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*Published in:*  
Journal of Cognitive Neuroscience

*DOI:*  
[10.1162/jocn\\_a\\_00213](https://doi.org/10.1162/jocn_a_00213)

**IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.**

*Document Version*  
Publisher's PDF, also known as Version of record

*Publication date:*  
2012

[Link to publication in University of Groningen/UMCG research database](#)

*Citation for published version (APA):*

Goerlich, K. S., Witteman, J., Schiller, N. O., Van Heuven, V. J., Aleman, A., & Martens, S. (2012). The Nature of Affective Priming in Music and Speech. *Journal of Cognitive Neuroscience*, 24(8), 1725-1741. [https://doi.org/10.1162/jocn\\_a\\_00213](https://doi.org/10.1162/jocn_a_00213)

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# The Nature of Affective Priming in Music and Speech

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## Abstract

■ The phenomenon of affective priming has caught scientific interest for over 30 years, yet the nature of the affective priming effect remains elusive. This study investigated the underlying mechanism of cross-modal affective priming and the influence of affective incongruence in music and speech on negativities in the N400 time-window. In Experiment 1, participants judged the valence of affective targets (affective categorization). We found that music and speech targets were evaluated faster when preceded by affectively congruent visual word primes, and vice versa. This affective priming effect was accompanied by a significantly larger N400-like effect following incongruent targets. In this experiment, both spreading of activation and response competition could underlie the affective priming effect. In Experi-

ment 2, participants categorized the same affective targets based on nonaffective characteristics. However, as prime valence was irrelevant to the response dimension, affective priming effects could no longer be attributable to response competition. In Experiment 2, affective priming effects were observed neither at the behavioral nor electrophysiological level. The results of this study indicate that both affective music and speech prosody can prime the processing of visual words with emotional connotations, and vice versa. Affective incongruence seems to be associated with N400-like effects during evaluative categorization. The present data further suggest a role of response competition during the affective categorization of music, prosody, and words with emotional connotations. ■

## INTRODUCTION

In daily life, the ability to adequately process emotional information from our environment is of vital importance. Central to research on affective processing is the long standing “primacy of emotion” debate, which can be traced back to the founder of experimental psychology (Wundt, 1907). The affective primacy hypothesis assumes that humans are endowed with an evaluative decision mechanism allowing them to automatically evaluate affective stimulus information (e.g., Zajonc, 1980, 1984; Arnold, 1960; Bartlett, 1932). In line with this hypothesis, Fazio, Sanbonmatsu, Powell, and Kardes (1986) showed that participants need less time to judge the affective valence of a target stimulus (e.g., “ugly”) if it is preceded by an affectively related prime (e.g., “hate”). This affective priming effect is thought to be an early, fast-acting, automatic process that can occur outside conscious awareness (for reviews, see Klauer & Musch, 2003; Fazio, 2001). Affective priming has been found for a variety of stimuli, such as pictures, prosody (i.e., melodic and rhythmic aspects of speech), music, and odors. The affective priming effect has caught scientific interest for more than three decades, yet the exact nature of the mechanism causing affective priming remains unclear.

Early explanations proposed spreading of activation as the mechanism underlying affective priming. The spreading

of activation account (e.g., Spruyt, Hermans, De Houwer, & Eelen, 2002; De Houwer, Hermans, & Spruyt, 2001; Bargh, Chaiken, Raymond, & Hymes, 1996; Anderson, 1983) assumes an associative network of interconnected concept nodes, in which affective valence is represented. An affective prime preactivates the representations of affectively related targets at the conceptual level by spreading of activation through this network and thereby leads to faster encoding of targets with the same valence as the prime.

More recently, researchers have begun to conceptualize the affective priming effect in terms of conflict at the response stage of processing rather than at the conceptual level (e.g., De Houwer, Hermans, Rothermund, & Wentura, 2002; Wentura, 1999, 2000). According to this account, an affective prime automatically triggers a response tendency that corresponds to its valence. This leads to response facilitation for targets with the same valence as the prime and to response inhibition when the valence of the target is different from the valence of the prime (Stroop-like interference process). Note that the two accounts need not be mutually exclusive.

