, speech can signal emotions. The present work investigates which of the two aspects of speech *dominates* an emotional judgment: the emotion put into words – for example, when someone says ‘I am happy!’; or the emotional tone of a speaker – for example, when he or she actually sounds happy. Moreover, this study should determine whether the impact incongruent emotional prosody has on semantic processing is stronger than the impact incongruent semantic information has on prosodic processing.

A similar question, namely whether incongruence between two different types of stimulus information causes interference, was investigated by Stroop (1935). In the classic Stroop paradigm, subjects see color names (e.g., 'red') printed in the same or different color ink. When naming the ink color, subjects are slower on incongruent (e.g., 'red' printed in green color) than on congruent trials. In contrast, incongruent color information has little or no effect on subjects’ reading ability. On the basis of these findings, it has been argued that reading is an automatic response when encountering a word, whereas color naming relies on controlled processes and, therefore, is subject to interference (Posner & Snyder, 1975). However, MacLeod and Dunbar (1988) demonstrated that after participants learn to use color-words as shape names, they show behavioral interference effects in a shape-naming task when the shapes are printed in color. This finding called the all-or-none concept of automaticity into question. As a consequence, it has been suggested that automaticity depends upon the strength a particular processing pathway has gained via practice (Cohen, Dunbar & McClelland, 1990; MacLeod & Dunbar, 1988; MacLeod & MacDonald, 2000). Moreover, it has been argued that automaticity is a continuum and that the Stroop effect during color naming in normal untrained participants results from the fact that naming the ink color of a word is *less* automatic than reading.

The present study employed an emotional Stroop paradigm. Participants listened to words that had a positive, neutral, or negative valence and were spoken with a happy, neutral, or angry prosody. Consequently, there were trials in which prosodic and semantic information were congruent, and there were trials in which this information was incongruent. In one experimental block, participants made a semantic judgment. They were asked to rate word valence as positive, neutral, or negative, while ignoring emotional prosody. In another experimental block, participants had to judge emotional prosody as positive, neutral, or negative, while ignoring semantic information. Participants were asked to respond by pressing one of three buttons on a response box as quickly and as accurately as possible.

In the cross-modal priming experiments presented in the preceding chapter, sex differences in the prosody-semantics interaction depended on whether or not participants attended to prosody. Therefore, it was possible that men and women would also differ in an emotional Stroop paradigm. However, sex differences could occur on two different processing dimensions. First, men and women could differ in whether or not they show interference in the two tasks. This would indicate the dominance or automaticity of processing emotional prosody as compared to word meaning.

A second dimension that could reveal sex differences is the processing stage during which interference occurs. Hock and Egeth (1970), for example, proposed that interference in a Stroop task arises during the perceptual encoding of a stimulus. Others suggested that the locus of interference is at a semantic processing stage (Liotti, Woldorff, Perez, & Mayberg, 2000; Rayner & Springer, 1986; Seymour, 1977) or at the output stage caused by the parallel activation of the correct and the incorrect response (DeSoto, Fabiani, Geary, & Gratton, 2001; Duncan-Johnson & Kopell, 1981; Masaki, Takasawa, & Yamazaki, 2000). With respect to interference occurring in emotional speech, men and women might differ in the stage that elicits an interaction between prosody and semantics. If true, one would expect women to show an earlier interaction of emotional prosody and word meaning as compared to men.

Beside the dominance-question and the locus of interference, there was another question that arose from Experiments 1 and 2. The sex difference in the time course of emotional-prosodic context effects, might have been modulated by the sex of the speaker. Previous studies revealed different communication patterns between mixed- and same-gender dyads (Flannagan & Perese, 1998; Leaper, 1998). If such differences in communication are reflected in the processing of emotional speech, the presentation of a male instead of a female speaker in Experiments 1 and 2 might have lead to different findings. On the other hand, if there are general processing differences between men and women they should not be affected by the sex of the speaker. To test both hypotheses, the stimulus material of the present study was spoken by a male and a female speaker.

6.2 Methods

Participants. Seventy-one volunteers were invited to participate in the experiment. Thirty-six listened to the stimulus material spoken by a female speaker. Because of excessive artifacts in the ERP, three of these subjects were excluded from the data analysis. Another subject was excluded because his behavioral responses were slower than two standard deviations from the group mean. Sixteen of the remaining 32 subjects were female with a mean age of 22.9 (sd 2.3). Male participants had a mean age of 23.5 (sd 2.9). Thirty-five out of 71 subjects listened to the stimulus material spoken by a male speaker. The error rate in two participants was too high to provide enough trials for the ERP analysis. Another subject was excluded from the data analysis because of excessive ERP artifacts. Sixteen of the remaining 32 subjects were female with a mean age of 24.0 (sd 4.1). Male participants had a mean age of 24.1 (sd 2.3). All subjects were right-handed, had no hearing impairment and were native speakers of German.

Materials. The stimulus material consisted of 74 positive, 74 neutral, and 74 negative verbs. Word valence was obtained in an earlier rating study (see Appendix 2). Forty subjects rated all words on a 5-point scale that ranged from -2 to +2 for emotional valence. Negative words had a mean valence of -1.7 (sd 0.44), neutral words of 0.05 (sd 0.46), and positive words of 1.08 (sd 0.55). Word frequency did not differ between the three word valence conditions (Celex, 1995). A female and a male native speaker of German produced all words with happy, neutral, and angry prosody. Words were taped with a DAT recorder and digitized at a 16-bit/44.1 kHz sampling rate. The stimulus material was divided into two lists. Each list contained 37 positive, 37 neutral, and 37 negative words spoken with a happy, neutral, or angry voice. Each list was presented with a prosodic and a semantic instruction. Whenever a subject heard one list with a prosodic instruction he or she heard the other list with a semantic instruction. Half the participants listened to the stimulus material spoken by the female speaker and half the participants listened to the stimulus material spoken by the male speaker.

Procedure. Testing was carried out in a sound proof and electrically shielded chamber. Participants were seated in a comfortable chair facing a computer monitor at a distance of 1.15 meters. Words were presented over speakers positioned at the left and the right side of the monitor. Preceding every word, a fixation cross appeared on the screen for 200, 300, or 400 ms for a third of the trials, respectively. The temporal jitter was included to reduce baseline artifacts due to expectancy. Thousand and five hundred milliseconds following word onset the fixation cross turned off and the screen was blank for 300 ms until the next trial started. An experimental session consisted of two blocks. In one block, subjects had to judge word valence as positive, neutral, or negative while ignoring prosody. In another block, subjects had to judge emotional prosody as positive, neutral, or negative while ignoring word valence. Block order was counterbalanced across subjects. Responses were given by pressing one of three buttons of a response box as quickly and as accurately as possible. Subjects used the index and the middle finger of the right hand to press the middle and the right button, respectively; they used their left hand index finger to press the left button. Half the subjects pressed the left button for positive responses and the right button for negative responses; the remaining subjects had the reversed button-assignment. Neutral responses were always assigned to the middle button. Thirty-six practice trials preceded every experimental block.

ERP-Recordings. The EEG was recorded (250 Hz sampling rate) from 58 electrodes, which were placed on the head according to the modified expanded 10-20 system. The reference electrode was placed on the nose tip. In order to control for horizontal and vertical eye movements, a bipolar electrooculogram was recorded using 4 electrodes. Electrode resistance was kept below 5 kOhm. ERP averages were computed with a 150 ms baseline and a 900 ms ERP time window. Trials containing eye blinks or movement artifacts were omitted from the data analysis. Grand averages were smoothed with an 8-Hz low pass filter for illustration only.

For statistical analysis, electrodes were grouped into 4 regions of interest: left anterior (F7, F5, F3, FT7, FC5, FC3, T7, C5, C3), right anterior (F8, F6, F4, FT8, FC6, FC4, T8, C6, C4), left posterior (TP7, CP5, CP3, P7, P5, P3, PO7, PO3, O1), and right posterior (TP8, CP6, CP4, P8, P6, P4, PO8, PO4, O2). Separate ANOVAs were conducted for the P200 (180-300 ms), the N400 (300-600 ms), and a late positivity (600-900 ms). Time windows were determined after visual inspection of the ERP waveforms. Where appropriate, p-values for post-hoc comparisons were corrected using a modified Bonferroni procedure (see Keppel, 1991). The factor VOICE was only of interest in an interaction with SEX. Therefore, no main effects of VOICE or interactions with experimental factors other than SEX are reported. The null-hypothesis was rejected for p-values smaller than 0.05. Significant interactions are reported only when post-hoc comparisons revealed significant effects.

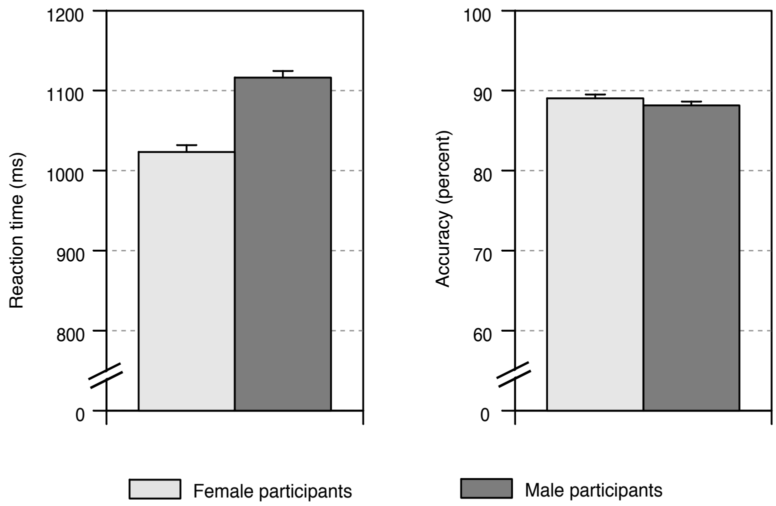

Figure 6.1. Mean reaction time and accuracy (±1 s.e.) plotted as a function of target valence.

6.3 Results

Behavioral Results. Reaction times and accuracy data were entered into separate ANOVAs treating TASK (semantic/prosodic), WORD (positive/neutral/negative), and PROSODY (happy/neutral/angry) as repeated measures factors and SEX and VOICE (male/female) as between subjects factors.

Statistical analysis of the reaction times revealed a main effect for SEX ($F_{1,61}$ = 11.27, p < .01) indicating faster reaction times for female as compared to male participants (Fig. 6.1). Furthermore, there was a significant interaction involving TASK, WORD, and PROSODY ($F_{4,244}$ = 2.34, p = .05). As both tasks revealed a significant WORD*PROSODY interaction (semantic task, $F_{4,244}$ = 19.48, p < .0001; prosodic task $F_{4,244}$ = 9.41, p < .0001), the WORD effect for each level of PROSODY for the semantic and the prosodic judgment was analyzed separately (Tab. 6.1). Examination of the interaction by looking at the WORD effect in each prosodic condition was motivated by the difference in word length across the prosodic conditions. Angrily spoken words (886.69; sd 114.7) were longer than happily spoken words (863.48; sd 143.25); happily spoken words were longer than words with neutral prosody (719.21; sd 100.94). This temporal difference had a strong influence on the reaction times for the semantic task (Fig. 6.2) and confounds the prosodic effect for the three word valences. Therefore, the analysis of the prosody-semantics interaction was conducted by comparing the response latencies for positive, neutral, and negative words for each prosodic condition. During the prosodic judgment, happily spoken words were responded to faster when word valence was positive as compared to neutral or negative. No significant effects occurred for words with neutral or angry prosody. During the semantic judgment, response latencies for happily and angrily spoken words were significantly shorter when word meaning was congruent as compared to incongruent. Neutrally spoken words elicited shorter response latencies when the meaning had an emotional rather than a neutral valence (Table 6.1, Fig. 6.2).

