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Contextual influences of emotional speech prosody on face processing: How much is enough?

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The influence of emotional prosody on the evaluation of emotional facial expressions was investigated in an event-related brain potential (ERP) study using a priming paradigm, the facial affective decision task. Emotional prosodic fragments of short (200-msec) and medium (400-msec) duration were presented as primes, followed by an emotionally related or unrelated facial expression (or facial grimace, which does not resemble an emotion). Participants judged whether or not the facial expression represented an emotion. ERP results revealed an N400-like differentiation for emotionally related prime–target pairs when compared with unrelated prime–target pairs. Faces preceded by prosodic primes of medium length led to a normal priming effect (larger negativity for unrelated than for related prime–target pairs), but the reverse ERP pattern (larger negativity for related than for unrelated prime–target pairs) was observed for faces preceded by short prosodic primes. These results demonstrate that brief exposure to prosodic cues can establish a meaningful emotional context that influences related facial processing; however, this context does not always lead to a processing advantage when prosodic information is very short in duration.

Efforts to understand how the brain processes emotional information have increased rapidly over the last years. New studies are shedding light on the complex and diverse nature of these processes and on the speed with which emotional information is assimilated to ensure effective social behavior. The emotional significance of incoming events needs to be evaluated within milliseconds, followed by more conceptual-based knowledge processing, which often regulates emotionally appropriate behaviors (cf. Phillips, Drevets, Rauch, & Lane, 2003). In everyday situations, emotional stimuli are not often processed in isolation; rather, we are confronted with a stream of incoming information or events from different sources. To advance knowledge of how our brain successfully processes emotions from different information sources and how these sources influence each other, we investigated how and when emotional tone of voice influences the processing of an emotional face, a situation that occurs routinely in face-to-face social interactions.

Effects of Emotional Context

The importance of context in emotion perception has been emphasized by several researchers (e.g., de Gelder et al., 2006; Feldmann Barett, Lindquist, & Gendron, 2007; Russell & Fehr, 1987). *Context* may be defined as the situation or circumstances that precede and/or accompany certain events, and both verbal contexts (created by language use) and social contexts (created by situations, scenes, etc.) have been shown to influence emotion perception. For example, depending on how the sentence, “Your parents are here? I can’t wait to see them,” is intoned, the speaker may be interpreted either as being pleasantly surprised by the unforeseen event or as feeling the very opposite. Here, emotional prosody—that is, the acoustic variations of perceived pitch, intensity, speech rate, and voice quality—serves as a context for interpreting the verbal message. Emotional prosody can influence not only the interpretation of a verbal message but also the early perception of facial expressions (de Gelder & Vroomen, 2000; Massaro & Egan, 1996; Pourtois, de Gelder, Vroomen, Rossion, & Crommelinck, 2000). The latter reports have led to the proposal that emotional information in the prosody and face channels is automatically evaluated and integrated early during the processing of these events (de Gelder et al., 2006). In fact, recent evidence from event-related brain potentials (ERPs) is consistent with this hypoth-

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esis; early ERP components, such as the N100 (and other related components), are known to be differently modulated for affectively congruent and incongruent face–voice pairs (Pourtois et al., 2000; Werheid, Alpay, Jentzsch, & Sommer, 2005).

It seems to be established that early face perception can be influenced by temporally adjacent emotional prosodic cues, but the question remains whether later processes, such as emotional meaning evaluation, can also be influenced by an emotional prosodic context. A common way to investigate contextual influences on emotional meaning processing is through associative priming studies, which present prime–target events related on specific affective (i.e., positive/negative) or emotional dimensions of interest (for a methodological overview, see Klauer & Musch, 2003). For researchers interested in the processing of basic emotion meanings, a prime stimulus (emotional face, word, or picture) conveying a discrete emotion (e.g., joy or anger) is presented for a specified duration, followed by a target event that is either emotionally congruent or emotionally incongruent with the prime. These studies show that the processing of emotional targets is systematically influenced by corresponding features of an emotionally congruent prime, as revealed by both behavioral data (reaction times and accuracy scores; Carroll & Young, 2005; Hansen & Shantz, 1995; Pell, 2005a, 2005b) and ERP results (Schirmer, Kotz, & Friederici, 2002, 2005; Werheid et al., 2005; Zhang, Lawson, Guo, & Jiang, 2006).

There are several theories that attempt to explain the mechanism of emotional (or affective) priming: The spreading activation account (Bower, 1991; Fazio, Sanbonmatsu, Powell, & Kardes, 1986) and affective matching account are probably the most prominent (for a detailed review, see Klauer & Musch, 2003). *Spreading activation* assumes that emotional primes preactivate nodes or mental representations corresponding to related targets in an emotion-based semantic network, thus leading to greater accessibility for related than for unrelated targets. *Affective matching*, when applied to discrete emotion concepts, assumes that emotional details activated by the target are matched or integrated with the emotional context established by the prime at a somewhat later processing stage. Both of these accounts were postulated to explain positive influences of the prime on the target (e.g., superior behavioral performance for related vs. that for unrelated prime–target pairs). Other accounts, such as the center-surround inhibition theory (Carr & Dagenbach, 1990), attempt to explain potential negative influences of an emotional prime on the target (i.e., impaired performance for related vs. that for unrelated pairs). This theory assumes that, under certain circumstances (such as low visibility for visual primes), a prime would activate a matching network node only weakly; as a result of this weak activation, surrounding nodes become inhibited to increase the prime activation. This serves to reduce activation for related targets under these conditions as the inhibition of surrounding nodes hampers their activation (Bermeitinger, Frings, & Wentura, 2008; Carr & Dagenbach, 1990). In the following sections, we will refer to positive influences of the prime–target as *normal* priming and negative influences as *reversed* priming. It should be kept in mind that, irrespective of the direction of a reported effect, both forms of priming point to differential processing of related and unrelated prime–target pairs according to their hypothesized emotional (or semantic) relationship.

Emotional Priming: Behavioral and ERP Evidence

As noted, depending on the researcher's perspective, priming effects have been linked to specific affective dimensions of the prime–target pair (e.g., shared negative or positive valence) or emotion-specific features of the two events (e.g., both the prime and target represent anger or fear). Priming has been observed for stimuli presented within the same channel (e.g., Power, Brewin, Stuessy, & Mahony, 1991; Werheid et al., 2005) and between channels (e.g., Bostanov & Kotchoubey, 2004; Carroll & Young, 2005; Pell, 2005a, 2005b; Pell & Skorup, 2008; Ruys & Stapel, 2008; Schirmer et al., 2002, 2005; Zhang et al., 2006), with the latter leading to the assumption of shared representation in the brain and the existence of emotion concepts (Borod et al., 2000; Bower, 1981; Bowers, Bauer, & Heilman, 1993; Niedenthal & Halberstadt, 1995; Russell & Lemay, 2000). A variety of tasks have also been used to investigate priming: lexical decision (e.g., Hermans, De Houwer, Smeesteres, & Van den Broeck, 1997; Wentura, 1998), categorization (Bargh, Chaiken, Govender, & Pratto, 1992; Fazio et al., 1986; Hermans, De Houwer, & Eelen, 1994; Klauer, Roßnagel, & Musch, 1997), and facial affective decision (Pell, 2005a, 2005b; Pell & Skorup, 2008), among others. Two variables known to play a critical role in understanding priming effects are the overall prime duration and the time interval between the onset of the prime and the target, known as the *stimulus onset asynchrony* (SOA; for details on the influence of SOA on priming, see Spruyt, Hermans, De Houwer, Vandromme, & Eelen, 2007). In a nutshell, short primes or SOAs (below 300 msec) are believed to capture early (i.e., automatic) processes in priming tasks, whereas longer primes or SOAs capture late (i.e., controlled or strategic) processes (Hermans, De Houwer, & Eelen, 2001; Klauer & Musch, 2003).