Music, the “language of the emotions” (Scherer, 1995), and speech prosody, the vocal expression of emotions (“melody of speech”), have long been assumed to share a common ancestry (Brown, 2000; Dissanayake, 2000; Pinker, 1995; Joseph, 1988; Rousseau, 1986; Helmholtz, 1954). Recent studies on the expression of emotion through music and speech have shown that both involve similar emotion-specific acoustic cues (such as pitch, tempo, and intensity),

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through which emotion is conveyed in similar ways (Ilie & Thompson, 2006; Juslin & Laukka, 2003; Zatorre, Belin, & Penhune, 2002). Such acoustic attributes are thought to be connected with affective connotations that are used to communicate discrete emotions in both vocal and musical expression of emotion (Ilie & Thompson, 2006; Juslin & Laukka, 2003). Recent studies have suggested that both affective speech prosody and music may influence the processing of visual affective stimuli (e.g., Schirmer, Kotz, & Friederici, 2002, 2005; Bostanov & Kotchoubey, 2004; Schirmer & Kotz, 2003 [for prosody]; Jolij & Meurs, 2011; Steinbeis & Koelsch, 2008, 2011; Daltrozzo & Schön, 2009; Logeswaran & Bhattacharya, 2009; Kotz & Paulmann, 2007; Koelsch et al., 2004; Sollberger, Reber, & Eckstein, 2003 [for music]). Electrophysiological studies employing affective priming paradigms found that the N400, an ERP known to be elicited by semantic mismatches (for a review, see Kutas & Federmeier, 2011), also occurs for mismatches in affective meaning between speech prosody and visually presented words (e.g., Schirmer et al., 2002, 2005; Schirmer & Kotz, 2003). Recently, the N400 has additionally been observed for mismatches in affective meaning between music and linguistic stimuli (Steinbeis & Koelsch, 2008, 2011; Daltrozzo & Schön, 2009; see Koelsch, in press, for a review on musical meaning processing). In this study, we employed both speech prosody and music to compare the capability of both media of interacting with the processing of linguistic stimuli in a cross-modal affective priming paradigm.

The N400 in response to affectively incongruent prosody and music has generally been interpreted to reflect spreading of activation (e.g., Steinbeis & Koelsch, 2008, in press; Daltrozzo & Schön, 2009). However, studies investigating the underlying mechanisms of affective priming have pointed out the importance of response competition in such affective evaluation tasks (e.g., Bartholow, Riordan, Saults, & Lust, 2009; Wentura, 1999; Klauer, Roßnagel, & Musch, 1997). One method to test the contribution of response competition to affective priming is to have subjects categorize affective stimuli based on nonaffective characteristics or to name the affective targets. As the prime does not convey response-relevant information in these situations, conflict at the response level is eliminated, while spreading of activation remains as a possible mechanism of affective priming. Interestingly, affective priming effects have been observed less reliably in studies using nonaffective categorization of affective targets and naming paradigms than in the affective evaluation paradigm (e.g., Spruyt, Hermans, Pandelaere, De Houwer, & Eelen, 2004; De Houwer et al., 2002; Klauer & Musch, 2001; Klinger, Burton, & Pitts, 2000; De Houwer, Hermans, & Eelen, 1998; but see Spruyt, De Houwer, Hermans, & Eelen, 2007; De Houwer & Randell, 2004; Spruyt, Hermans, De Houwer, & Eelen, 2004, for positive evidence of affective priming in such tasks). Such failures to find affective priming effects during nonaffective categorization tasks illustrate the role of response conflict during affective priming. Taken to-

gether, a number of studies using behavioral paradigms have provided evidence for a contribution of response competition to affective priming in the evaluative categorization task. It is important to note, however, that affective priming effects may not be exclusively explained by either spreading of activation or response competition but may also depend on contextual and attentional factors. In fact, Gawronski and coworkers recently showed that affective priming effects in a paradigm based on response conflict (affective evaluation) depended on participants' attention to the category membership of the primes (Gawronski, Cunningham, LeBel, & Deutsch, 2010). This demonstrates that affective evaluations as assessed by implicit measures may not be as rigid and inflexible as previously assumed but may vary with depth of processing and attention under task-specific conditions.