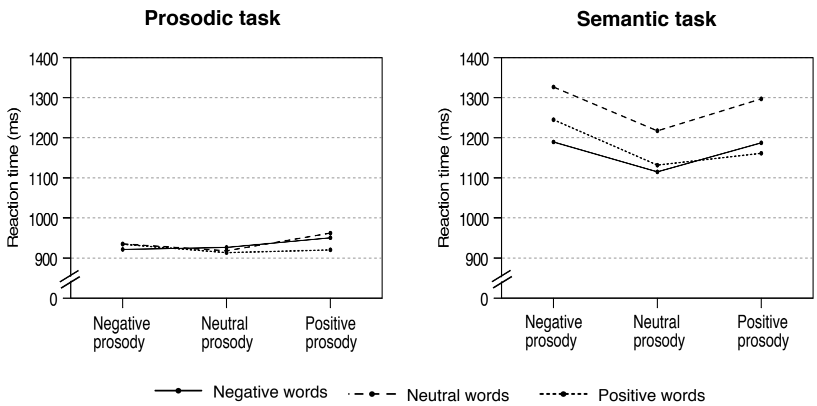

Figure 6.2. Mean reaction time plotted as a function of target prosody.

There was also a significant TASK*WORD*PROSODY interaction in the accuracy data ($F_{4,244}$ = 10.23, p < .0001). Post hoc comparisons indicated that emotional prosody and word meaning interacted during the semantic task (WORD*PROSODY, $F_{4,244}$ = 20.18, p < .0001). As there was a WORD main effect (WORD, $F_{2,120}$ = 9.78, p < .0001) that confounded word valence effects for each level of prosody, this interaction was approached by looking at the prosodic effect for each level of WORD. Whenever there was congruence between prosody and word meaning, accuracy was significantly higher as compared to the incongruence condition (Fig. 6.3). Although the PROSODY*WORD interaction also reached significance in the prosodic task ($F_{4,244}$ = 8.44, $p < .0001$), post hoc comparisons revealed only small or no effects of prosody-semantics congruence (Tab. 6.2, Fig. 6.3). Independent of emotional meaning, words with happy prosody were rated less accurately than words with neutral or angry prosody. Words with angry prosody were rated less accurately than words with neutral prosody, except when words carried a negative meaning in which case neutrally and angrily spoken words did not differ. In contrast to the reaction times, accuracy revealed no main effect of SEX ($p > .1$).

Table 6.1. Reaction time:
Post hoc comparisons for the TASK by PROSODY by WORD interaction

Semantic Task

	Positive Prosody	Neutral Prosody	Negative Prosody
Word	$F_{2,122}$ = 77.38, p < .0001	$F_{2,122}$ = 47.92, p < .0001	$F_{2,122}$ = 66.81, p < .0001
neu-neg	$F_{1,61}$ = 75.04, p < .0001	$F_{1,61}$ = 88.4, p < .0001	$F_{1,61}$ = 101.58, p < .0001
pos-neg	$F_{1,61}$ = 7.31, p < .01	$F_{1,61}$ = 3.05, p = .085	$F_{1,61}$ = 38.23, p < .0001
pos-neu	$F_{1,61}$ = 123.6, p < .0001	$F_{1,61}$ = 44.14, p < .0001	$F_{1,61}$ = 38.23, p < .0001

Prosodic Task

	Positive Prosody	Neutral Prosody	Negative Prosody
Word	$F_{2,122}$ = 23.81, p < .0001	p > .1	p > .1
neu-neg	$F_{1,61}$ = 3.18, p = .079	--	--
pos-neg	$F_{1,61}$ = 23.78, p < .0001	--	--
pos-neu	$F_{1,61}$ = 47.37, p < .0001	--	--

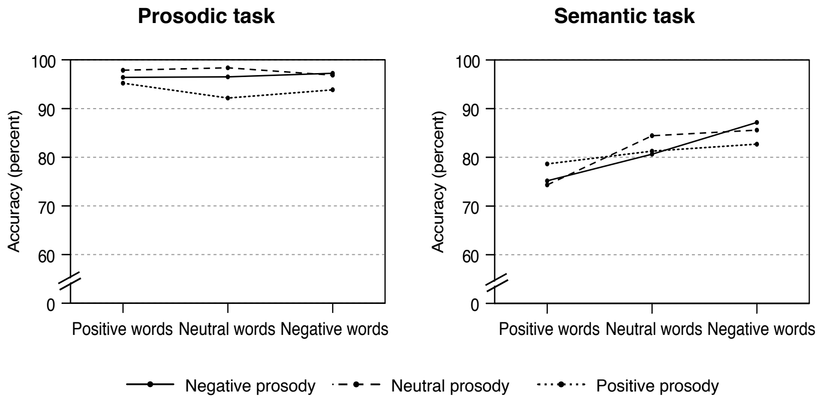

Figure 6.3. Accuracy plotted as a function of target valence.

Table 6.2. Accuracy:

Post hoc comparisons for the TASK by PROSODY by WORD interaction

Semantic Task

	Positive Word	Neutral Word	Negative Word
Prosody	$F_{2,122} = 13.73$, $p < .0001$	$F_{2,122} = 9.84$, $p < .0001$	$F_{2,122} = 17.99$, $p < .0001$
Neu-neg	$p > .1$	$F_{1,61} = 20.56$, $p < .0001$	$F_{1,61} = 7.36$, $p < .01$
Pos-neg	$F_{1,61} = 15.18$, $p < .001$	$p > .1$	$F_{1,61} = 28.26$, $p < .0001$
Pos-neu	$F_{1,61} = 25.82$, $p < .0001$	$F_{1,61} = 13.02$, $p < .001$	$F_{1,61} = 12.62$, $p < .001$

Prosodic Task

	Positive Word	Neutral Word	Negative Word
Prosody	$F_{2,122} = 8.05$, $p < .001$	$F_{2,122} = 27.28$, $p < .0001$	$F_{2,122} = 9.74$, $p < .0001$
Neu-neg	$F_{1,61} = 7.18$, $p < .01$	$F_{1,61} = 9.3$, $p < .01$	$p > .1$
Pos-neg	$F_{1,61} = 4.17$, $p = .045$	$F_{1,61} = 27.37$, $p < .0001$	$F_{1,61} = 12.4$, $p < .001$
Pos-neu	$F_{1,61} = 10.34$, $p < .01$	$F_{1,61} = 32.92$, $p < .0001$	$F_{1,61} = 10.8$, $p < .01$

In sum, women made generally faster emotional judgments than men. The sex of the speaker did not affect this speed advantage in women. Furthermore, both men and women showed an emotional Stroop effect that was considerably stronger during the semantic than during the prosodic task. Together with the overall lower accuracy ($F_{1,61}$ = 611.05, $p < .0001$) and the slower reaction times ($F_{1,61}$ = 381.81, $p < .0001$) for the semantic task this suggests that the processing of a word's emotional meaning is somewhat more demanding and perhaps less automatized than the detection of emotions in a speaker's voice.

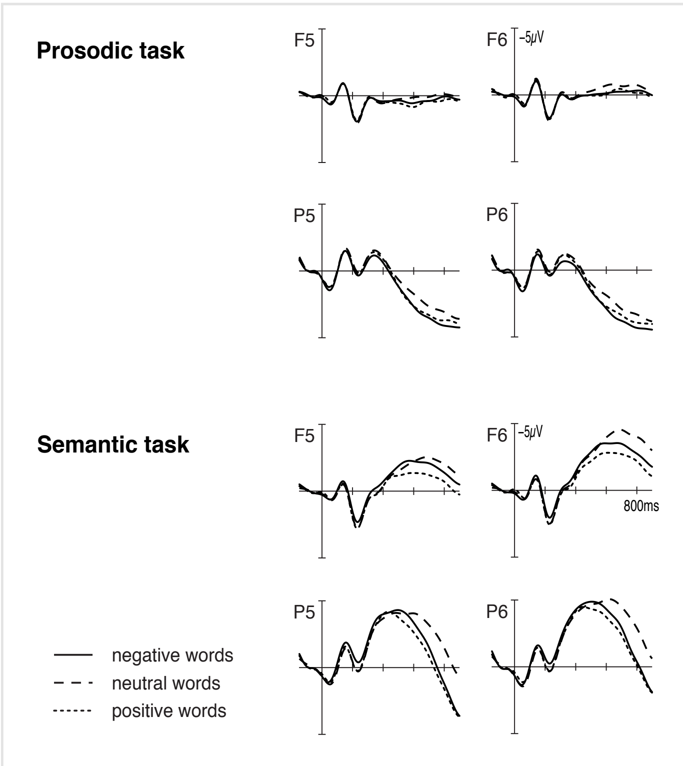

Figure 6.4. ERPs time locked to target onset for negative, neutral, and positive words. Both the prosodic and the semantic task elicit a larger late positivity for emotional as compared to neutral words. Word valence effects for the prosodic task start later (N400) than for the semantic task (P200).

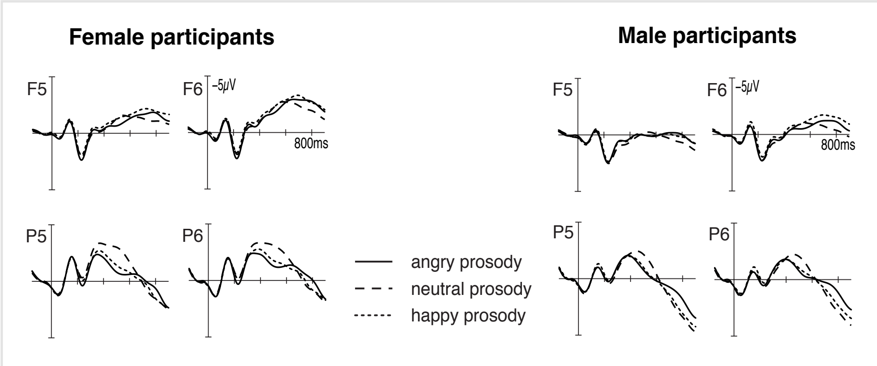

Figure 6.5. ERPs time locked to target onset for angry, neutral, and happy prosody. Women show earlier prosodic processing (P200) than men (N400). The prosodic N400 effect in women is larger than in men. The prosodic effect for the late positivity is larger in men than in women.

Electrophysiological Results. An ANOVA was conducted with TASK (prosodic/ semantic), PROSODY (happy/neutral/angry), WORD (positive/neutral/negative), and ROI (anterior-left/anterior-right/posterior-left/posterior-right) as repeated measures factors and SEX and VOICE (male/female) as between subjects factors for each of three different time windows. The results for each time window are presented below.

P200 (180-300 ms). Statistical analysis of the P200 time window revealed a significant TASK*WORD interaction ($F_{2,120} = 7.26$, $p < .01$). Post hoc comparisons indicated that the semantic ($F_{2,120} = 8.94$, $p < .001$), but not the prosodic task ($p > .1$) elicited differences between the three word valence conditions. When judging the emotional meaning of a word, P200 amplitudes were larger for neutral and positive words as compared to negative words (neu-neg, $F_{1,60} = 11.39$, $p < .01$; pos-neg, $F_{1,60} = 17.72$, $p < .0001$; neu-pos, $p > .1$; Fig. 6.4).