Most emotional priming studies to date have used behavioral methodologies. However, recent electrophysiological studies have also reported emotional priming effects (e.g., Bostanov & Kotchoubey, 2004; Schirmer et al., 2002; Werheid et al., 2005; Zhang et al., 2006). For instance, in a study reported by Bostanov and Kotchoubey, emotionally incongruent prime–target pairs (i.e., emotion names paired with emotional vocalizations) elicited more negative-going N300 components than did emotionally congruent pairs. The authors interpreted the N300 as analogous to the N400, a well-known index of semantically inappropriate target words,[1] where the N300 could be an indicator of emotionally inappropriate targets. Along similar lines, Zhang et al. presented visual emotional primes (pictures and words), followed by emotionally matching or mismatching target words. They reported that emotionally incongruent pairs elicited a larger N400 amplitude than did emotionally congruent pairs. Whereas emotion words and/or pictures acted as primes in these studies to establish an emotional processing context, Schirmer et al. (2002) used emotionally inflected speech (prosody) as context. Sentences intoned in either a happy or a sad voice were presented as primes, followed by a visually presented emotional target word. Their results revealed larger N400 amplitudes for emotionally incongruent than for congruent prime–target pairs.

In the semantic priming literature, N400 effects have been linked to spreading activation accounts (e.g., Deacon, Hewitt, Yang, & Nagata, 2000), context integration (e.g., Brown & Hagoort, 1993), or both (e.g., Besson, Kutas, & Van Petten, 1992; Holcomb, 1988; Kutas & Federmeier, 2000). Recent research has also linked the N400 to reduced access to contextually related target representations in the context of faintly visible primes (i.e., reversed priming; Bermeitinger et al., 2008). The data summarized above underline the fact that the N400 is not only sensitive to semantic incongruities but also to emotional incongruities within and across modalities: Hypothetically, the prime–target emotional relationship is implicitly registered in the electrophysiological signal by an emotional conceptual system that processes the significance of emotional stimuli, irrespective of modality (Bower, 1981; Bowers et al., 1993; Niedenthal & Halberstadt, 1995; Russell & Lemay, 2000). Thus, differentiation in the N400 can be explored to find whether emotional meanings are (sufficiently) activated in the face of specific contextual information. When prosody acts as an emotional context, differences in prime duration could well modulate the N400, since prosodic meanings unfold over time. This possibility, however, has not been investigated yet.

Visual primes presented in emotional priming studies tend to be very brief (100–200 msec), whereas auditory primes tend to be much longer in duration. For example, Schirmer et al. (2002) used emotionally intoned sentences as primes, which were approximately at least 1 sec in duration, as did Pell (2005a) in a related behavioral study. This raises the question of whether emotional priming effects (and related N400 responses) would be similar when the context supplied by emotional prosody is also very brief in duration. In an attempt to answer this question, Pell (2005b) used the facial affect decision task (FADT), a crossmodal priming paradigm resembling the lexical decision task, to investigate the time course of emotional prosodic processing. Emotionally inflected utterances were cut to specific durations from sentence onset (300, 600, and 1,000 msec) and presented as primes, followed immediately by a related or unrelated face target (or a facial grimace that did not represent an emotion). Participants judged whether or not the face target represented an emotional expression (yes/no response). Results showed that decisions about emotionally related faces were primed when prosodic stimuli lasted 600 or 1,000 msec, but not when they were very short in duration (300 msec; Pell, 2005b). These findings imply that it takes much longer (between 300 and 600 msec) for emotional prosody to establish a context that can influence conceptual processing of a related stimulus than is typically observed for emotional words or pictures. This result is surprising, in light of ERP evidence that suggests a comparable time course for early perceptual processes in the visual and auditory modalities (e.g., Balconi & Pozzoli, 2003; Eimer & Holmes, 2002; Paulmann & Kotz, 2008a; Paulmann & Pell, 2009) and rapid integration of information in the two modalities (de Gelder & Vroomen, 2000; Pourtois et al., 2000). However, since behavioral responses—namely, response times (RTs) and accuracy rates—are measured at discrete points in time, these measures tend to be less sensitive to subtle online effects than ERPs are; it is, therefore, likely that the behavioral data reported by Pell (2005b) do not adequately reflect the underlying processes that could signal conceptual processing of prosodic events of brief duration. In fact, it is not uncommon for studies that report no behavioral priming effects to reveal ERP priming effects (e.g., Kotz, 2001).

To explore the influence of emotional prosody as a context for emotional face evaluation with a highly time-sensitive measurement, the present study used the FADT in an ERP priming paradigm. Specifically, our goal was to establish whether emotional prosodic events of relatively brief duration (200 or 400 msec) establish a context that influences (i.e., that primes) conceptual processing of a related versus an unrelated target face. On the basis of evidence from the ERP priming literature involving visual stimuli, we hypothesized that emotional prosodic fragments of both short and medium duration would activate emotion knowledge, which would impact the evaluation of related and unrelated facial expressions, as reflected in differently modulated N400 amplitudes in both prime-duration conditions. However, recent ERP evidence from the semantic priming literature (Bermeitinger et al., 2008) has given rise to the possibility that very brief fragments serving as primes may not provide sufficient information for fully activating corresponding nodes in the emotional network, leading to temporary inhibition of emotionally related nodes, as would be reflected in reversed N400 priming effects.

METHOD

Participants

Twenty-six right-handed native speakers of English (12 female; mean age = 21.2 years, *SD* = 2.6 years) participated in the study. None of the participants reported any hearing impairments, and all had normal or corrected-to-normal vision. All participants gave informed consent before taking part in the study, which was approved by the McGill Faculty of Medicine Institutional Review Board as ethical. All participants were financially compensated for their involvement.

Stimuli

The materials used in the study were fragments of emotionally inflected utterances (as the primes) and pictures of emotional facial expressions (as the targets), which were paired for crossmodal

Table 1
Fundamental Frequency (f_0) and Intensity (dB) Values From Acoustic Analyses Carried Out for Short- and Medium-Duration Primes

Prime Duration	Emotion	Mean f_0	Min f_0	Max f_0	Mean dB	Min dB	Max dB
Short (200 msec)	Anger	240.7	212.1	274.4	71.6	58.9	78.8
	Fear	310.4	275.4	368.2	70.1	58.4	78.6
	Happiness	222.7	201.5	256.0	71.7	58.9	79.5
Medium (400 msec)	Anger	250.3	201.1	306.8	71.5	53.5	81.0
	Fear	297.8	255.9	373.9	72.5	56.6	80.7
	Happiness	223.2	185.6	280.0	71.4	54.9	81.4

presentation according to the FADT. All of the stimuli were taken from an established inventory (for details, see Pell, 2002, 2005a; Pell, Paulmann, Dara, Alasseri, & Kotz, 2009). For detailed commentary on the construction and assumptions of the FADT, see Pell (2005a).