At the electrophysiological level, two previous studies have investigated the contribution of conflict at the response level to affective priming effects during evaluative categorization using visual primes and targets. Bartholow and colleagues (2009) showed that an important factor in driving affective priming effects between words with positive and negative connotations indeed lies in the response system: After prime onset, preferred response activation occurred in motor cortex, as the lateralized readiness potential (LRP) indicated. In addition, increased N2 amplitudes in affectively incongruent conditions suggested that response conflict occurred when the response activated by the prime differed from the target response. Eder and coworkers tested the contribution of semantic priming versus response priming on affective priming between pictures and words (Eder, Leuthold, Rothermund, & Schweinberger, in press). These authors likewise used the LRP to measure prime-induced response activations and further tested the effect of affective incongruence on the P300 and the N400. Their findings show an earlier-occurring stimulus-locked LRP in affectively congruent conditions and increased amplitudes of the N400 in affectively incongruent conditions, whereas the P300 remained unaffected by affective congruence. The authors concluded that both semantic priming and response priming are likely to constitute affective priming effects in the evaluative categorization task.

In summary, the view that affective priming is driven only by spreading of activation has recently been challenged by studies employing electrophysiology in combination with behavioral measures. Using unimodal visual priming paradigms, these studies suggested that conflict at the response level contributes to affective priming in the evaluative categorization task. This study tested for the first time the mechanisms contributing to cross-modal affective priming between auditory and visual stimuli by systematically varying the possibility of response conflict to occur between two otherwise identical experiments. Furthermore, we aimed to compare the capability of speech prosody and music of affectively priming visually presented linguistic stimuli. To this end, we employed a cross-modal

paradigm to test affective priming effects between music, speech prosody, and visually presented words with affective connotations at the behavioral level as well as the impact of affective congruence on negativities in the N400 time-window.

The study comprised two experiments: Experiment 1 aimed to test the occurrence of cross-modal affective priming by emotional music and speech on visually presented word targets, and vice versa. Participants judged the affective valence of the targets (affective categorization task). In this experiment, spreading of activation as well as response competition may cause the affective priming effect. We hypothesized to find a behavioral affective priming effect (longer RTs) for affectively incongruent music, speech, and word targets, accompanied by increased negativities in the N400 time-window in affectively incongruent compared with congruent conditions.

Experiment 2 employed the same stimuli as Experiment 1. However, participants were now asked to categorize the targets based on nonaffective characteristics (nonaffective categorization task), excluding response competition to occur while still allowing for spreading of activation. If the affective priming effect and N400-like effect in Experiment 1 were indeed caused by response competition, no affective priming effect and no negativities in the N400 range should be found in Experiment 2.

## METHODS

### Participants

Thirty-two students (16 men, mean age = 23.8 years,  $SD = 4.4$  years) from the University of Groningen participated in Experiment 1; 49 different students (24 men, mean age = 23.3 years,  $SD = 4.9$  years) in Experiment 2. All participants were right-handed native speakers of Dutch and had normal or corrected-to-normal vision and no hearing impairment. None of the participants were professional musicians. Participants received € 20 for their participation in the 2-hr EEG session. Informed consent was obtained from all participants before the study. The study was approved by the local ethics committee of the BCN Neuroimaging Center Groningen and was conducted in accordance with the Declaration of Helsinki.

### Stimuli

The stimulus set comprised 48 words for visual presentation (24 positive, 24 negative, with 50% denoting persons and 50% denoting objects), 48 pseudowords spoken in happy (24) and sad (24) prosody, and 48 music segments expressing happy (24) or sad (24) emotion. All stimuli were validated in three separate pilot studies before the experiment.

In the visual word pilot, 10 independent raters of Leiden University judged the words with emotional connotations

on a 9-point Likert scale ( $-4 = \textit{very negative}$ ,  $0 = \textit{neutral}$ ,  $4 = \textit{very positive}$ ). Only words rated 3 or higher by 9 of 10 raters were included as positive word stimuli; only words rated  $-3$  or lower by 9 of 10 raters were included as negative word stimuli. Table 1 shows the positive and negative words used as experimental stimuli in both experiments.

For the prosody pilot, bisyllabic pseudowords that obeyed Dutch phonotactics were recorded with the help of an actress, cut to a length of approximately 600 msec, and amplitude-normalized using the Praat speech processing software (Boersma & Weenink, 1996). The normalization procedure amplified every stimulus item, such that the digitalized sample with the maximum amplitude was set at the maximum positive or negative value of the converter range, and all other samples were scaled proportionally. As a result, all stimuli had about equal intensity. Ten independent raters at Leiden University judged the pseudowords on a 9-point Likert scale ( $-4 = \textit{very sad}$ ,  $0 = \textit{neutral}$ ,  $4 = \textit{very happy}$ ) with the additional option to choose “other” if another emotion than happy or sad was perceived. Only pseudowords rated 3 or higher for happy prosody and  $-3$  or lower for sad prosody by 9 of 10 raters were included in the study.