Additionally, the P200 was modulated by emotional-prosodic information (PROSODY* ROI*SEX, $F_{6,360} = 3.32$, $p < .01$). Moreover, the prosodic P200 effect occurred independently of the task and was significant for female ($F_{6,180} = 6.12$, $p < .0001$), but not for male participants ($p > .1$). At anterior-right electrodes ($F_{2,60} = 3.39$, $p < .05$), happy prosody elicited a significantly smaller P200 than angry prosody ($F_{1,30}$

= 6.03, $p < .03$) and a tendentially smaller P200 than neutral prosody ($F_{1,30} = 4.57$, $p =$ .04). Neutral and angry prosody did not differ ($p > .1$). At posterior-left electrodes ($F_{2,60} = 3.84$, $p < .05$), the P200 was smaller for neutral prosody as compared to angry prosody ($F_{1,30} = 5.7$, $p < .03$). Both conditions did not differ from happy prosody ($p >$ .1). No effects occurred for anterior-left and posterior-right electrode sites (Fig. 6.5).

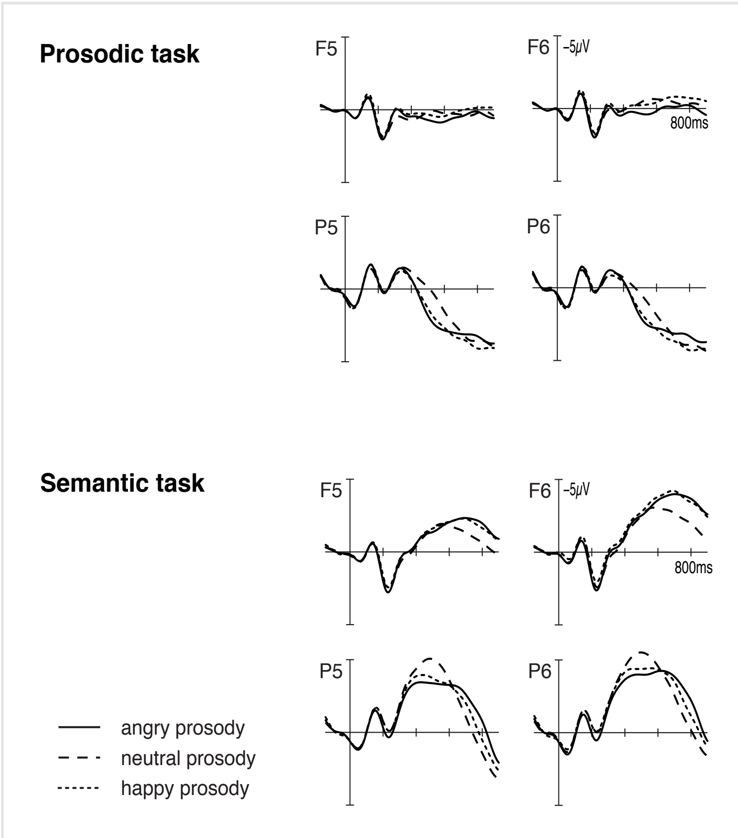

Figure 6.6. ERPs time locked to target onset for angry, neutral, and happy prosody. Both the prosodic and the semantic task elicit a larger N400 for neutral as compared to emotional words.

N400 (300-600 ms). As illustrated in Figure 6.4, the TASK*WORD interaction was also significant for the N400 time window ($F_{2,120} = 3.2$, $p < .05$). During the prosodic task, the ERP for neutral words was more negative than that for negative words (WORD, $F_{2,120} = 3.25$, $p < .05$; neu-neg, $F_{1,60} = 5.25$, $p < .03$; pos-neg, $p > .1$; neu-pos, $F_{1,60} = 3.28$, $p = .075$). In contrast, during the semantic task, neutral and negative words did not differ (WORD, $F_{2,120} = 3.41$, $p < .05$; neu-neg, $p > .1$; pos-neg, $F_{1,60} = 6.38$, $p < .03$; neu-pos, $F_{1,60} = 2.96$, $p = .091$). Instead, they elicited a tendentially and significantly larger N400 than positive words, respectively.

Furthermore, the PROSODY*ROI*SEX interaction ($F_{6,360} = 3.32$, $p < .01$) indicated differential prosodic processing in men and women. Although both sexes showed an effect of prosody, it was restricted to left-posterior sites in men, whereas women showed a contribution of posterior and anterior regions. Neutral prosody elicited a larger N400 than happy and angry prosody (Table 6.3, Fig. 6.5). Additionally, the PROSODY*ROI interaction was modified by TASK. The prosodic effect was restricted to posterior regions during the semantic task, whereas both posterior and anterior regions were involved during the prosodic task (Table 6.3, Fig. 6.6).

Additionally, the N400 amplitude reflected an interaction between emotional prosody and word valence (WORD*PROSODY*SEX, $F_{4,240} = 3.54$, $p < .01$) that was independent of task. This interaction was significant in female ($F_{4,120} = 7.6$, $p < .0001$), but not in male participants ($p > .1$; Fig. 6.7, Fig. A2.1 and A2.2 in Appendix 2). Women showed a larger N400 for happily spoken words when word valence was neutral or negative as compared to positive (WORD, $F_{2,60} = 8.43$, $p < .001$; pos-neu, $F_{1,30} = 5.17$, $p = .03$; pos-neg, $F_{1,30} = 19.91$, $p < .0001$; neu-neg, $p > .1$). Similarly, angrily spoken words elicited significantly larger N400 amplitudes when word valence was neutral or positive as compared to negative (WORD, $F_{2,60} = 9.21$, $p < .001$; neg-neu, $F_{1,30} = 11.95$, $p < .01$; neg-pos, $F_{1,30} = 20.87$, $p < .0001$; neu-pos, $p > .1$). Word valence did not affect the processing of neutrally spoken words ($p > .1$). A single comparison between the neutral congruence condition and the maximal incongruence conditions revealed tendential amplitude differences ($F_{2,60} = 2.55$, $p = .086$).

Moreover, this was due to somewhat larger N400 amplitudes in response to the neutral congruence condition:

WORD neutral / PROSODY neutral: mean –2.21 μV (sd 4.35)
WORD negative / PROSODY positive: mean –2.12 μV (sd 4.54)
WORD positive / PROSODY negative: mean –1.63 μV (sd 4.08).

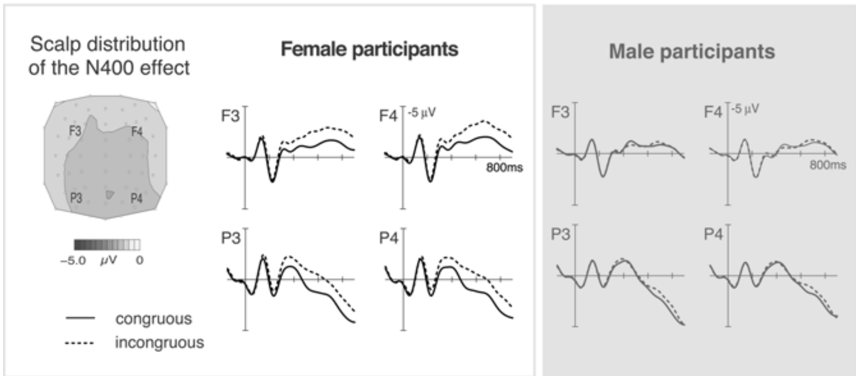

Figure 6.7. ERPs time locked to target onset for congruous and maximally incongruous emotional words (negative meaning and happy prosody; positive meaning and angry prosody). Incongruous words elicited a larger N400 as compared to congruous words in women but not in men. Although the late positivity revealed a prosody-semantics interaction in both sexes it was stronger in women than in men (see also Fig. A2.1 and A2.2 in Appendix 2).

If one considers the neutral match as a baseline, then one could conclude that the N400 effect in women does not reflect an increase in amplitude for the incongruence condition, but rather a decrease in amplitude and therefore facilitated processing when semantic and prosodic information are congruent. However, as the neutral match condition elicited longer behavioral responses than neutrally spoken positive and negative words in both sexes, this conclusion may not be warranted.

Table 6.3. N400:

Post hoc comparisons for the PROSODY by ROI by SEX and the PROSODY by ROI by TASK interaction

	Female Participants	Male Participants	Prosodic Task	Semantic Task
PROSODY*ROI	$F_{6,180}$ = 16.67****	$F_{6,180}$ = 4.77***	$F_{6,360}$ = 8.95****	$F_{6,360}$ = 16.34****
left-anterior	$F_{2,60}$ = 3.92*	$p > .1$	$F_{2,120} = 2.53^{\#}$	$p > .1$
neu-neg	$F_{1,30}$ = 5.85°	--	--	--
pos-neg	$F_{1,30} = 4.59^{\#}$	--	--	--
pos-neu	$p > .1$	--	--	--
right-anterior	$p > .1$	$p > .1$	$F_{2,120}$ = 3.23*	$p > .1$
neu-neg	--	--	$F_{1,60} = 4.15^{\#}$	--
pos-neg	--	--	$F_{1,60}$ = 5.98°	--
pos-neu	--	--	$p > .1$	--
left-posterior	$F_{2,60}$ = 24.76****	$F_{2,60}$ = 4.6*	$F_{2,120}$ = 13.72****	$F_{2,120}$ = 11.82****
neu-neg	$F_{1,30}$ = 33.86****	$F_{1,30}$ = 6.07°	$F_{1,60}$ = 18.39****	$F_{1,60}$ = 19.7****
pos-neg	$F_{1,30} = 3.13^{\#}$	$p > .1$	$p > .1$	$p > .1$
pos-neu	$F_{1,30}$ = 35.38****	$F_{1,30}$ = 9.44**	$F_{1,60}$ = 21.67****	$F_{1,60}$ = 13.51***
right-posterior	$F_{2,60}$ = 18.61****	$F_{2,60} = 2.79^{\#}$	$F_{2,120}$ = 9.03***	$F_{2,120}$ = 8.99***
neu-neg	$F_{1,30}$ = 24.61****	--	$F_{1,60}$ = 11.46**	$F_{1,60}$ = 15.99***
pos-neg	$F_{1,30} = 4.17^{\#}$	--	$p > .1$	$F_{1,60} = 3.65^{\#}$
pos-neu	$F_{1,30}$ = 21.09****	--	$F_{1,60}$ = 13.46***	$F_{1,60}$ = 6.01°

**** p < .0001; *** p < .001; ** p < .01; * p < .05; $^{\#}$ p < .1

For Bonferroni adjusted single comparisons °p < .03

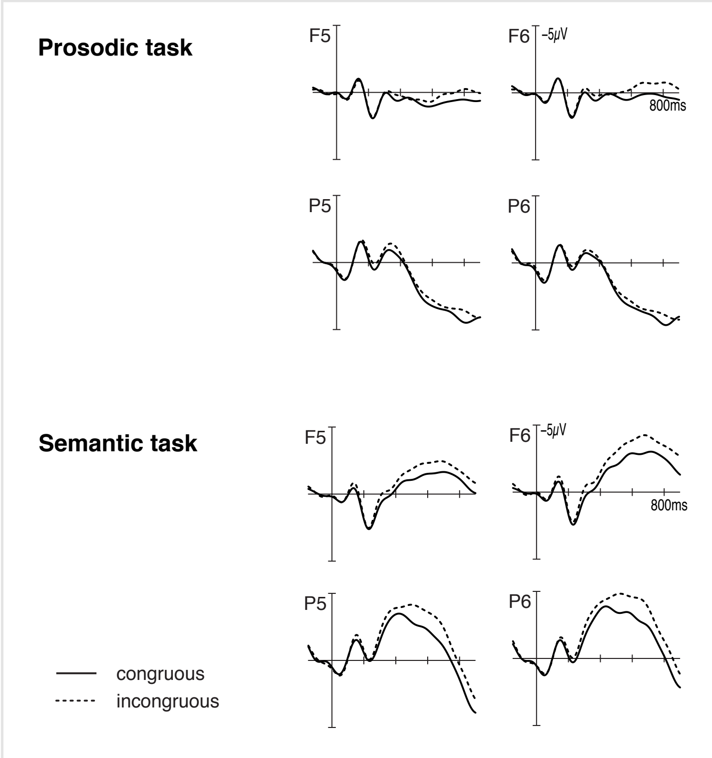

Figure 6.8. ERPs time locked to target onset for congruous and maximally incongruous emotional words (negative meaning and happy prosody; positive meaning and angry prosody). For the prosodic task the difference between congruous and incongruous words for the time window of the late positivity was smaller and had a more frontally restricted scalp distribution than for the semantic task.