Prime stimuli. The prime stimuli were constructed by extracting 200-msec and 400-msec fragments from the onset of emotionally intoned (anger, fear, happy) pseudoutterances (e.g., "They nestered the flugs."). We also included fragments of pseudoutterances produced in a neutral tone as filler material. Pseudoutterances are commonly used by researchers for determining how emotional prosody is processed independent of semantic information using materials that closely resemble the participant's language (e.g., Grandjean et al., 2005; Paulmann & Kotz, 2008b). Here, the prime stimuli were produced by four different speakers (2 female) and then selected for presentation on the basis of the average recognition rate for each item in a validation study (Pell et al., 2009). For each speaker, the 10 best recognized sentences were selected for each emotion category, for a total of 40 items per emotion category. Emotional-target accuracy rates for the sentences from which the fragments were cut were as follows: Anger = 93%; fear = 95%; happy = 89%; neutral fillers = 90%. Each of the 160 primes was cut into 200- and 400-msec fragments, measured from sentence onset, using Praat speech-analysis software (Boersma & Weenink, 2009). Forty non-speech-related filler primes (a 300-Hz tone) were also presented in the experiment. Acoustical characteristics of the prime stimuli are reported in Table 1, and examples are illustrated in Figure 1.

Target stimuli. The target stimuli were 13.5 × 19 cm static facial expressions (black-and-white photographs) of an actor's face cropped to restrict information to facial features. Three female and 3 male actors of different ethnicities (Caucasian, Black, Asian) posed for the photographs. Participants were required to render a facial affect decision at the end of each trial (in response to the question, "Does the facial expression represent an emotion?"), and face targets represented characteristic expressions of angry (n = 24), fearful (n = 24), or happy (n = 24) emotions (*yes* trials) or were facial grimaces (posed by the same actors) that did not represent an emotion (*no* trials, n = 76 different expressions). Here, the term *grimace* refers to any facial expression involving movements of the brow, mouth, jaw, and lips that does not lead to recognition of an emotion on the basis of previous data. Prior to this study, all face targets were validated in order to establish their emotional status and meaning (Pell, 2002): For *yes* targets, angry facial expressions were recognized with 88% accuracy on average; fearful expressions were recognized with 89% accuracy; and happy facial expressions were recognized with 98% accuracy overall. Twenty-four neutral facial expressions, which were presented solely as filler targets in the experiment, were identified with 75% accuracy, on average. Finally, all facial grimaces (*no* targets) were identified as not conveying one of six basic emotions by at least 60% of the participants in the same validation study (Pell, 2002). Typically, these expressions are described as "silly" by raters; thus, it can be said that most of the grimace faces possessed certain affective characteristics. However, our data clearly show that these affective features do not symbolize discrete emotions, since participants systematically reject these exemplars as representing an emotion at rates exceeding 90% when instructed to make a facial affect decision about grimace targets (Pell, 2005a, 2005b; Pell & Skorup, 2008). Moreover, we have recently shown that grimace expressions elicit neural responses distinct from "real" emotional expressions in three different ERP components during early facial expression decoding (Paulmann & Pell, 2009), arguing that grimaces are conceptually distinct from real expressions of emotion in the face. An example of emotional facial expressions and grimaces posed by one of the actors is displayed in Figure 2.

Design

As described in detail elsewhere (Pell, 2005a, 2005b), the FADT requires a participant to make a yes/no judgment about the emotional meaning status of a face, analogous to rendering a lexical decision about a word target. Participants decide whether the target facial expression represents an emotion (*yes* response) or not (*no* response). Presumably, this decision taps whether the stimulus can be mapped onto preexisting knowledge about how emotions are expressed in the face. However, participants are not required to consciously retrieve or name the emotion conveyed by the face (or by the prime). Half of the trials required a *yes* response by the participants; the other half required a *no* response. *Yes* trials consisted of emotionally congruent prime–target pairs or incongruent prime–target pairs. To factorially control for the type and duration of auditory primes paired with each emotional, neutral, and grimace face, each facial expression was presented several times in the experiment (five to eight repetitions for *yes* trials and eight or nine repetitions for *no* trials), although they were paired with different primes. A total of 1,360 trials were presented in a single session (680 trials in the 200-msec condition and 680 trials in the 400-msec condition). All trials in the 200-msec condition were always presented before participants heard the 400-msec primes, since there was a greater potential for carryover effects if listeners were first exposed to extended emotional information in the longer, 400-msec vocal primes condition prior to hearing the corresponding 200-msec primes. The possibility that performance in the 400-msec condition would be systematically improved by always performing the 200-msec condition first was mitigated by completely randomizing trials within both the 200- and 400-msec conditions, as well as by imposing breaks throughout the experiment. The randomized stimuli were presented to participants, split into 10 blocks of 136 trials each (first 5 blocks for the 200-msec condition, second 5 blocks for the 400-msec condition). Table 2 summarizes the exact distribution of trials in each experimental condition.

Procedure

After the preparation for EEG recording, the participants were seated in a dimly lit, sound-attenuated room at a distance of approximately 65 cm in front of a monitor. The facial expressions were presented in the center of the monitor, and the emotional prosodic stimuli were presented at a comfortable listening level via loudspeakers positioned directly to the left and right of the monitor. A trial was as follows. A fixation cross was presented in