Music excerpts were created from a number of piano and guitar compositions by Western classical music composers (e.g., Bach, Beethoven, Chopin, Mendelssohn; for a full list of compositions, see Table 2). From these compositions, segments with a length of 600 msec were excerpted in Praat (cut at zero-crossings), amplitude normalized and subsequently judged by 13 independent raters at the University of Groningen on a 9-point Likert scale ( $-4 = \textit{very sad}$ ,  $0 = \textit{neutral}$ ,  $4 = \textit{very happy}$ ) with the additional option to choose “other” if another emotion than happy or sad was perceived. Only music segments rated 3 or higher for happy music and  $-3$  or lower for sad music by 11 of 13 raters were included in the study.

Only piano segments served as experimental stimuli. Guitar segments were additionally included as fillers in Experiment 2 for the purpose of an instrument categorization task (piano vs. guitar).

### Procedure

The cross-modal affective priming paradigm used in Experiments 1 and 2 included four main conditions (see Figure 1): *MusicTarget* (music target preceded by visual word prime), *ProsodyTarget* (prosody target preceded by visual word prime), *MusicPrime* (visual word target preceded by music prime), and *ProsodyPrime* (word target preceded by prosody prime). Each main condition comprised two congruent and two incongruent subconditions (congruent: positive prime–positive target, negative prime–negative target; incongruent: positive prime–negative target, negative prime–positive target). Each of the four main conditions (*MusicTarget*, *ProsodyTarget*, *MusicPrime*, *ProsodyPrime*) consisted of 96 trials. Overall, each word, prosody, and music stimulus was presented twice,

**Table 1.** Affective Word Stimuli (Dutch Originals and English Translation) Used in Experiments 1 and 2

	<i>Positive Words</i>	<i>English Translation</i>	<i>Negative Words</i>	<i>English Translation</i>
1	Bloem	<i>Flower</i>	Beul	<i>Hangman</i>
2	Bonbon	<i>Chocolate</i>	Bom	<i>Bomb</i>
3	Cake	<i>Cake</i>	Braaksel	<i>Vomit</i>
4	Echtpaar	<i>Married couple</i>	Dief	<i>Thief</i>
5	Expert	<i>Expert</i>	Galg	<i>Gallows</i>
6	Genie	<i>Genius</i>	Graf	<i>Grave</i>
7	Geschenk	<i>Present</i>	Hoer	<i>Whore</i>
8	Goedzak	<i>Good soul</i>	Junk	<i>Junk</i>
9	Held	<i>Hero</i>	Klootzak	<i>Asshole</i>
10	Honing	<i>Honey</i>	Monster	<i>Monster</i>
11	Ijsje	<i>Ice cream</i>	Pijnbank	<i>Rack</i>
12	Kanjer	<i>Hunk</i>	Pis	<i>Piss</i>
13	Lieverd	<i>Darling</i>	Pus	<i>Pus</i>
14	Maatje	<i>Buddy</i>	Racist	<i>Racist</i>
15	Paleis	<i>Palace</i>	Sadist	<i>Sadist</i>
16	Parel	<i>Perl</i>	Schijt	<i>Sbit</i>
17	Roos	<i>Rose</i>	Slet	<i>Shut</i>
18	Satijn	<i>Satin</i>	Sloerie	<i>Shut</i>
19	Schatje	<i>Baby</i>	Tiran	<i>Tyrant</i>
20	Snoep	<i>Candy</i>	Tumor	<i>Tumor</i>
21	Vriend	<i>Friend</i>	Vandaal	<i>Vandal</i>
22	Vriendin	<i>Girlfriend</i>	Vergif	<i>Poison</i>
23	Winnaar	<i>Winner</i>	Vetkwab	<i>Fat roll</i>
24	Zon	<i>Sun</i>	Viespeuk	<i>Dirt bag</i>

once congruent and once incongruent, eliminating stimulus characteristics as an explanation of priming effects. Prime–target pairs were created in a randomized fashion. The order in which prime–target pairs were presented was random with the restriction that consecutive targets or primes were never the same and no more than three targets were presented consecutively. The four main conditions were presented in four separate blocks, whose order of presentation was counterbalanced according to a Latin square.