Late positivity (600-900 ms). The WORD*PROSODY*SEX interaction reported for the N400 time window carried over to the late positivity ($F_{6,360} = 6.29$, $p < .0001$). Post hoc comparisons revealed a significant WORD*PROSODY interaction in both men and women. However, the effect in women was stronger than in men (Fig. 6.7, Fig. A2.1 and A2.2 in Appendix 2). As reported for the N400 time window, happily and angrily spoken words were more positive in amplitude when word valence was congruent as compared to incongruent. Although significant in females, critical comparisons were not always significant in males (Table 6.4). Furthermore, the late positivity was larger for neutrally spoken words with positive and negative valence as compared to neutral valence in both men and women.

Table 6.4. Late Positivity:
Post hoc comparisons for the WORD by PROSODY by SEX interaction

	Female Participants	Male Participants
WORD*PROSODY	$F_{4,120} = 8.15, p < .0001$	$F_{4,120} = 3.14, p < .05$
Happy Prosody	$F_{2,60} = 18.05, p < .0001$	$F_{2,60} = 13.05, p < .0001$
neu-neg	$F_{1,30} = 3.84, p = .059$	$F_{1,30} = 19.05, p < .001$
pos-neg	$F_{1,30} = 18.44, p < .001$	$p > .1$
pos-neu	$F_{1,30} = 32.37, p < .0001$	$F_{1,30} = 15.21, p < .001$
Neutral Prosody	$F_{2,60} = 10.33, p < .001$	$F_{2,60} = 12.49, p < .0001$
neu-neg	$F_{1,30} = 8.97, p < .01$	$F_{1,30} = 5.48, p < .03$
pos-neg	$p > .1$	$F_{1,30} = 9.98, p < .01$
pos-neu	$F_{1,30} = 21.23, p < .0001$	$F_{1,30} = 19.09, p < .0001$
Angry Prosody	$F_{2,60} = 16.84, p < .0001$	$F_{2,60} = 5.25, p < .01$
neu-neg	$F_{1,30} = 30.35, p < .0001$	$F_{1,30} = 9.84, p < .01$
pos-neg	$F_{1,30} = 19.0, p < .001$	$F_{1,30} = 4.63, p = .039$
pos-neu	$F_{1,30} = 3.77, p = .062$	$p > .1$

Additionally, the WORD*PROSODY interaction was modified by ROI and TASK (WORD*PROSODY*ROI*TASK, $F_{12,720} = 2.21$, $p < .05$; prosodic task, $F_{12,720} = 1.98$, $p < .05$; semantic task, $F_{12,720} = 2.71$, $p < .01$). For the prosodic task this interaction was smaller and reached significance at anterior regions only, whereas for the semantic task it was significant at anterior and posterior regions (Fig. 6.8). As the post hoc comparisons added no relevant information to the results described in the preceding paragraph, they are presented in Appendix 2 rather than here (Table A2.2, Fig. A2.1 and A2.2).

Again, prosodic processing differed with respect to gender (PROSODY*ROI*SEX, $F_{6,360} = 2.56$, $p < .05$). For the late positivity, prosodic effects had a broader scalp distribution in men ($F_{6,180} = 7.43$, $p < .0001$) than in women ($F_{6,180} = 5.29$, $p < .0001$). In men, there was a main effect of PROSODY at right-anterior ($F_{2,60} = 8.51$, $p < .001$), right-posterior ($F_{2,60} = 8.71$, $p < .001$) and left-posterior regions ($F_{2,60} = 9.44$, $p < .001$). In contrast, women showed a significant PROSODY effect only at right-anterior regions ($F_{2,60} = 3.75$, $p < .05$). Post hoc comparisons indicated that the anterior effect was caused by a larger positivity in response to neutral as compared to happy and angry prosody (men, neu-pos, $F_{1,30} = 17.36$, $p < .001$; women, neu-pos, $F_{1,30} = 4.73$, $p = .037$; men, neu-neg, $F_{1,30} = 10.25$, $p < .01$; women, neu-neg, $F_{1,30} = 5.38$, $p < .03$; pos-neg, $p > .1$). At posterior sites, neutral prosody did not differ significantly from happy prosody ($p > .1$); both elicited a larger positivity than angry prosody (pl, neu-neg, $F_{1,30} = 15.84$, $p < .001$; pr, neu-neg, $F_{1,30} = 14.66$, $p < .001$; pl, pos-neg, $F_{1,30} = 7.23$, $p < .03$; pr, pos-neg, $F_{1,30} = 5.07$, $p = .032$; Fig. 6.5).

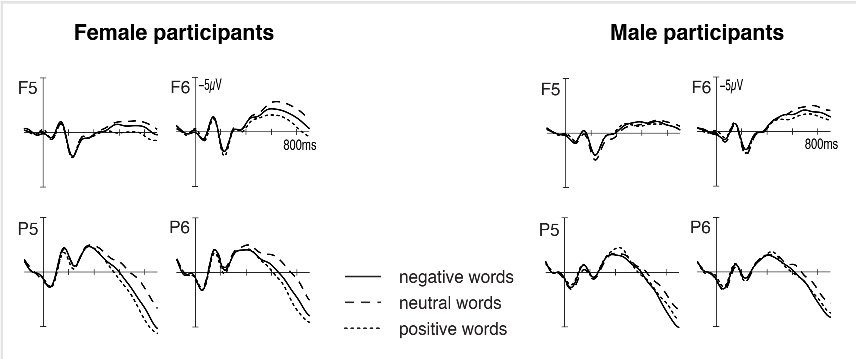

Figure 6.9. ERPs time locked to target onset for negative, neutral, and positive words spoken by the male speaker. The word valence effect for the late positivity was larger in women than in men.

Finally, men and women differed in the processing of word valence dependent on whether words were produced by a male or a female speaker (WORD*SEX*VOICE, $F_{2,120} = 3.86$, $p < .05$; female voice, $p > .1$; male voice, $F_{2,60} = 3.89$, $p < .05$). While listening to the male speaker, word valence effects were somewhat stronger in women

($F_{2,30}$ = 13.15, $p < .0001$) than in men ($F_{2,30}$ = 8.99, $p < .001$; Fig. 6.9). Nevertheless, both men and women showed a smaller positivity to neutral words as compared to positive (man, $F_{1,15}$ = 7.42, $p < .03$, women, $F_{1,15}$ = 20.71, $p < .001$) and negative words (man, $F_{1,15}$ = 15.09, $p < .01$, women, $F_{1,15}$ = 9.23, $p < .01$). Furthermore, women, but not men, showed a tendentially smaller positivity to negative as compared to positive words (man, $p > .1$, women, $F_{1,15}$ = 5.16, $p = .038$). Additionally, it was of interest to determine whether this speaker dependent sex difference resulted from men showing smaller or women showing larger semantic effects when listening to a male as compared to a female voice. Therefore, the WORD*SEX*VOICE interaction was analyzed again looking at the WORD*VOICE interaction in male and female participants. This analysis indicated no significant processing differences depending on the speaker's sex in female listeners ($p > .1$). Male listeners, however, showed a weak tendency toward different processing of words produced by a male as compared to a female speaker ($F_{2,60}$ = 2.4, $p = .099$).

To summarize, ERPs revealed an interaction between prosodic and word valence processing. ERPs were more negative to incongruous trials as compared to congruous trials for the N400 and a late positivity. While the N400 effect was present only in female participants, the late positivity effect was present in both sexes. Moreover, this later effect was stronger during the semantic than during the prosodic task.

Additionally, ERPs revealed sex differences in the time course of prosodic processing. Women showed a differentiation between the three prosodic conditions in the P200; processing differences were strongest during the N400 time window and declined for the late positivity. In contrast, the prosodic effect in men started within the N400 time range and was strongest for the late positivity.

The time course of semantic processing was comparable between men and women. Word valence modulated the P200, the N400, and the late positivity. The task determined onset and morphology of word valence effects. Furthermore, when listening to a male speaker, word valence effects were more pronounced in women than in men.

6.4 Discussion

The present study investigated whether emotional prosody or word valence dominates an emotional judgment. Furthermore, it examined whether men and women differ in their use of prosodic and semantic information for emotional comprehension. There was no such evidence in the behavioral data. Although men were about 100 ms slower than women, they showed a similar interaction between word valence and emotional prosody. Both responded faster and more accurately to positive and negative words when prosodic information was congruent as compared to incongruent. Moreover, this effect was stronger and more consistent when participants judged the emotional valence of a word as compared to emotional prosody.

In contrast to emotional words, neutral words elicited a somewhat unexpected response pattern. During the semantic task, they were responded to slower than positive and negative words regardless of prosody. There are at least two possible causes of this effect. First, one could imagine a general processing advantage for emotional as compared to neutral stimuli because they are of higher significance to the individual (Kayser et al., 2000). However, with regard to the present study an alternative explanation seems more plausible. As reaction time differences between neutral and emotional words were apparent during the semantic, but not during the prosodic task they might be due to instruction. Moreover, an emotional judgment of emotional words might be performed faster as strong and non-ambiguous emotional associations are more readily available. In contrast, neutral words, such as ‘parked’, may elicit weak positive and negative associations. For example, a parking spot may be something good, whereas a parking ticket is undoubtedly something bad. Therefore, reaction times may simply reflect longer decisions for neutral as compared to emotional items. In contrast, accuracy during the semantic task revealed an emotional Stroop effect also for neutral words: participants responded more accurately to neutral words with neutral prosody as compared to neutral words with happy or angry prosody. There was no such effect in accuracy for the prosodic task.

Together with the overall longer reaction times and lower accuracy for the semantic as compared to the prosodic task, the behavioral data suggest that prosody dominates an emotional judgment more than word valence. This interpretation receives further support from the ERPs as they showed a stronger prosody-semantics interaction with a broader scalp distribution for the semantic than for the prosodic task.

A second hypothesis concerned the time course of the interaction between prosodic and semantic information. The ERPs suggest an earlier onset in women than in men. Female but not male participants showed a larger N400 to happily and angrily spoken words when word valence was incongruous as compared to congruous. Similar findings have been reported for the classic word-color Stroop task (Liotti, Woldorff, Perez, & Mayberg, 2000; Rebai, Bernard, & Lannou, 1997; West & Alain, 1999). As the N400 is known to reflect semantic processing (Kutas & Hillyard, 1980), it is reasonable to argue that emotional prosody and word valence interact in women during a semantic processing stage.