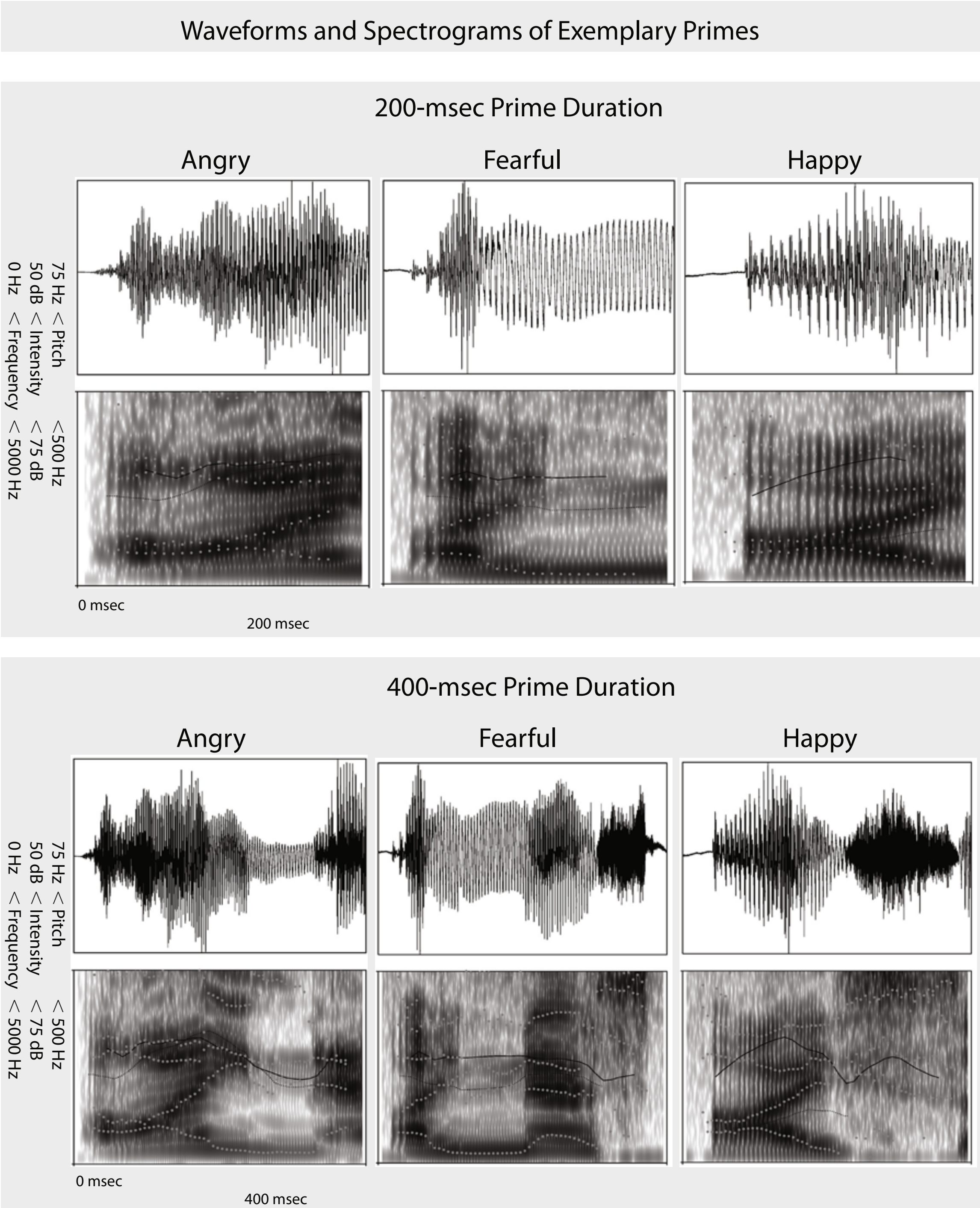

Figure 1. Example waveforms and spectrograms for primes with short (200-msec) and medium (400-msec) durations. Examples of each emotional category tested (anger, fear, happiness) are displayed. Spectrograms show visible pitch contours (black dotted line; floor and ceiling of viewable pitch range set at 75 Hz and 500 Hz, respectively), intensity contours (black solid lines; view range set from 50 to 75 dB), and formant contours (gray dots). All visualizations were created with Praat (Boersma & Weenink, 2009).

the center of the screen for 200 msec. A blank screen was presented for 500 msec. The vocal stimulus was presented for either 200 or 400 msec. The visual target was presented on the screen at the offset of the vocal stimulus until participants responded (or after 3,500 msec had elapsed, in the event of no response). After the response, an interstimulus interval of 1,500 msec occurred before the next trial was presented (see Figure 3 for the trial sequence). Participants were instructed to listen to the auditory stimulus but to look carefully at the facial expression and indicate whether or not the face represented an emotion by pressing the left or right button

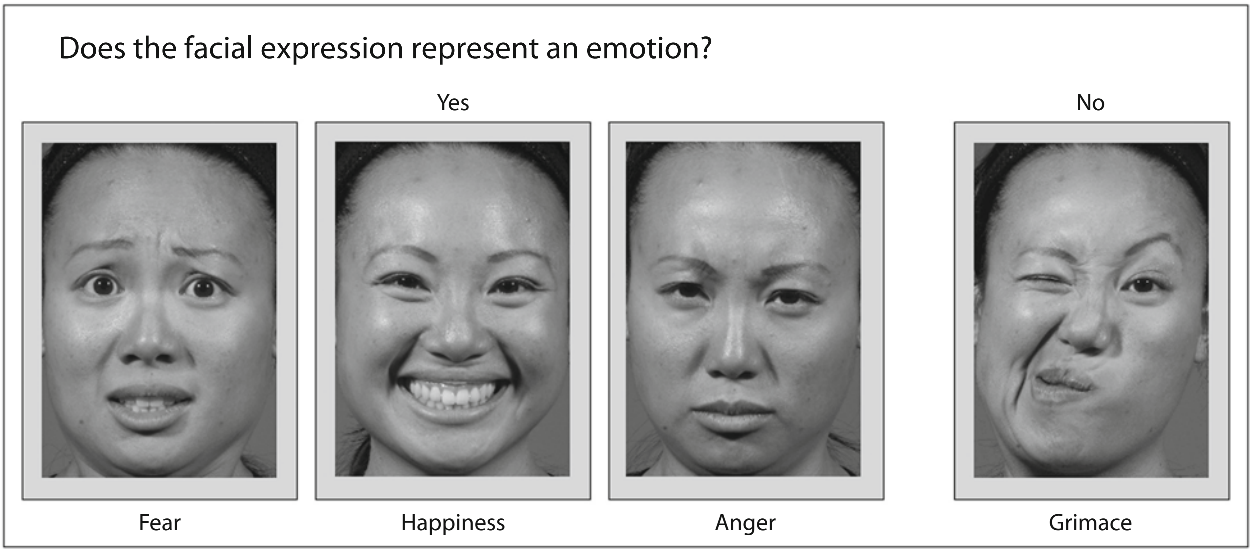

Figure 2. Examples of face targets, as presented in the experiment, posed by one of the actors.

of a response panel (computer mouse). The assignment of *yes* and *no* responses to the right and left buttons was varied equally among participants. After each block, the participant paused for a self-determined duration before proceeding (approximately 2–3 min). Each recording session started with 10 practice trials to familiarize participants with the procedure. When fewer than 8 practice trials were answered correctly, the practice block was repeated (this rarely occurred). The experimental session lasted approximately 2.5 h, including electroencephalogram (EEG) preparation.

ERP Recording and Data Analysis

The EEG was recorded from 64 active Ag/AgCl electrodes (BioSemi, Amsterdam) mounted in an elastic cap. Signals were recorded continuously with a band pass between 0.1 and 70 Hz and digitized at a sampling rate of 256 Hz. The EEG was recorded with a common mode sense active electrode and data were re-referenced offline to linked mastoids. Bipolar horizontal and vertical electrooculograms (EOGs) were recorded for artifact rejection purposes. The data were inspected visually in order to exclude trials containing extreme artifacts and drifts, and all trials containing EOG artifacts above 30.00 μV were rejected automatically. Approximately 18% of the data for each participant were rejected. For further analysis, only trials in which the participants responded correctly were used. For all conditions, the trials were averaged over a time range from stimulus onset to 600 msec after stimulus onset (with an in-stimulus baseline of 100 msec).