Stimulus presentation was controlled using E-Prime (1.2). Each trial started with a black fixation cross in the middle of the screen (1500 msec), followed by a red fixation cross (500 msec) signaling the occurrence of the prime. To reduce blink artifacts, participants were instructed to blink when the fixation cross was black and not to blink anymore when it turned red. When the red fixation cross disappeared, the prime was presented, followed by the target after 200 msec. The SOA of 200 msec

was chosen based on findings that the affective priming effect dissipates after 300 msec (Hermans, De Houwer, & Eelen, 2001). RT was recorded from the onset of the target.

In Experiment 1, participants were to judge the pleasantness of the target as fast and accurately as possible (affective categorization task). In Experiment 2 (nonaffective semantic/phonological categorization task), participants judged whether a visual target word was an object or a person, whether a spoken pseudoword contained a monophthong (pure vowel) or a diphthong (gliding vowel), or whether a music segment was played by a piano or a guitar.

### ERP Recordings

EEG was recorded from 64 tin electrodes mounted in an elastic electro cap organized according to the international



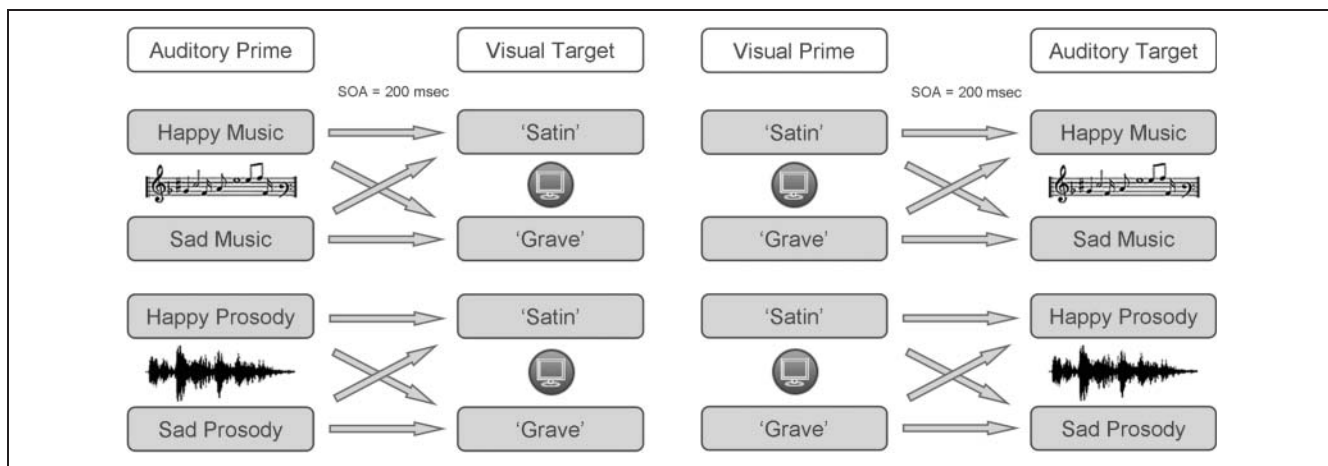
10/20 system. EEG data were recorded with a linked mastoid physical reference and were rereferenced using an average reference. Bipolar vertical and horizontal EOGs were recorded for artifact rejection purposes. The ground electrode was applied to the sternum. Impedance of all electrodes was kept below 5 k $\Omega$  for each participant. EEG

was continuously recorded with a sampling rate of 500 Hz, amplified, and off-line digitally low-pass filtered with a cut-off frequency of 30 Hz. Participants were seated in front of a monitor at a distance of approximately 50 cm in a dimly lit, electrically shielded and sound-attenuated booth. Music and speech stimuli were presented via loudspeakers placed