Men showed a later onset of the prosody-semantics interaction. A late positivity measured between 600 and 900 ms following word onset was larger for emotionally spoken words with congruous as compared to incongruous word valence. Furthermore, neutrally spoken words elicited a larger positivity when word valence was positive or negative as compared to neutral. These effects were smaller in men than in women and differed somewhat with respect to the task. The semantic task elicited a stronger and spatially more distributed prosody-semantics interaction than the prosodic task. In contrast to the N400 effect, the functional significance of this late positivity effect is less clear.

It may be modulated by response related processes. DeSoto and colleagues (2001) showed that response preparation can be influenced by incongruous information. They presented the words 'above' and 'below' above and below a fixation cross. Participants indicated either the meaning or the position of a word by pressing one of two buttons on a response box. Optical imaging measures indicated that for incongruent trials (e.g., the word 'above' presented below the fixation cross) the motor cortex for both the correct and the incorrect response was activated. This activation started to develop approximately 200 ms prior to the behavioral response. Given these findings, it seems plausible that also an emotional Stroop experiment might elicit interference at an output stage. Moreover, the response latencies for the prosodic task coincided with the late ERP Stroop effect. The semantic task, however, elicited responses that lagged more than 200 ms behind the prosody-semantics interaction in the ERP. Therefore, it seems unlikely that the late positivity for the semantic task reflects response processes. Furthermore, to my knowledge, none of the ERP studies using a Stroop-like interference task reported a direct ERP correlate for response interference (Liotti et al., 2000; McCarthy & Donchin, 1981; Rebai et al., 1997; West & Alain, 1999; for an indirect measure – the lateralized readiness potential - see Dehaene et al., 1998). Given that the emotional Stroop effect for the late positivity closely resembles the preceding N400 Stroop effect, the present data more strongly suggest that it might be modulated by late semantic processes that interact with prosody.

Taken together, the present data indicate that prosody and semantics interact during intermediate processing prior to response preparation in both men and women. This intermediate stage comprises semantic processes that are influenced by emotional prosody: semantic processing is facilitated when prosody and word meaning are congruent as compared to incongruent. In women, this interaction starts 300 ms earlier and is more salient than in men.

A further interesting finding that might be correlated with the earlier onset of the prosody-semantics interaction in women is the sex difference in time course and strength of prosodic processing. Women showed prosodic effects already for the P200, whereas prosodic processing in men showed for the following N400 component. Furthermore, the prosodic N400 effect – that is the larger N400 in response to neutrally as compared to emotionally spoken words – was stronger and had a broader scalp distribution in women than in men. This suggests the following: First, women access emotional-prosodic information earlier and perhaps more automatically than men. Second, the earlier and stronger effect that prosody has in women might trigger an earlier interaction with semantic information. Therefore, the observed sex differences in the time course of the prosody-semantics interaction may have resulted from a higher significance of emotional prosody for female as compared to male speech comprehension.

The early prosodic effect in women also revealed insights into the functional significance of the P200. It has been argued that the P200 is an exogenous component because it reflects sensory stimulus aspects (Kotz et al. 2000; Ritter et al. 1983). As the prosodic effect in the present study may have been modulated by acoustic or emotional differences between the three prosodic conditions, it neither supports nor contradicts this assumption. However, the present findings strongly suggest that the P200 is sensitive to the significance information has for further processing. That the P200 differentiated between the three word valence conditions only when semantic information was in the focus of the task provides further support for this interpretation. As for the prosodic effect, however, it remains unclear whether it was caused by acoustic stimulus properties or an early access to word valence.

Finally, it was examined whether the speaker's sex affects the time course of the prosody-semantics interaction in men and women differently. However, this does not seem to be the case as the reported sex differences were comparable for the male and the female speaker. Rather, the speaker's sex modulated the processing of word valence only. When listening to a male speaker, men showed a smaller effect of word valence during the time window of the late positivity than women did. Research on communication between same and mixed-gender dyads provides a speculative account of this finding. It has been shown that males are less aggressive, more prosocial, and cooperative when interacting with females as compared to males (Leaper, 1991; Strough & Diriwächter, 2000). In line with this, one might assume that men are also more sensitive to the emotions communicated by women than by men. However, the speaker dependent word valence effect for males was only marginally significant and the sex difference in word valence processing reported for the male speaker may not be representative. Moreover, because the interpretation of this effect is post-hoc and rather speculative it must be replicated and investigated in more detail.

Although this experiment does answer the questions raised in the Introduction, some aspects deserve critical consideration. First of all, it is not clear whether the reported Stroop effects result from inhibition or facilitation. The neutral match condition, which was intended to serve as a baseline, elicited similar reaction times as the positive and the negative mismatch condition. This might give rise to the view that congruent emotional prosody facilitated processing whereas incongruent emotional prosody did not add any additional processing costs. However, this conclusion may not be appropriate because neutral words, regardless of prosody, elicited longer reaction times and a larger N400 in the ERP than emotional words. This suggests that participants put more effort into the processing of neutral as compared to emotional stimuli. Therefore, neutral words may not have established a solid baseline for the distinction between facilitation and inhibition effects.

A second problem that one has to keep in mind is that the present study could not sufficiently control the time course of prosodic and semantic processing. It remains unclear when during processing participants completely identified the emotional meaning of word prosody and word content. It is possible that access to emotional prosody is completed prior to semantic access. Moreover, the stronger influence of prosody as compared to semantics on an emotional judgment may result from a prosodic head start. If we could process the meaning of a word first, then perhaps prosody would not have a chance to interfere. That the relative timing of information processing affects Stroop interference is documented in the literature (Glaser & Glaser, 1982; Lu & Proctor, 2001). Glaser and Glaser (1982), for example, demonstrated that when color information precedes word information in the word-color Stroop task then interference is stronger as compared to simultaneous presentation. Therefore, the relative timing of information processing is indeed a serious concern regarding the automaticity of prosodic and semantic processing and requires further investigation. However, two arguments can be made. First, it seems men started semantic processing prior to prosodic processing during the semantic task. Nevertheless, their behavioral judgment was heavily influenced by emotional prosody. Second, this work should investigate emotional speech as it occurs in everyday communication. There, words do not precede prosody. In contrast, words are usually embedded in longer utterances and prosody has even more time to influence emotional comprehension. Therefore, the present results suggest that emotional prosody dominates the comprehension of emotions in speech.

CHAPTER 7: GENERAL DISCUSSION

The major objective of this dissertation was to investigate the role of emotional prosody in the communication of emotions in speech. One question was whether the influence of emotional prosody on word processing resembles effects of semantic context. The results of several cross-modal priming experiments suggest that this is indeed the case. Words that fit into the emotional-prosodic context are processed more easily as compared to words that do not fit. This emotional-prosodic context effect is reflected in smaller N400 amplitudes and faster responses to congruous as compared to incongruous words. Therefore, it seems that emotional prosody affects word processing in a similar time window and with similar consequences as semantic context. However, this work also reveals differences between prosodic and semantic priming effects. For example, whether or not the emotional prosody of the prime modulates word processing depends on the ISI, on the attention that is addressed to the prime's prosody, and on the listener's sex. Moreover, when asked to merely perform a lexical decision on the target, women show prosodic priming with a short and men with a long ISI. When asked to indicate the emotional congruity between prime prosody and target valence, both men and women show prosodic priming with a short and a long ISI. These findings have been interpreted as reflecting task-strategic differences between men and women (see Chapter 5.7). It has been argued that women allocate more attention to the prime's prosody than men during the lexical decision task and therefore show an earlier interaction (i.e., with a shorter ISI) between prosody and word valence. Forcing men to allocate similar attention to the prime as women eliminates sex differences. However, the results from the emotional Stroop experiment suggest an alternative explanation.

The emotional Stroop experiment was designed to answer the question whether word meaning or emotional prosody dominates an emotional judgment. The results suggest that emotional-prosodic information is processed more automatically and affects an emotional judgment more strongly than word valence in both sexes. However, differences between men and women were apparent for the time course and the intensity of prosodic processing. Women showed an earlier and stronger differentiation between emotional and neutral prosody in the ERPs than men. Furthermore, emotional speech elicited an earlier prosody-semantics interaction in women than in men. In contrast to the cross-modal priming experiments, the temporal difference in the onset of prosodic effects between men and women in the emotional Stroop experiment can hardly be explained by strategy. Both were instructed to ignore either prosodic or semantic information. Moreover, in order to perform the task correctly, participants were forced to focus on task relevant information only. Therefore, one can conclude that prosody is of higher significance in women than in men. However, the role prosody has for female emotional comprehension does not seem to be under conscious control. Women cannot disregard prosody. Interestingly, the same is true for men as they were also influenced by prosody when judging the emotional meaning of a word. However, this influence occured later and was less salient than in women, suggesting that prosody is of less importance for male than for female speech comprehension. Given the emotional Stroop findings, one might want to reconsider the interpretation of the cross-modal priming results. Rather than different strategies, they may reflect a different time course for the prosody-semantics interaction in men and women when they do not consciously attend to emotional prosody.

A further objective of this dissertation was to determine whether sex differences reported for emotional tasks (Hall, 1978; Rotter & Rotter, 1988; Sutton & Davidson, 2000) result from quantitative or qualitative processing differences. In other words, do women perform slightly better than men in the recognition of emotions because they are more sensitive to emotional aspects of communication or because they rely on different processing mechanisms? The cross-modal priming and emotional Stroop experiments indicate that women rely earlier on prosodic information during emotional comprehension than men do. Moreover, emotional prosody has an earlier and stronger influence on the processing of word meaning. However, if words are presented without prosodic information, valence processing in men and women is comparable. Therefore, one can conclude that sex differences in emotional comprehension are quantitative as well as qualitative in nature. They are quantitative – because the influence of emotional prosody on word processing is stronger in women than in men. They are qualitative – because the onset of prosodic effects and the prosody-semantics interaction occur earlier in women than in men. Interestingly, however, the present experiments failed to reveal a superior female performance in emotional recognition other than the reaction time advantage in the emotional Stroop task. This may be explained by the sample size. Hall (1978) in her survey of emotion recognition studies mentioned an average effect size of Cohen's d = 0.4. If we assume a similar effect size for the emotional tasks presented here and an estimated power of 0.8, it would take a sample size of approximately 80 to obtain gender differences in accuracy. However, this may be an underestimation if the present tasks were easier than in the studies surveyed by Hall. Taken together, the chances were low to obtain performance differences between men and women. On the other hand, this work nicely demonstrates that sometimes ERPs are more sensitive than behavioral measures to cognitive processes.

What do the present findings contribute to the understanding of word processing and the role of emotional prosody? In the literature, word processing is thought to consist of three stages: lexical access, selection, and integration (e.g., Swinney, 1979; Zwisterlood, 1998). During lexical access, the acoustical input activates word entries in the mental lexicon. According to the Cohort model proposed by Marslen-Wilson (1984), the initial set of activated word candidates gets smaller as more acoustic information becomes available. Finally, if the auditory input is sufficient to correctly identify a word, the appropriate word candidate is selected and integrated in the preceding sentence context. There is still an ongoing debate as to what word processing stage the N400 might reflect. While many researchers view the N400 as a marker for contextual integration (Besson & Kutas, 1993; Brown & Hagoort, 1993; Hinojosa, Martin-Loeches, & Rubia, 2001; Holcomb, 1993; Van Petten, Coulson, Rubin, Plante, Parks, 1999) others argue that it is sensitive to lexical access (Deacon et al., 2000; Kiefer, 2002; Kutas & Van Petten, 1988). These interpretations are not necessarily exclusive as it is possible that, depending on methodological aspects such as task and modality, the N400 may reflect access, integration or both.