Both the accuracy rates (correct responses to *yes* trials only) and ERP data were analyzed separately for each prime-duration condition using a repeated measures ANOVA. The within-participants factors in each analysis were congruency (congruent, incongruent voice–face pair), defined as the emotional relationship between the prime and the target, and face emotion (angry, fear, happy). For the ERP analyses, we additionally included the factor region of interest (ROI). Seven ROIs were formed by grouping the following electrodes together: left frontal electrodes (F3, F5, F7, FC3, FC5, FT7); right frontal electrodes (F4, F6, F8, FC4, FC6, FT8); left central electrodes (C3, C5, T7, CP3, CP5, TP7); right central electrodes (C4, C6, T8, CP4, CP6, TP8); left parietal electrodes (P3, P5, P7, PO3, PO7, O1); right parietal (P4, P6, P8, PO4, PO8, O2); and midline electrodes (FZ, FCz, Cz, CPz, Pz, POz). Comparisons with more than one degree of freedom in the numerator were corrected for nonsphericity using the Greenhouse–Geisser correction (Greenhouse & Geisser, 1959). Because there is considerable variability in the reported latency of N400-like effects in the literature on emotional processing, with studies reporting both early (Bostanov & Kotchoubey, 2004) and late (Kanske & Kotz, 2007; Zhang et al., 2006) onset of this component, we did not adopt the classical N400 time window (350–550 msec) for our mean amplitude analysis; rather, this decision was guided by previous evidence from the emotional ERP priming literature (Zhang et al., 2006), as well as from visual inspection (for a discussion of exploratory ERP analyses, see Handy, 2004). Time windows ranging from 440 to 540 msec after picture onset were subsequently selected for analysis. To increase readability, only significant effects involving the critical factors of congruency or face emotion of the target face are reported in the section below.

RESULTS

Behavioral Results

Prime duration of 200 msec. Analysis of accuracy rates revealed a significant main effect of face emotion [$F(2,50) = 14.20$, $p < .0001$]. There were overall differences in the ability to judge whether a facial expression represented an emotion according to the emotion category, with significantly greater accuracy for happy (96%) than for fearful (85%) or angry (82%) facial expressions. The main effect was informed by a signifi-

Table 2
Amount and Distribution of Trials Presented

Face/Voice	Anger	Happiness	Fear	Neutral	300-Hz Tones
		Yes Trials			
Anger	40	20	20	20	20
Happiness	20	40	20	20	20
Fear	20	20	40	20	20
Neutral	20	20	20	40	20
		No Trials			
Grimace	80	80	80	80	20

Note—For each prime duration, 160 congruent trials, 180 incongruent trials, and 340 *no* trials were presented to each participant in a pseudorandomized order. In total, 1,360 trials (680 trials for the short- and 680 trials for the medium-length prime duration) were presented in one session. Neutral items were considered filler items.

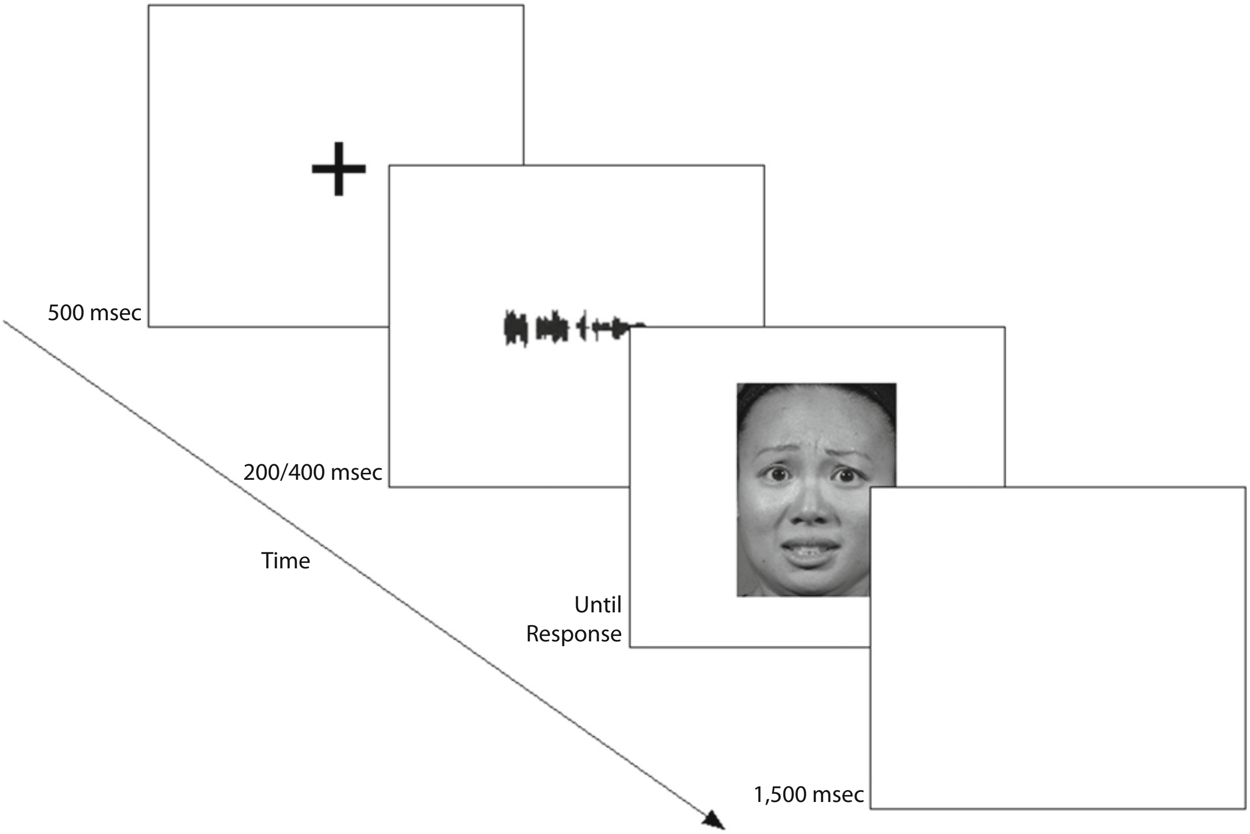

Figure 3. A trial sequence. In the first five blocks, primes were presented for 200 msec. In the last five blocks, primes were presented for 400 msec.

cant interaction between congruency and face emotion [$F(2,50) = 9.18$, $p < .001$]. Step-down analyses indicated that there was no consistent congruency effect when 200-msec prosodic primes were presented as a function of face target: For angry faces, accuracy was significantly higher following congruent than incongruent prosody [$F(1,25) = 8.76$, $p < .01$]; for fearful faces, accuracy was significantly greater following incongruent than congruent prosody [$F(1,25) = 5.99$, $p < .05$]; and for happy faces, there was no significant effect of prime congruency on facial affect decisions. These effects are summarized in Table 3.

Prime duration of 400 msec. When medium-duration primes were presented, analysis of accuracy rates again revealed a significant main effect of face emotion [$F(2,50) = 8.99$, $p < .01$]. Comparable to the effects described in the 200-msec prime condition, participants were significantly better at judging happy facial expressions (96%) as representing an emotion than they were at judging either fearful (85%) or angry (82%) facial expressions. The interaction between congruency and face emotion was again significant for 400-msec primes [$F(2,100) = 4.97$, $p < .05$]. For the interaction, step-down analyses revealed a significant emotional congruency effect of the prime when participants judged fearful target expressions [$F(1,25) = 7.38$, $p < .05$]; facial affective decisions were more accurate when preceded by congruent (fearful) vocal primes than by incongruent primes. No significant congruency effects were found for angry or happy facial expressions for this prime duration (see Table 3).