**Table 2.** Piano and Guitar Compositions Used as a Basis for the Musical Stimuli

<i>Instrument</i>	<i>Valence</i>	<i>Composer</i>	<i>Composition</i>		
Piano	Happy	Johann Sebastian Bach	Violin Partita in E major (piano transcription), Suite: <i>Prelude</i> Violin Partita in E major (piano transcription), Suite: <i>Gigue</i>		
		Felix Mendelssohn	“A Midsummer Night’s Dream” for Piano, TN iii/7: <i>Scherzo</i> Pièces caractéristiques (7), Op. 7: <i>Leicht und Luftig</i>		
		Fryderyk Chopin	Etude in G flat major		
		Jean Sibelius	Five Pieces for Piano, Op. 85: <i>Bellis</i>		
		Ludwig van Beethoven	Sonata No. 14 in C sharp minor, Op. 27 No. 2 “Moonlight”: <i>Adagio sostenuto</i> Sonata No. 8 in C minor, Op. 13 “Pathétique”: <i>Adagio cantabile</i>		
Guitar	Happy	Fryderyk Chopin	Nocturne Op. 27 No. 1: C sharp Minor Nocturne B I 49: C sharp minor		
		Felix Mendelssohn	Pièces caractéristiques (7), Op. 6: <i>Sehnsuchtig</i>		
		Moreno Torroba	Sonatina: <i>Allegretto</i> Sonatina: <i>Allegro</i> Castillos de España: <i>Turégano</i> Castillos de España: <i>Olites</i> <i>Aires de la Mancha</i>		
		Johan Sebastian Bach	Sonata in A minor, BWV 1003: <i>Allegro</i> Sonata in A minor, BWV 1003: <i>Fuga</i>		
		Isaac Albéniz	<i>Sevilla</i>		
		Edward Grieg	Op. 12 No. 6: <i>Norwegian Melody</i>		
		Ferdinand Sor	<i>Aire Venezolano</i> (harmonized by Vicente Emilio Sojo)		
		Francisco Tárrega	<i>Maria</i>		
		Guitar	Sad	Frederico Mompou	Suite Compostelana: <i>Canción</i> Suite Compostelana: <i>Cuna</i> Suite Compostelana: <i>Coral</i>
				Isaac Albéniz	<i>Mallorca</i>
Johann Sebastian Bach	Sonata in A minor, BWV 1003: <i>Grave</i>				
Francisco Tárrega	<i>Endecha</i>				
Robert de Visée	<i>Changing my tune</i>				

Excerpts with a length of 600 msec were extracted from these compositions and validated in pilot studies, resulting in 24 happy and 24 sad piano excerpts as well as 24 happy and 24 sad guitar excerpts. Piano excerpts served as experimental stimuli in both experiments; guitar excerpts were additionally included in Experiment 2.



**Figure 1.** Design of the cross-modal affective priming paradigm. Happy or sad speech prosody and music segments with a length of 600 msec primed visually presented words with positive or negative connotations, presented for 600 msec, in affectively congruent (straight arrows) or affectively incongruent (skewed arrows) conditions, and vice versa. SOA was kept constant at 200 msec in all conditions.

at the left and right side of the participant at approximately 70 dB.

### Data Analysis

The EEG data were analysed with Brain Vision Analyzer (version 1.05). Before averaging, trials with eye movement and blink artifacts were excluded from analysis. Criteria for artifact rejection within an epoch were a maximal voltage step of 50  $\mu\text{V}$ , a maximal difference between two values in a segment of 100  $\mu\text{V}$ , and a minimum and maximum amplitude of  $-100$  and  $100$   $\mu\text{V}$ , respectively.

For Experiment 1, all 32 participants (16 men) were included in the analysis. For Experiment 2, one participant was excluded because of noisy ERP data, leaving a total of 48 participants (25 men) for analysis. ERP epochs for each participant were computed in a 1000-msec time-window and aligned to a 100-msec prestimulus baseline. Mean amplitudes for music, speech, and word targets were computed at the N400 time-window (400–500 msec after target-onset) for affectively congruent and incongruent conditions in each participant. This time-window was chosen based on previous N400 literature and on visual inspection of the data, which showed consistent differences between conditions for affectively congruent and incongruent targets between 400 and 500 msec.

Regional repeated measures ANOVA (RM-ANOVA) was conducted in SPSS (17.0) using 30 electrodes in six regions (anterior, central, posterior) in the left and right hemisphere. The left anterior region included electrodes F3, F5, F7, FC3, and FC5; the right anterior region included electrodes F4, F6, F8, FC4, and FC6. The left central region included electrodes C3, C5, CP3, CP5, and T7; the right central region included electrodes C4, C6, CP4, CP6, and T8. The left posterior region included electrodes P3, P5, P7, PO3, and PO5; the right posterior region included electrodes P4, P6, P8, PO4, and PO6. Figure 2 depicts an elec-

trode map with the six regions of electrodes used for analysis.