That the task is likely to affect the nature and timing of word processing is demonstrated by the results from the emotional Stroop experiment. A semantic instruction triggers an earlier onset of semantic effects in the ERPs than does a prosodic instruction. Therefore, during the semantic task, processing might progress further within 400 ms poststimulus onset than during the prosodic task. Moreover, the N400 elicited during the semantic task may reflect later processes than the N400 elicited for the prosodic task. Furthermore, modality should be taken into account when studying the functional role of the N400. Based on the results of a visual word recognition study, Sereno, Rayner, and Posner (1998) restrict the time range of lexical access to approximately 150 ms following word onset. Hinojosa et al. (2001) mention a similar time range of 80 to 200 ms during which a lexical entry gets activated in the mental lexicon. According to this, lexical access is already completed before an N400 component is elicited in the ERP signal. However, these conclusions have been drawn on the basis of reading experiments. Acoustical analysis of the stimulus material used in the present study suggests that a 200 ms time frame for lexical access is an underestimation with regard to spoken word recognition where words unfold in time. The stimulus material consisted of inflected German verbs that started with a pre-syllable that did not predict the meaning of the following word stem (e.g., 'ge' in 'geliebt', 'gekannt'; loved, known). This pre-syllable had a mean length of 220 ms (sd 50 ms). Consequently, lexical access could not be accomplished within 200 ms as proposed by Sereno et al. (1998) and Hinojosa et al. (2001).

Given the acoustic properties of the emotional Stroop material, there are at least two possible accounts for the N400 effect in female participants. First, women might start integration before lexical access is completed. They might match the emotional valence of multiple word candidates against the emotional prosody of the speech input. Emotional prosody may not influence the activation of lexical access candidates. Rather, prosody serves as context information for the interpretation of a word's emotional meaning. An alternative explanation is that the N400 effect in women reflects an influence of emotional prosody on lexical access. Emotionally congruous candidates might receive additional activation from prosody and therefore succeed earlier in selection than incongruous candidates. To decide between both accounts, one might consider the proposed nature of access and integration. Despite the instruction to ignore task-irrelevant information, women showed a prosody-semantics interaction for the N400. This suggests that the underlying process was stimulus driven and not subject to cognitive control. As lexical access, but not integration, is a candidate for such a process (Brown & Hagoort, 1993; Chwilla, Kolk, & Mulder, 2000; Frauenfelder & Floccia, 1998; Soto-Faraco & Sebastian-Galles, & Cutler, 2001) one might take the present findings as evidence that in women emotional prosody modulates lexical access.

However, this interpretation is challenged by the finding of a prosody-semantics interaction for a later time window of 600 to 900 ms in both men and women. Given a mean word length of 853 ms (sd 62 ms), it seems likely that at this point in time lexical access has been completed and the correct meaning of a word is available to the listener. Moreover, if this latter effect reflects post-lexical semantic processing, which is assumed to be under the subjects' control, why were they unable to avoid being influenced by prosody? Again there are at least two possible explanations. First, the late time window may not reflect semantic processing but response preparation. However, this interpretation has been rejected for several reasons (see Chapter 6.4). For example, the temporal gap between the late positivity time window and the behavioral response in the semantic task seems too large to account for response processes. Therefore, a second explanation seems more appropriate. The late positivity may indeed reflect late semantic processing such as the integration of a word's meaning into the prosodic context. This, however, requires a reconsideration of the nature of integration. According to the assumption that there is a continuum of automaticity (MacLeod & MacDonald, 2000), integration might be a process that is *less* automatized than lexical access rather than non-automatic. Depending on the presentation modus and context type, participants may be more or less able to prevent integration processes. In an emotional Stroop experiment, listeners might reduce but not eliminate such effects. However, if we assume that integration is not completely under the listener's control, then again it is not clear what the N400 effect in women reflects: access, integration, or both.

Although the present data do not unequivocally account for the functional significance of emotional prosody during word processing they provide evidence that women use emotional prosody earlier and more automatically during word processing than men. To fully understand the influence of emotional prosody on male and female speech comprehension, future research must specify the cognitive processes that elicit and modulate the N400. Moreover, we need to gain a better knowledge of the word processing stages, their temporal structure, and their susceptibility to cognitive control.

However, this work leads to other interesting questions. For example, one might ask why women rely on prosodic information earlier than men. Closely related is the question why women recognize non-verbal cues more accurately then men (Hall, 1978). Hall (see also Kimura, 1999) suggests a genetic account. She argues that women with a better innate understanding of non-verbal emotional signals are better able to satisfy the needs of their offspring. In ancient human history, this might have secured survival and the genes responsible for emotional comprehension would have been passed along. However, there are alternative explanations. There are some studies that suggest a relationship between socialization and emotional comprehension (Brown & Dunn, 1996; Cervantes & Callanan, 1998). Perhaps during childhood girls are more strongly encouraged than boys to detect and interpret emotional signals from others. Socialization might affect a child's language development and modulate the brain mechanisms that underlie emotional speech processing.

A further question relates to the time course of emotional-prosodic influences on word processing and whether they depend on the amount of prosodic context available. It would be interesting to modify the emotional Stroop experiment so that congruous and incongruous words are embedded in a semantically neutral sentence context. Perhaps men make earlier use of emotional prosody when it has been completely processed before the critical word is presented. There are many other relevant questions that should be tackled in the future. Do men and women differ in the interaction of emotional information from other sources such as mimic and gesture as well? Do women still show a temporal advantage in the use of prosody when it carries non-emotional but linguistic information? What are the brain structures that mediate emotional speech comprehension in men and women? An fMRI investigation could be conducted to determine whether sex differences in lateralization contributed to the present findings. Further questions arise concerning the developmental aspect of the reported sex differences. It would be interesting to determine when they emerge during development and whether they still exist after women enter menopause?

Beside various open questions, the present work reveals evidence for an interaction between emotional prosody and semantics during speech processing. It indicates that prosody can influence the processing of words and that the emotion carried by prosody is of higher significance for emotional comprehension than word valence.

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APPENDIX 1

The following text describes the construction of the stimulus material for the cross-modal priming experiments (Experiment 1 to 4).

One-hundred and sixty-nine sentences were constructed that carried an emotionally ambiguous word (e.g., exam) in sentence final position. Although the sentences itself should be of emotionally neutral valence, they should elicit positive or negative associations depending on whether they were spoken with a happy or sad prosody. In order to be able to control for the onset of semantic priming effects, the sentence final word should not be predictable by preceding context. To ensure this, all sentences were presented without the final word to 15 participants (6 male) on a questionnaire. Participants should write down a word that would make an expected sentence completion. Sentences that were completed with the original or to those semantically related words were modified so that they would be less predictable. Following this modification, critical sentences were again presented to 15 participants (7 male). Nine sentences had to be excluded from the stimulus material because one or more participants produced the original or a semantically related sentence completion.

Five female speakers were invited to read 50 of those sentences once with a happy and once with a sad intonation. One speaker was trained as an actor, one was a professional radio speaker, one was a singer and two were untrained speakers. Sentence production was recorded and presented to 5 male and 5 female naive listeners. They heard each sentence over speakers and should rate the emotionality of the speakers voice on a 5-point scale that ranged from -2 for very sad to +2 for very happy. Participants pressed one of six buttons to indicate their judgment. The sixth button was assigned to sentences for which none of the preceding emotional categories was appropriate (e.g., when it sounded angry). Table A1.1 lists mean emotional judgments for sentences that were meant to be happy and sentences that were meant to be sad for each of the 5 speakers.

Table A1.1. Emotional Rating of Sentence Prosody

Emotional Prosody	Speaker 1	Speaker 2	Speaker 3	Speaker 4	Speaker 5
Happy	0.99 (sd 0.36)	0.44 (sd 0.31)	0.77 (sd 0.31)	0.68 (sd 0.36)	1.02 (sd 0.41)
Sad	-1.47 (sd 0.18)	-0.28 (sd 0.2)	-0.76 (sd 0.18)	-0.70 (sd 0.17)	-1.16 (sd 0.34)

Speaker 1 and 5 were reinvited to read all 160 sentences once with a happy and once with a sad intonation. Again sentences were recorded and presented to 3 male and 3 female naive listeners. The listeners should indicate the emotion conveyed in a speaker’s voice per button press. This rating revealed an overall better recognition of emotional prosody for speaker 1 (happy: 1.53; sad: -0.85) as compared to speaker 2 (happy: 0.45; sad: -1.18). Therefore, sentences produced by speaker 1 (the singer) were selected for the following experiments.

Twenty-three naive listeners (11 male) were invited to participate in an association experiment. They heard each sentence produced by speaker 1 over speakers. Following sentence offset listeners had to name 3 nouns that first came to mind. The speech production was recorded on tape. Four participants (1 male) had to be excluded from the data analysis because they had difficulties performing the task. They often thought of only one or two words and repeated associations across different sentences and intonations. The speech production of the remaining subjects was analyzed for each sentence separately. Out of 160 sentences 50 were selected to serve as primes in Experiment 1 to 4. Those 50 sentences elicited different (i.e., positive and negative) associations depending on sentence prosody. Furthermore, there was at least one word (e.g., success) or a group of closely associated words (e.g., victory, prize) to each of those 50 sentences that was produced by more than 4 participants. This word or an associate was selected as the prosodically related target word. On average positive target words were produced by 24 percent of the participants and negative target words by 22.6 percent of the participants.

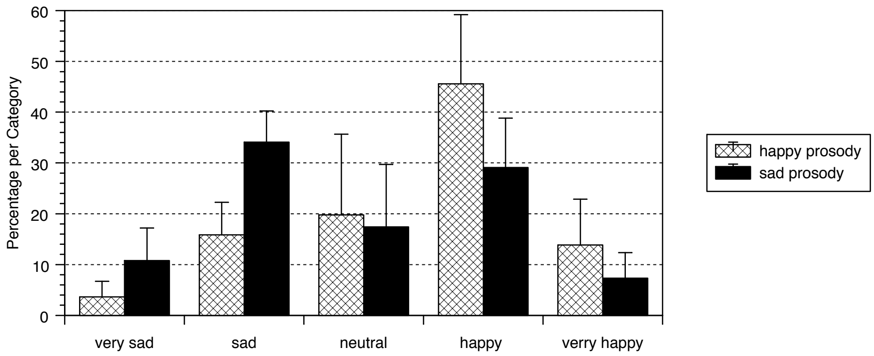

Figure A1.1. Emotional valence rating for words produced in response to the selected prime sentences. The figure illustrates how many words elicited following a happily (red) or sadly (blue) spoken sentence were classified as very negative, negative, neutral, positive, and very positive. While both prosodic conditions produced an equal number of neutral words, happy and sad prosody differed in the amount of positive and negative words they elicited.

In a further study all the associations produced to the 50 prime sentences were rated for emotional valence. Sixteen participants (8 male) were invited to perform the rating. They saw 820 words presented on a computer screen in front of them. Following each word they had to indicate on a 5-point scale whether the word was very positive (+2), positive (+1), neutral (0), negative (-1) or very negative (-2). Responses were given by pressing one out of 5 buttons on a response box. Figure A1.1 illustrates the results. Associations produced in response to happily and angrily spoken sentences were rated as positive (0.51, sd 0.27) and negative (-0.12, sd 0.16), respectively. Furthermore, valence scores for both word classes differed significantly from 0 (positive associations: t_{15} = 7.4, p < .0001; negative associations: t_{15} = -2.91, p < .05). An additional analysis was carried out for target words only. However, only 98 words were included as one prime sentence was excluded from the stimulus material because of ethical concerns. Both positive and negative targets differed significantly from 0 (positive targets: $t_{15} = 5.82$, $p < .0001$; negative targets: $t_{15} = -5.18$, $p < .0001$). Furthermore, absolute valence was comparable (mean positive targets: 0.61, sd 0.77; mean negative targets: -0.59, sd 0.82; $t_{15} = 0.14$).