Table 3
Mean Accuracy Rates (in Percentages) for Each Emotional Category for Congruent and Incongruent Prime–Target Pairs for Short- and Medium-Length Primes

	Prime Duration							
	Short (200 msec)				Medium (400 msec)			
	Congruent		Incongruent		Congruent		Incongruent	
Emotion	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Anger	84.4	17.5	80.8	18.4	83.9	18.6	85.3	18.1
Fear	83.9	96.3	86.6	20.5	91.2	18.8	88.3	19.0
Happiness	96.3	7.4	96.7	6.8	96.2	7.3	95.6	8.8

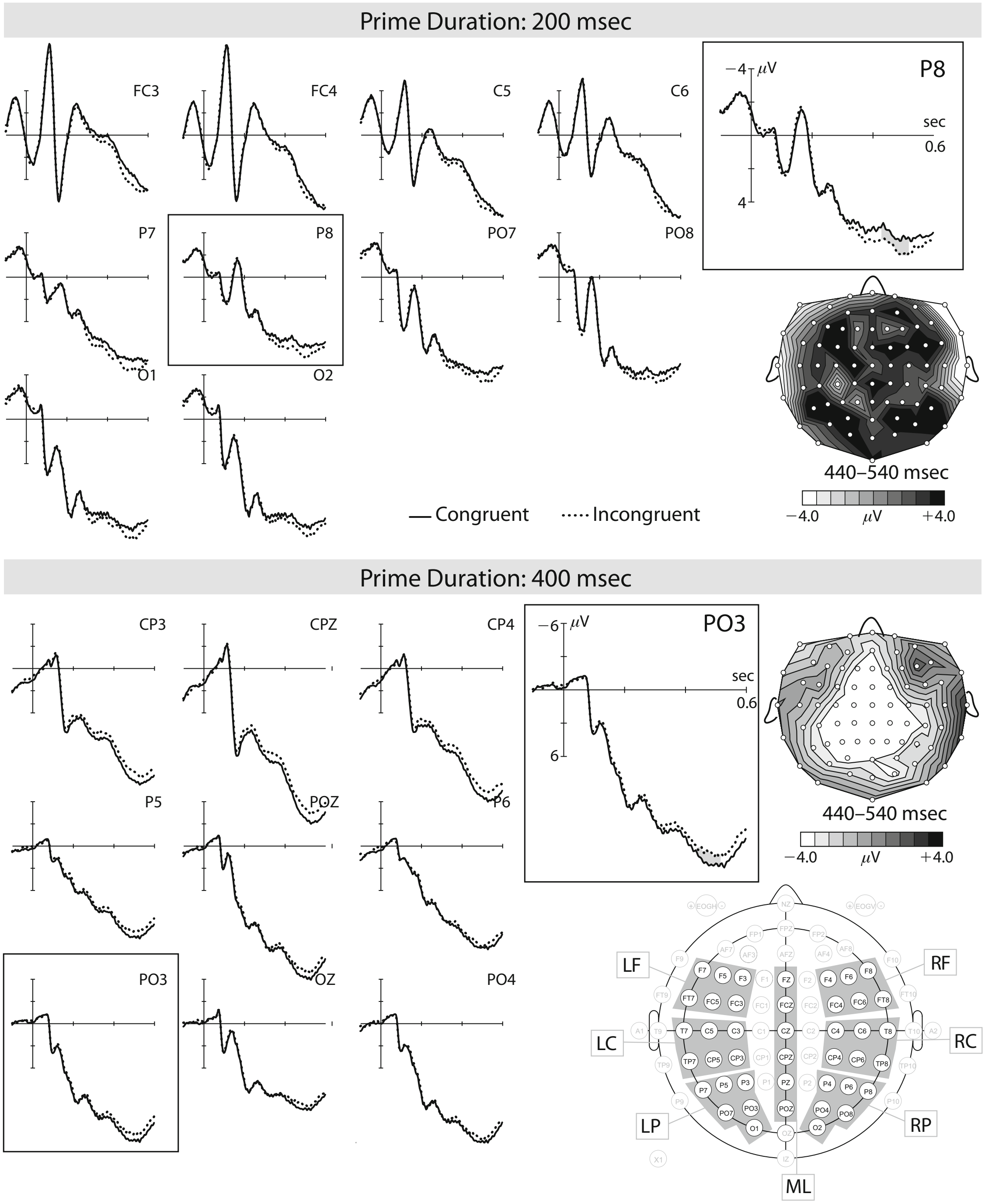

Figure 4. Averaged ERPs elicited by congruent and incongruent prime–target pairs time-locked to target onset at selected electrode sites. ERP difference maps comparing the congruent and incongruent pairs are displayed. Waveforms show the averages for congruent (black, solid) and incongruent (dotted) prime–target pairs from 100 msec prior to stimulus onset up to 600 msec after stimulus onset. The diagram on the right side shows where selected electrode sites were located.

ERP Results

Prime duration of 200 msec. The analysis for the time window of 440–540 msec revealed a significant main effect of prime–target emotional congruency [$F(1,25) = 4.48$, $p < .05$]. Overall, more positive-going ERP amplitudes were observed in response to emotionally incongruent prime–target pairs than to emotionally congruent prime–target pairs. In addition, a significant interaction of face emotion and ROI was found [$F(12,300) = 2.35$, $p < .05$], suggesting that ERP amplitudes were modulated in response to the different emotional target faces as a function of ROI. Step-down analyses by ROI revealed a significant effect of target face emotion only at right parietal electrode sites [$F(2,50) = 3.46, p < .05$]. Post hoc contrasts revealed significantly more positive-going amplitudes for fearful than for angry facial expressions [$F(1,25) = 7.85, p = .001$]. No other effects reached significance in this time window. Effects are displayed in Figure 4.

Prime duration of 400 msec. The analysis of 400-msec primes yielded no significant main effects, although there was a significant interaction between the critical factor congruency and the factor ROI [$F(6,150) = 3.23, p < .05$]. Step-down analysis by ROI revealed significant congruency effects for left parietal [$F(1,25) = 6.47, p < .05$] electrode sites and marginally significant congruency effects for right parietal [$F(1,25) = 3.39, p = .07$] and midline [$F(1,25) = 3.88, p < .06$] electrode sites. In all ROIs, emotionally incongruent prime–target pairs elicited a more negative-going ERP amplitude than emotionally congruent prime–target pairs did, as is shown in Figure 4. Similar to the findings in the 200-msec duration condition, the analysis also revealed a relationship between face emotion and ROI, which represented a strong trend in the 400-msec condition [$F(12,300) = 2.44, p < .06$].

In summary, the analysis of ERP amplitudes in the time windows of 440–540 msec revealed significant congruency effects of prosodic primes of both short (200-msec) and medium (400-msec) duration on related versus unrelated emotional faces. In particular, amplitudes were more negative-going for face targets that followed emotionally congruent primes of short duration, whereas more negative-going amplitudes were found for face targets that followed emotionally incongruent primes of longer duration.