To test for the effect of prime valence on target processing, the factors Prime Valence (positive vs. negative) and Target Valence (positive vs. negative) were entered into the analysis separately. A significant interaction between Prime Valence and Target Valence, indicating ERP differences between affectively congruent and incongruent conditions was interpreted as an affective priming effect. As the main goal of this study was to examine affective priming effects, only the results of the Prime Valence  $\times$  Target Valence interaction (i.e., the affective priming effect) and the factors qualifying this interaction at the behavioral and electrophysiological level are presented. In case of sphericity violations, Greenhouse–Geisser corrected  $p$  values are reported.

### BEHAVIORAL RESULTS

Behavioral data analysis showed that performance was higher than 90% in all conditions, indicating ceiling effects. Therefore, only the results of the RT analyses on correctly identified targets are reported. Significant interactions between prime and target indicate an affective priming effect. Table 3 shows the mean RTs to positive and negative targets in affectively congruent and incongruent conditions in both experiments. Further information on the percentage of affective priming effects is provided by Table 4 for Experiment 1 ( $n = 32$ ) and by Table 5 for Experiment 2 ( $n = 49$ ).

First, a full ANOVA including the factors Condition (Music-Target vs. Prosody-Target vs. Music-Prime vs. Prosody-Prime), Prime Valence (positive vs. negative), and Target Valence (positive vs. negative) was conducted, with Sex (male vs. female) and Experiment (1 vs. 2) as between-subject factors. Results showed that there were significant prime–target interactions for RT in Experiment 1 (see Figure 3)

but not in Experiment 2 (see Figure 4), indicated by a significant three-way interaction Prime Valence × Target Valence × Experiment,  $F(1, 77) = 24.29, p < .001$  (see Figure 5 for a comparison of the overall affective priming effect between the two experiments). Follow-up ANOVAs were subsequently performed in each condition for Experiment 1 (affective categorization) and Experiment 2 (nonaffective categorization).

### Experiment 1: Affective Categorization

#### MusicTarget

Participants evaluated music segments preceded by affectively congruent visual word primes significantly faster than music segments preceded by affectively incongruent word primes. RM-ANOVA revealed a significant two-way Prime Valence × Target Valence interaction [ $F(1, 30) = 27, p < .001$ ], indicating a behavioral affective priming effect for congruent music targets.

#### ProsodyTarget

Prosody targets were evaluated significantly faster when preceded by affectively congruent visual word primes compared with prosody targets preceded by incongruent word primes. RM-ANOVA revealed a significant two-way Prime Valence × Target Valence interaction for RT [ $F(1,$

$30) = 13.1, p < .001$ ], indicating a behavioral affective priming effect for congruent prosody targets.

#### MusicPrime

There was a trend to evaluate visual word targets faster when preceded by affectively congruent music primes compared with incongruent music primes. RM-ANOVA revealed a trend of the Prime Valence × Target Valence interaction for RT [ $F(1, 30) = 3.4, p = .073$ ]. Music excerpts as primes elicited behavioral affective priming effects in only 56% of the participants (Table 4).