Finally, a questionnaire was constructed that listed all prime sentences. Nine male and 11 female participants rated each sentence on a 5-point scale that ranged from very positive to very negative. Prime sentences were rated as emotionally neutral (0.07, sd 0.69). Moreover, the obtained valence scores differed not significantly from 0 ($t_{19} = 0.72$).

Table A1.2. Stimulus Material – Experimental Trials

ID	Prime Sentence	Positive Target	Negative Target
1	Sie erzählte mir von ihrer Wette.	Gewinn	Verlust
2	Ich komme gerade vom Essen.	Geschmack	Übelkeit
3	Sie nahmen das Flugzeug.	Urlaub	Absturz
4	Plötzlich hörte sie den Hund.	Freude	Angst
5	Er suchte nach einem Weg.	Hoffnung	Verzweiflung
6	Sie sprach von ihrer Zukunft.	Zuversicht	Ungewißheit
7	Wir haben schon seit langem das selbe Wetter.	Sonne	Regen
8	In kurzer Zeit bekamen wir eine hohe Geschwindigkeit.	Spaß	Unfall
9	Sie sprachen über mein Aussehen.	Zufriedenheit	Unzufriedenheit
10	Zum ersten mal bekam ich eine Chance.	Begeisterung	Mißmut
11	Sie hatte sehr viele Fragen.	Neugier	Unwissenheit
12	Gestern erhielt ich eine Einladung	Freunde	Beerdigung
13	Sie hatte gestern Prüfung.	Können	Unsicherheit
14	Es erwartete ihn schon der Chef.	Beförderung	Rausschmiß
15	Am Freitag kam er zurück von seinem Wettkampf.	Sieg	Niederlage
16	Man sah ihre Tränen.	Glück	Trauer
17	Morgen habe ich Abschied.	Vorfreude	Traurigkeit
18	Heute endete unsere Gerichtsverhandlung.	Freispruch	Gefängnis
19	Erst seit wenigen Wochen hat mein Bruder sein Geschäft.	Erfolg	Mißerfolg
20	Mein Freund sprach letzte Woche mit seinem Arzt.	Heilung	Schmerzen
21	Damals entschieden sie sich für die Operation.	Genesung	Risiko
22	Er hatte Zeit für seine Bewährung.	Chance	Fehler
23	Das war alles ein Bluff.	Scherz	Ärger
24	Er war für sie ein Clown.	Zirkus	Enttäuschung
25	Sie berichtete er sei aus Stein.	Denkmal	Kälte
26	Er erzählte ihr von seiner Eifersucht.	Vertrauen	Streit
27	Er berichtete von seiner Entdeckung.	Stolz	Entsetzen
28	Nach einer Woche kam es zum Ende.	Arbeit	Beziehung

ID	Prime Sentence	Positive Target	Negative Target
29	Er sicherte sich ihrer durch eine Entführung.	Braut	Raub
30	Er sagte sie hätte eine große Phantasie.	Bewunderung	Eifersucht
31	Sie hatte in den letzten Wochen einen nicht unerheblichen Gewichtsverlust.	Diät	Krankheit
~~32~~	~~Sie verwendeten dafür Gas.~~	~~Heizung~~	~~Nazis~~
33	Er wußte, diesmal ging es um sein Herz.	Liebe	Operation
34	Sie hatten dieses Jahr eine andere Ernte.	Überschuß	Hunger
35	Gestern brachte er die Nachricht zum Pfarrer.	Hochzeit	Tod
36	Er betrachtete ihre Haut.	Schönheit	Flecke
37	Auf diesem Platz sah man das gesamte Volk.	Fest	Demonstration
38	Vom Fenster aus sah sie den Himmel.	Freiheit	Sehnsucht
39	Am Morgen hatte er eine Idee.	Frühstück	Problem
40	Man merkte es war wieder Herbst.	Kastanien	Depression
41	Schließlich fand er seine Knochen.	Hund	Grab
42	Sie sagten etwas zu seiner Kompetenz.	Wissen	Entlassung
43	Sie sammelten die Kräfte.	Sport	Kampf
44	Später saß er in einem Lokal.	Geselligkeit	Einsamkeit
45	Letzte Woche veranstalteten sie eine Parade.	Musik	Soldaten
46	Sie hatten eine lange Reise.	Ferien	Anstrengung
47	Sie machten daraus ein langes Ritual	Feier	Opfer
48	Das beeinflußte die Vegetation.	Wachstum	Schaden
49	Er gab ihr sein Vertrauen.	Verläßlichkeit	Mißbrauch
50	Über ihnen waren lauter Vögel	Möwen	Raben

Table A1.3. Stimulus Material – Filler Trials

	Filler Sentences	***Positive Targets*/ Pseudowords**	***Negative Targets*/ Pseudowords**
1	Die ganze Zeit hatte ich ein Ziel.	Vorwarrung	*Verirrung*
2	Diese Woche hatten wir Besuch	Zwong	*Zwang*
3	Gestern ging ich zur Arbeit.	Striß	*Streß*
4	Gestern war er beim Friseur.	Antstollung	*Entstellung*
5	Am Abend hörte sie eine Stimme.	Grasal	*Grusel*
6	Als sie aus der Tür kam, sah sie die Polizei.	*Rettung*	Rattung
7	Vom Waldrand aus sahen wir ein Feuer.	*Lagerfeuer*	Legerfauer
8	Er hatte dabei einen hohen Einsatz.	*Mut*	Mot
9	Das verursachte für sie eine Veränderung.	*Verbesserung*	Varbisserung
10	Er hatte eine Menge Erinnerungen.	*Album*	Olbim
11	Er antwortete mit einem Witz.	*Humor*	Himor
12	Sie betrachteten seine Kunst.	*Genie*	Gonei
13	Er wußte Bescheid über seine Möglichkeiten.	*Talent*	Tulint
14	Er erzählte ihr von seinem Leben.	*Abenteuer*	Ebentauer
15	Später machte er ihr ein Versprechen	*Verlobung*	Vorlabung
16	Sie erzählte von ihrem zu Hause.	Hiemweh	*Heimweh*
17	Er sprach von einem Ausweg.	Arrwog	*Irrweg*
18	Das war wieder ein Anfang.	Frastrution	*Frustration*
19	Er wollte unbedingt eine Lösung.	Storrsann	*Starrsinn*
20	Gestern bekam sie einen Rat.	Leuge	*Lüge*
21	Die ganze Zeit über hatten wir Schnee.	Biden	Bewartang
22	In den letzten Tagen hatten wir viel Regen.	Tollor	Bör
23	Auf der anderen Straßenseite war ein Restaurant.	Bedanging	Gewußhiet
24	Er kam frisch vom Land.	Hirazont	Sargericht
25	Er dachte an den Aufstieg.	Modchen	Gisecht
26	Gestern machte er einen Antrag.	Jogünd	Erwirtang
27	Letzte Woche hatten wir jeden Tag Sonne.	Angerichtigkeit	Wassen
28	Diese Woche ging ich das erste mal zur Fahrstunde.	Siche	Sai
29	Am Freitag hatte ich ein Vorstellungsgespräch.	Otalioner	Ontsutzen
30	Das hatte Auswirkungen auf mein Konto.	Heltlisigkeit	Tupferkat

	Filler Sentences	***Positive Targets*/ Pseudowords**	***Negative Targets*/ Pseudowords**
31	Letzten Samstag hatte ich Auftritt.	Funsternas	Schnaflöcken
32	Plötzlich war er umgeben von Licht.	Fonstarsams	Triffpankt
33	Sie sendet ihre Strahlen.	Kamo	Treum
34	Als wir ankamen, sahen wir die hohe Brandung.	Fuld	Gapfel
35	Als man ihn fragte, sprach er von Glauben	Palezei	Perspiktave
36	Sie gaben ihm Blut.	Schele	Ormeu
37	Er berührte ihn mit dem Schwert.	Rächtor	Beum
38	Er war ein richtiger Drache.	Masuk	Klosse
39	Am Abend fuhren sie zu einem See.	Lite	Foninzen
40	Er sagte, das sei sein Eigentum.	Verfohrang	Piblukum
41	Sie liefen zusammen in der Finsternis.	Glübe	Deumin
42	Gestern bekam er davon ein Foto.	Vorgabung	Rolegiösität
43	Letzte Woche erzählte ich von dem Geheimnis.	Strife	Gacht
44	Sie erkannte ihn an seinem Geruch.	Wäg	Bitrog
45	Damals brauchte ich Glück.	Straugat	Lechtquolle
46	Am Abend begannen die Wehen	Beggarse	Färno
47	Sie waren in großer Höhe.	Dime	Fimalie
48	Als sie ankamen spürten sie den Hunger.	Klastor	Odalle
49	Gestern war sie in einem Rausch.	Ulter	Trugodie
50	Gestern ging ich zum Zahnarzt.	Sogelschaff	Seu

APPENDIX 2

The following text describes the stimulus material for the emotional Stroop experiments.

Table A2.1. Stimulus Material

ID	Negative Words	Neutral Words	Positive Words
1	erkrankt	angeraten	geliebt
2	besetzt	zugekehrt	gepflegt
3	übersehen	durchgestellt	verdient
4	verzweifelt	angesagt	gewonnen
5	geschlachtet	hingewiesen	befördert
6	beleidigt	geworfen	besucht
7	gestreßt	angeschnallt	gelöst
8	bestochen	geklopft	gratuliert
9	benutzt	gepachtet	geblüht
10	geschieden	überschüttet	gepflanzt
11	verloren	befragt	angeregt
12	verlaufen	eingelassen	geehrt
13	bedauert	gesessen	geküßt
14	erzwungen	gebügelt	gelobt
15	getadelt	aufgeschaut	anerkannt
16	vergessen	gebadet	getanzt
17	verarmt	geordnet	geschmückt
18	entblößt	übertragen	vollendet
19	gehetzt	telefoniert	vereinigt

ID	Negative Words	Neutral Words	Positive Words
20	verbraucht	vorgelesen	unterhalten
21	geweint	gedüngt	angespornt
22	entstellt	angerufen	vertragen
23	getreten	angenommen	gewachsen
24	belogen	aufgehört	bestaunt
25	vertrocknet	berichtet	gesonnt
26	zertreten	verpackt	überwunden
27	verwelkt	gestopft	gefreut
28	gefeuert	zugetragen	zugezwinkert
29	vermißt	getrunken	massiert
30	behindert	verreist	aufgepaßt
31	entlassen	gesaugt	verlobt
32	gestraft	verspielt	entspannt
33	angesteckt	aufgezeichnet	befreit
34	gebrochen	ausgesagt	belesen
35	geschimpft	getragen	vertraut
36	ausgelacht	geschärft	umarmt
37	verschlossen	gestrichen	verbrüdert
38	überfüllt	abgesetzt	erholt
39	verzogen	verwaltet	befreundet
40	bekümmert	gebacken	verbunden
41	angezeigt	ermittelt	bewundert
42	gedrängt	verschönt	gejubelt
43	ertrunken	gezählt	geschwelgt
44	gelitten	angezogen	gefördert
45	verwirkt	befragt	geschlemmt
46	verpaßt	bestellt	gelacht
47	angewidert	gemäht	erheitert
48	geschlagen	gedeutet	gefeiert
49	gestoßen	getroffen	gelernt
50	gestört	gewandert	belustigt
51	befohlen	befolgt	überrascht
52	verworfen	gerufen	geholfen
53	gestohlen	verschoben	getraut
54	geschnitten	angehalten	geheilt
55	erkältet	gefolgt	gesiegt