DISCUSSION

The present study investigated how and when emotional prosody influences the evaluation of emotional facial expressions, as inferred by ERP priming effects. It was of particular interest to examine whether emotional prosodic fragments of short (200-msec) and medium (400-msec) duration could elicit emotional priming, as indexed by differently modulated ERP responses for related and unrelated prime–target pairs. In accord with previous findings that used visually presented emotional primes (Zhang et al., 2006), we report a strong online influence of emotional prosody on decisions about temporally adjacent emotional facial expressions. Specifically, facial expressions that were preceded by emotionally congruent (rather than incongruent) prosodic primes of short duration elicited a reversed whole-head-distributed N400-like priming effect. In contrast, facial expressions preceded by emotionally congruent prosodic primes of longer duration (400 msec) elicited a standard centroparietally distributed N400-like priming effect as compared with those preceded by emotionally incongruent prime–target pairs.

Our ERP results support the assumption that emotional information from prosody is detected and analyzed rapidly (cf. Paulmann & Kotz, 2008a; Schirmer & Kotz, 2006), even when this information is not task relevant (Kotz & Paulmann, 2007). These data confirm that prosodic cues can establish a meaningful emotional context that influences (i.e., that primes) subsequent emotional evaluations (de Gelder & Vroomen, 2000; Pell, 2005a, 2005b; Schirmer et al., 2002, 2005), extending this evidence to prosodic stimuli of very short duration. Whereas previous data have shown that early perceptual processing of emotional faces is influenced by emotional speech tone (de Gelder & Vroomen, 2000; Pourtois et al., 2000), our data imply that contextual influences of emotional prosody can also affect later, more evaluative processing stages required when judging the representative nature of emotional facial expressions (Pell, 2005a, 2005b), even when prosodic fragments are of rather short duration. Congruency effects observed in the ERP data were only partially mirrored by the behavioral results, but this is not surprising, given that Pell (2005b) also failed to detect behavioral priming effects when prosodic fragments were shorter than 600 msec. In fact, as stated earlier, one of the primary motivations for the present investigation was the observation that consistent behavioral priming effects could only be obtained with prosodic fragments that were at least 600 msec long. However, differences between behavioral methodologies and ERPs are not uncommon, given that behavioral methods are not as sensitive to subtle online effects as ERPs are. In fact, inconsistencies between ERPs and behavioral measures have previously been reported in both the semantic (e.g., Kotz, 2001) and emotional priming literature (e.g., Werheid et al., 2005). Nonetheless, behavioral responses analyzed here established that participants were able to carry out the task and were actively engaged in the emotional processing of the face target: Overall facial affect decision accuracy rates ranged from 82% to 96% in both prime-duration conditions. Moreover, behavioral analyses revealed an effect that was ubiquitously observed in all previous studies employing the FADT—namely, positive face targets are judged to represent an emotion more accurately than negative face targets are, irrespective of prime congruency and prime duration (for detailed discussions of this effect, see Pell, 2005a, 2005b). Still, clarifying the link between online processes tapped by ERPs and more conscious, task-related evaluation processes tapped by our behavioral responses in the context of emotional priming effects should be explored in future research.

Emotional Priming and the N400

Crossmodal priming effects, whether normal or reversed, reflect processing differences between emotionally congruent and incongruent prime–target pairs. Arguably, these effects are observed when the emotional category knowledge associated with both primes and targets is implicitly activated and processed in an emotional semantic memory store (e.g., Niedenthal & Halberstadt, 1995; Pell, 2005a, 2005b). One ERP component that has been repeatedly linked to semantic processing (for an overview, see Kutas & Federmeier, 2000; Kutas & Van Petten, 1994), and, more recently, to emotional (semantic) meaning processing (Schirmer et al., 2002, 2005; Zhang et al., 2006) is the N400. In particular, it has been argued that the N400 (and N400-like negativities, such as the N300) reflects the processing of broken emotional context expectations (Bostanov & Kotchoubey, 2004; Kotz & Paulmann, 2007; Paulmann & Kotz, 2008b; Paulmann, Pell, & Kotz, 2008; Schirmer et al., 2002; Zhang et al., 2006). Our data confirm that this emotional context violation response can be elicited by very briefly presented (200-msec) prosodic stimuli, although longer (400-msec) prime durations lead to different effect directions in the N400 (see the Discussion). Our data affirm that this response is not valence specific, since it is observed for both positive and negative stimuli (for similar observations using visual primes, see Zhang et al., 2006).

The N400 has been interpreted to reflect either automatic (e.g., Deacon et al., 2000; Deacon, Uhm, Ritter, Hewitt, & Dynowska, 1999) or controlled (e.g., Brown & Hagoort, 1993) processing of stimuli, and sometimes both (Besson et al., 1992; Holcomb, 1988; Kutas & Federmeier, 2000). The main argument is that short SOAs/prime durations should lead to automatic processing of (emotional) stimuli, since short prime durations would prevent participants from consciously or fully processing features of the prime. In contrast, long SOAs presumably allow strategic, attentional processing of the prime. It is likely that the present short-prime-duration condition (200 msec) elicited primarily automatic emotional processing, whereas the medium-length primes could have elicited more strategic processes. Because we found N400-like effects for both prime durations (but with different distributions), we will follow the view that the N400 can reflect both automatic activation (or, in our case, inhibition) of mental representations and integration processes (Besson et al., 1992; Holcomb, 1988; Kutas & Federmeier, 2000). In the short-prime-duration condition, we hypothesize that the observed ERP modulations reflect a first activation (inhibition) of the target-node representation that was previously preactivated (inhibited) by the prime. In the case of longer prime durations, the classic N400-like effect may also reflect the integration of the emotional target meaning with the context established by the prime. The theoretical implications of the reversed N400 are addressed below.

When one looks at the specific cognitive processes that could have led to the emotional priming effects observed here and in previous crossmodal studies, it appears likely that emotional faces and emotional vocal expressions share certain representational units in memory (Borod et al., 2000; Bowers et al., 1993; de Gelder & Vroomen, 2000; Massaro & Egan, 1996; Pell, 2005a, 2005b). For example, concepts referring to discrete emotions could guide the processing and integration of emotional faces and prosodic information, among other types of emotional events (Bower, 1981; Niedenthal, Halberstadt, & Setterlund, 1997). The FADT employed here requires "an analysis of emotional features of the face that includes reference to known prototypes in the mental store" (Pell, 2005a, p. 49), although participants do not have to consciously access emotional features of the prime or target in order to generate a correct response. Crucially, our data show that emotional mental representations corresponding to both the prime and the target stimuli get automatically activated, since emotionally unrelated targets are processed differently from emotionally related targets in both the 200- and 400-msec prime duration conditions.

These observations are in line with claims that emotional stimuli are evaluated automatically or unintentionally (e.g., Phillips et al., 2003; Schirmer & Kotz, 2006; Schupp, Junghöfer, Weike, & Hamm, 2004; Vroomen, Driver, & de Gelder, 2001). In addition, these observations imply that there is rapid access to emotional prototypical information in the mental store and that 200 msec of emotional prosodic information can be sufficient for (subconsciously) inferring emotion-specific category knowledge. Our findings add to previous ERP evidence showing that other emotionally relevant details about a stimulus, such as valence (Paulmann & Kotz, 2008a) and arousal (Paulmann & Kotz, 2006), are inferred from emotional prosody within the first 200 msec of stimulus presentation. Specifically, it has been shown that the P200 component is differentially modulated by vocal expressions of six basic emotions (anger, disgust, fear, sad, happy, pleasant surprise), which, collectively, can be distinguished from neutral prosody (Paulmann & Kotz, 2008a). Paired with the present evidence, which suggests that emotional category information is accessed very early, a pressing question for the future is to clarify which acoustical parameter(s) listeners use to activate emotion-based knowledge. This idea is being followed up by us in an acoustical parameter investigation study using an approach similar to the one adopted here.