ID	Negative Words	Neutral Words	Positive Words
56	angezündet	geblättert	geträumt
57	gefangen	verordnet	erklommen
58	verraten	verschickt	geerntet
59	geraubt	gesteckt	beeindruckt
60	betrogen	berechnet	gerettet
61	geärgert	dekliniert	zugehört
62	verhört	beschrieben	ausgeruht
63	ausgenutzt	ausgesprochen	gedankt
64	zerstört	zugestellt	gestaunt
65	beschnitten	gekannt	gebildet
66	ruiniert	geparkt	aufgeklärt
67	genötigt	erinnert	berufen
68	gestorben	verschrieben	unterstützt
69	gehaßt	gelöffelt	gestreichelt
70	abgewiesen	sortiert	genossen
71	bedroht	dargestellt	eingeladen
72	verbrannt	gegossen	vollbracht
73	erkauft	gekehrt	amüsiert
74	gelangweilt	transportiert	angefeuert

Eighty-eight negative, 100 neutral, and 81 positive inflected German verbs were generated. A questionnaire was constructed to control for emotional valence. This questionnaire was presented to 41 participants (23 female) who rated all words on a 5-point scale as very positive (+2), positive (+1), neutral (0), negative (-1) or very negative (-2). On the basis of valence scores and word frequency 74 positive, 74 neutral, and 74 negative words were selected to serve as stimulus material for the experiment. Negative words had a mean valence of -1.7 (sd 0.44), neutral words of 0.05 (sd 0.46), and positive words of 1.08 (sd 0.55). Word frequency did not differ significantly between the three word valence conditions (Celex, 1995). The speaker selected for the cross-modal priming experiments and a male actor produced all words with happy, neutral and angry prosody.

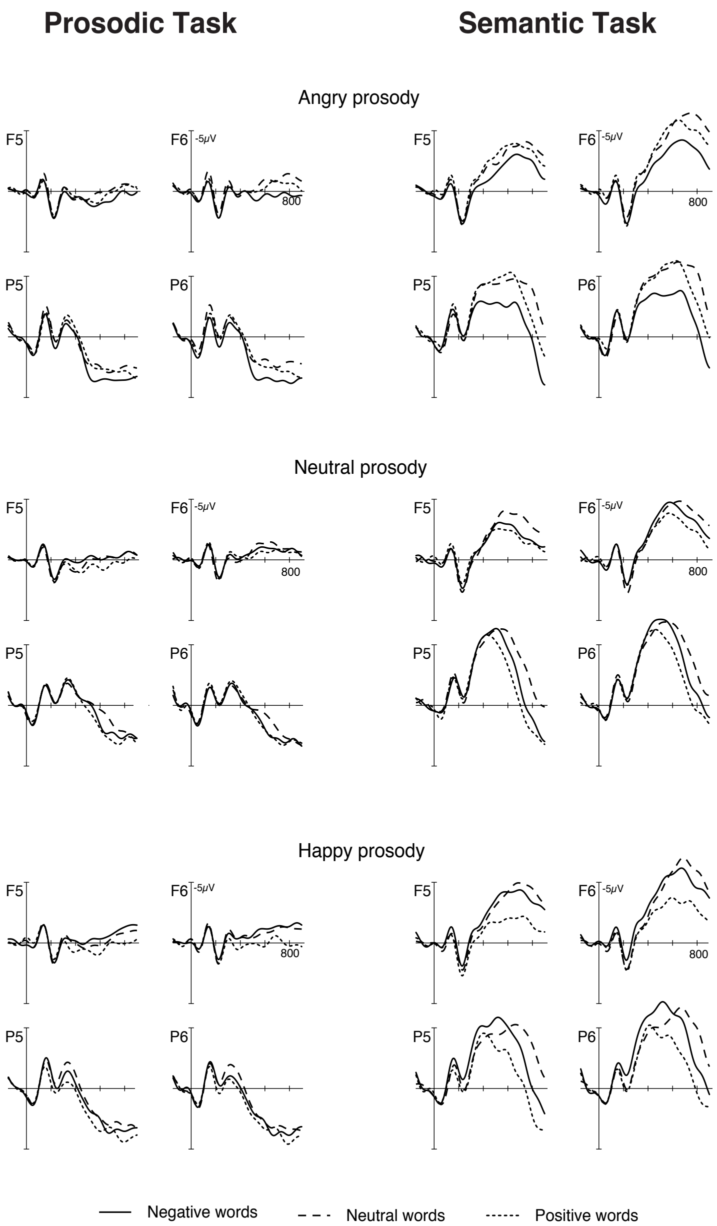

Figure A2.1. ERPs time locked to target onset for female participants.

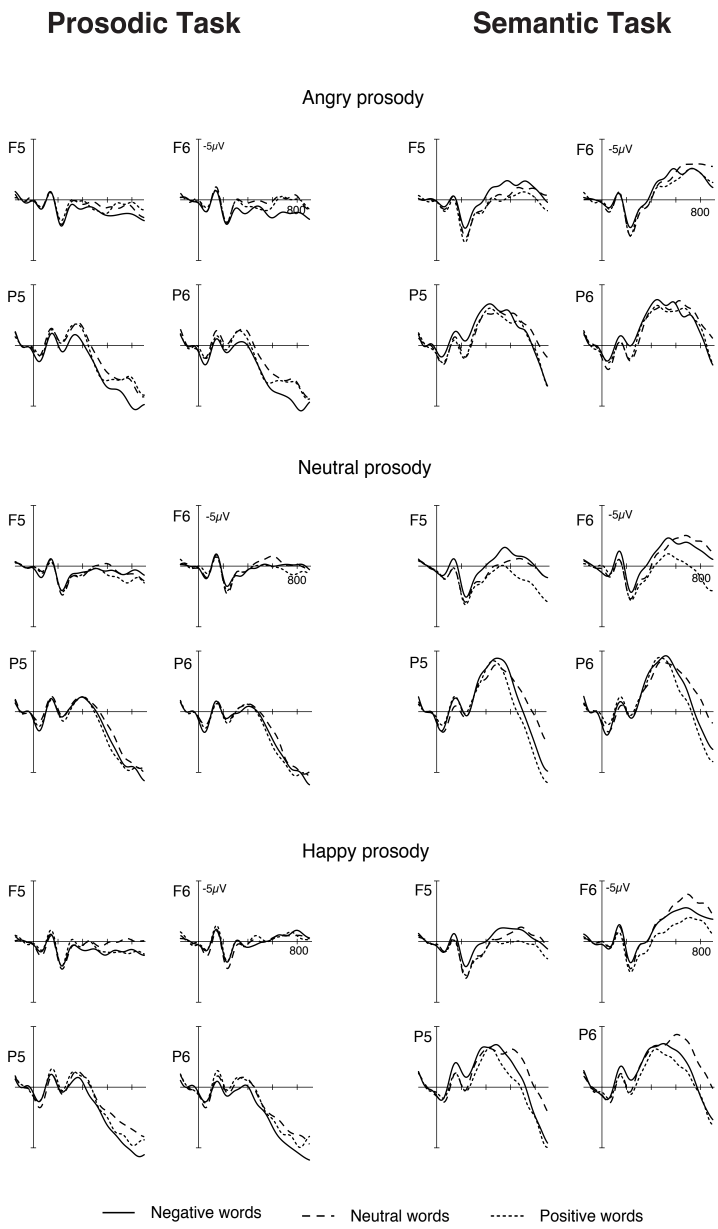

Figure A2.2. ERPs time locked to target onset for male participants.

Lebenslauf

Name:	Annett Schirmer
Geburtstag:	2. Februar 1975
Geburtsort:	Leipzig
Nationalität:	Deutsch

Schulbildung:

1981 – 1990	Besuch der 84. Polytechnischen Oberschule ‚Klement Gottwald' in Leipzig
1990 – 1993	Besuch des Max Klinger Gymnasiums in Leipzig
1993	Abitur

Studium:

1993 – 1994	Magisterstudium:Psychologie, Musikwissenschaft und Journalistik an der Universität Leipzig
1994 – 1999	Diplomstudium Psychologie an der Universität Leipzig
1999	Diplom in Psychologie

Wissenschaftlicher Werdegang:

Wintersemester 1996	Praktikum an der Tagesklinik für kognitive Neurologie in Leipzig
1997 – 1999	Studentische Hilfskraft am Max Planck Institut für neuropsychologische Forschung in Leipzig
1999 – 2002	Doktorand am Max Planck Institut für neuropsychologische Forschung in Leipzig

Bibliographische Beschreibung

Schirmer, Annett

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Die vorliegende Arbeit hatte zum Ziel, die Schnittstelle zwischen Wortvalenz und emotionaler Prosodie bei der Sprachverarbeitung zu untersuchen.

In einer Reihe von Priming-Experimenten konnte gezeigt werden, dass Wörter, die in ihrer emotionalen Bedeutung kongruent zur Satzprosodie sind, schnellere lexikalische Entscheidungen auslösen und eine kleinere N400 im Ereigniskorrelierten Potential (EKP) zeigen als inkongruente Wörter. Dieser prosodische Priming-Effekt ist jedoch abhängig vom Interstimulusintervall (ISI), vom Geschlecht der Probanden und von der auf die Satzprosodie gerichteten Aufmerksamkeit. War die Satzprosodie irrelevant für die Aufgabe, zeigten Frauen mit einem kurzen (200 ms) und Männer mit einem langen ISI (750 ms) prosodisches Priming. War die Satzprosodie jedoch aufgabenrelevant, zeigten beide Geschlechter unabhängig von der Länge des ISIs prosodisches Priming.

In einem emotionalen Stroop-Experiment hörten Probanden positive, neutrale und negative Wörter, die mit fröhlicher, neutraler oder ärgerlicher Prosodie gesprochen wurden. Stimmten Prosodie und Wortinhalt nicht überein, waren die Probanden langsamer und machten häufiger Fehler bei der Einschätzung der Wortvalenz als wenn beide Informationen übereinstimmten. Sollten die Probanden jedoch die Prosodie eines Wortes bewerten, störte ein inkongruenter Wortinhalt nur wenig. Unabhängig von der Aufgabe zeigte das EKP weiblicher Probanden frühere und stärkere Unterschiede in der Verarbeitung emotionaler und neutraler Prosodie verglichen mit dem EKP männlicher Probanden. Zudem spiegelte die N400 weiblicher Probanden

eine Interaktion zwischen Prosodie und Wortvalenz wider: die N400 war kleiner für kongruente als für inkongruente Wörter. Dieser Kongruenzeffekt dehnte sich bis auf eine nachfolgende Positivierung aus und war dort auch für männliche Probanden zu finden.

Die Ergebnisse dieser Arbeit zeigen, dass emotionale Prosodie in relativ flexibler Weise bei der Wortverarbeitung genutzt werden kann. Für die Verarbeitung von sprachlich geäußerten Gefühlen scheint die Prosodie von größerer Bedeutung zu sein als semantische Inhalte. Zudem reagieren Frauen früher und stärker auf prosodisch kommunizierte Informationen als Männer.

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