Reversed Emotional Priming Effects

Irrespective of how listeners inferred emotions from prosodic primes, the fact that brief (200-msec) prime durations led to reversed priming effects (in contrast to longer prime durations) needs to be addressed. In line with the center-surround inhibition theory (Bermeitinger et al., 2008; Carr & Dagenbach, 1990), recent ERP studies of semantic priming have reported reversed N400 effects for faintly visible primes (prime duration $\approx$ 133 msec). It is argued that faintly visible primes can only weakly activate the concept associated with the prime; to increase the activation of the prime concept, surrounding concepts become inhibited, leading to hampered access to related targets (Bermeitinger et al., 2008; Carr & Dagenbach, 1990). Applying these arguments to the emotional priming literature, one could hypothesize that an emotional prosodic prime of short duration can only weakly activate its corresponding emotional representation, causing inhibition of related nodes (e.g., the corresponding facial expression representation). Thus, an emotionally related target facial expression would become less accessible than an unrelated target facial expression, causing more negative-going amplitudes for related targets (in contrast to unrelated targets), as was witnessed in our data.

Reversed priming effects could also be accounted for by spreading inhibition. According to this perspective, short primes are specifically ignored by participants, and, because they are less activated (i.e., ignored), such primes cause inhibition of their corresponding emotional representation units. Similar to spreading activation, inhibition then spreads to related emotional representation units, leading to their hampered availability. Thus, related targets are less accessible than unrelated targets (cf. Frings, Bermeitinger, & Wentura, 2008). Obviously, the present study was not designed to help differentiate between the center-surround and spreading inhibition approaches. Still, our results add to the observation that a conceptual relationship between primes and targets does not necessarily lead to improved processing. Under certain conditions, when primes are too short, faint, or somehow "impoverished," they can also have costs on the processing of emotionally related versus unrelated events.

Excursus: ERP Amplitude Differences Between Fearful and Nonfearful Faces

Our ERP results also gave rise to an interesting observation that was not related to the primary research question at hand: For both short- and medium-length primes, we observed more positive-going ERP amplitudes for fearful than for angry facial expressions, irrespective of prime congruency. This effect was particularly pronounced at right parietal electrode sites. Previous research has reported similar effects, in that fearful facial expressions are often reported to yield stronger and/or more distinct ERP responses (e.g., Ashley, Vuilleumier, & Swick, 2004; Eimer & Holmes, 2002; Schupp et al., 2004). For instance, Ashley et al. reported an early enhanced positivity for fearful in contrast to neutral faces. In addition, later ERP components, such as the N400 or LPC, have also been reported to differentiate between fearful and nonfearful faces (e.g., Pegna, Landis, & Khateb, 2008).

Interestingly, these ERP results are mirrored by findings reported in the functional imaging literature, where differences in activation for specific brain regions, such as the amygdala, have been reported for fearful and nonfearful facial expressions (for a review, see, e.g., Vuilleumier & Pourtois, 2007). Moreover, eyetracking studies have also revealed differences in eye movements between fearful and nonfearful faces (e.g., Green, Williams, & Davidson, 2003). To explain the processing differences between fearful and nonfearful facial expressions, some researchers have proposed that fearful expressions are evolutionarily more significant and/or more arousing than nonfearful faces and, therefore, attract more attention (e.g., Schupp et al., 2004). Clearly, more research is needed to explore the processing differences between fearful and nonfearful faces.

Where Do We Go From Here?

Researchers have shown that the meanings encoded by emotional prosody develop incrementally over time (e.g., Banse & Scherer, 1996; Pell, 2001). For sentence prosody, this could imply that certain emotional prosodic features, which may be necessary for thorough emotional evaluation, only come into play later in an utterance, as it unfolds (rather than directly, at sentence onset). In future studies, it would be meaningful to investigate whether emotional conceptual knowledge can be accessed more fully by even short prosodic fragments, resulting in normal priming effects, if fragments are not taken from sentence onset (e.g., if they are taken from emotionally stressed content words in the middle of the utterance).

Moreover, as an anonymous reviewer noted, all participants in the present study were first presented with the blocks comprising short primes. Given that prime–target trial combination differed across and within blocks, we do not think that the ERP effects obtained here were influenced by this design feature. Still, to completely exclude the possibility that effects were influenced by learning strategies, future studies could present participants with long primes first and/or mix short- and long-prime-duration presentation.

Future studies could also try to further specify the time course of conceptual knowledge processing for different positive and negative emotions. Although the present investigation reports valence-independent, N400-like priming effects (for similar results, see Schirmer et al., 2002, 2005; Zhang et al., 2006), the onset of the N400-like negativity observed here is slightly later (~90 msec) than standard N400 time windows (for an example of an even later onset, see Zhang et al., 2006). This raises the question of whether emotional priming effects generally lead to a larger variability in N400 latency when both positive and negative stimuli are presented. For instance, some emotions (e.g., fear) may foster slightly earlier conceptual analyses than do other emotions (e.g., happiness), due to their evolutionary significance (Schupp et al., 2004). Given that visual inspection of our present effects displayed an earlier onset of the reported negativity—at least at some electrode sites—it can be speculated that the time course for processing different emotional expressions is slightly different, although here they are subsumed in the present negativity time window. For differently distributed N400-like effects for angry and happy stimuli, and for effects that are in line with the assumption that differently valenced stimuli may engage different neural networks, leading to a different processing time course, see, for example, Kotz and Paulmann (2007). Moreover, this hypothesis does not seem too far-fetched if one considers that visual inspection of emotional prosody effects in Paulmann and Kotz (2008a) suggests different latencies for ERP components directly following the P200 component. Future studies could investigate the time course of conceptual processing for different emotions in greater detail to verify whether variability in the onset of the N400-like negativities is related to emotional-category-specific processing differences.

Conclusion

The present findings illustrate that even short emotional prosodic fragments can influence decisions about emotional facial expressions, arguing for a strong associative link between emotional prosody and emotional faces. In particular, it was shown that targets preceded by short (200-msec) prime durations elicit a reversed N400-like priming effect, whereas targets preceded by longer (400-msec) prime durations elicit a classic distributed

N400-like priming effect. These results argue that even brief exposure to emotional vocal expressions can lead to an early automatic activation of associated emotional knowledge in the mental store. However, subsequent target-processing steps, such as emotional-meaning evaluation, may be altered by the duration and quality of the prime stimulus. Future studies are called for to clarify which acoustic parameters within the identified time intervals are critical to guide listeners' access to emotional representations during the processing of spoken language.

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NOTE

1. Note that the N400 has also been linked repeatedly to reflecting context integration difficulties for nonlinguistic visual targets—in particular, faces (e.g., Bentin & McCarthy, 1994; Bobes, Valdés-Sosa, & Olivares, 1994; Caldara, Jermann, López Arango, & Van der Linden, 2004).

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