#### ProsodyPrime

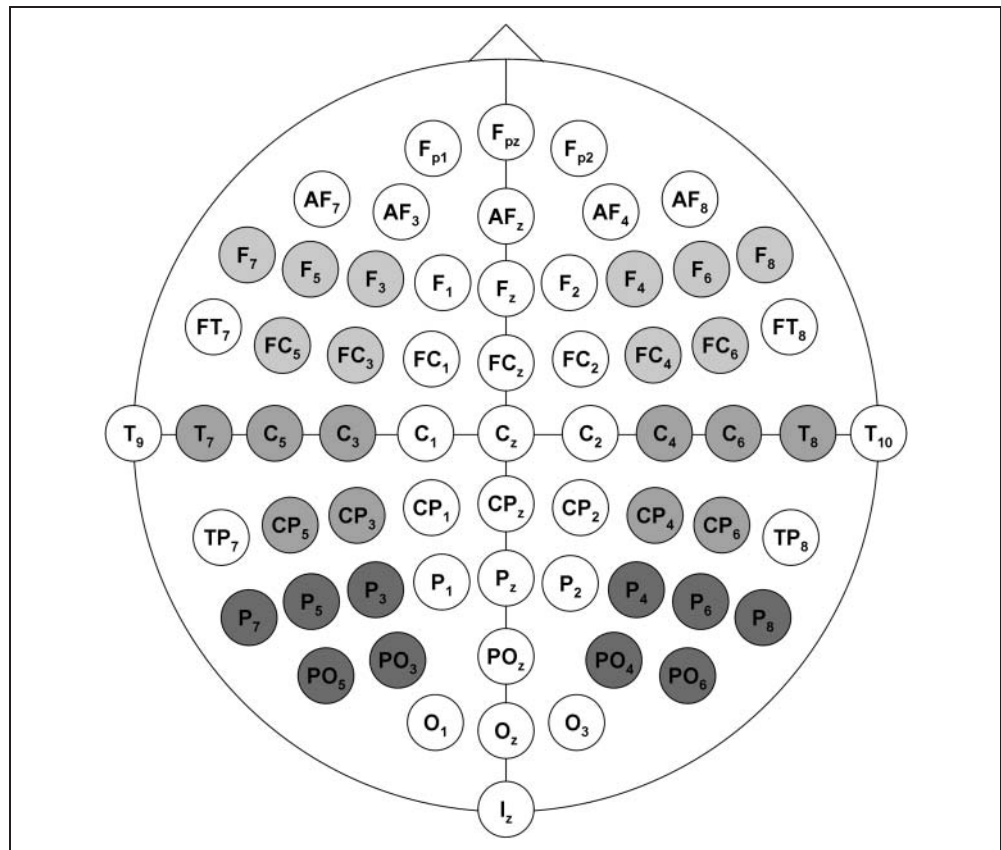
When preceded by affectively congruent prosody primes, visual words were evaluated significantly faster than words preceded by affectively incongruent prosody primes. RM-ANOVA revealed a significant two-way Prime Valence × Target Valence interaction for RT [ $F(1, 30) = 14.6, p < .001$ ]. Table 4 shows the frequency of affective priming effects in the four conditions of Experiment 1.

### Experiment 2: Nonaffective Categorization

#### MusicTarget

RM-ANOVA revealed that the two-way Prime Valence × Target Valence interaction was not significant for RT [ $F(1,$

**Figure 2.** Electrode map, with left and right anterior, central, and posterior regions identified.





**Table 3.** RTs in Response to Positive and Negative Targets in Congruent Compared with Incongruent Conditions in Experiment 1 (Affective Categorization) and Experiment 2 (Nonaffective Categorization)

Condition	Target Valence	Congruent Conditions		Incongruent Conditions	
		Mean (msec)	SD (msec)	Mean (msec)	SD (msec)
<i>Experiment 1</i>					
Music Target	Positive	589.39	84.24	625.66	85.31
	Negative	615.21	80.23	644.66	100.33
Prosody Target	Positive	691.13	128.89	736.66	129.28
	Negative	700.00	140.29	715.99	122.89
Music Prime	Positive	578.85	63.91	601.08	64.61
	Negative	591.26	71.13	586.50	53.58
Prosody Prime	Positive	612.42	94.11	637.85	96.52
	Negative	628.72	90.34	631.97	96.28
<i>Experiment 2</i>					
Music Target	Positive	707.68	122.03	697.59	116.91
	Negative	771.69	128.75	780.85	128.68
Prosody Target	Positive	903.98	146.82	890.03	155.47
	Negative	913.24	162.15	919.63	144.12
Music Prime	Positive	599.98	78.15	606.10	81.65
	Negative	617.38	81.84	614.21	80.29
Prosody Prime	Positive	651.00	97.18	650.57	91.87
	Negative	668.49	94.01	660.45	98.69

47) < 1], indicating the absence of an affective priming effect for music targets preceded by word primes during nonaffective semantic/phonological categorization.

#### *ProsodyTarget*

RM-ANOVA revealed a nonsignificant two-way Prime Valence × Target Valence interaction for RT [ $F(1, 47) < 1$ ], indicating the absence of an affective priming effect for prosody targets preceded by word primes during semantic/phonological categorization.

**Table 4.** Frequency of Affective Priming Effects in the 32 Participants of Experiment 1

Condition	Frequency (%)	Mean (msec)	SD (msec)
Music Target	87.50	41.31	29.44
Prosody Target	75.00	47.98	42.16
Music Prime	56.25	26.56	20.71
Prosody Prime	75.00	23.71	13.58

Mean and standard deviations (SD) of the difference in RTs between affectively congruent and incongruent conditions are shown.

#### *MusicPrime*

No affective priming effect during semantic/phonological categorization was found for word targets preceded by music primes, as a nonsignificant two-way Prime Valence × Target Valence interaction [ $F(1, 47) < 1$ ] indicated.

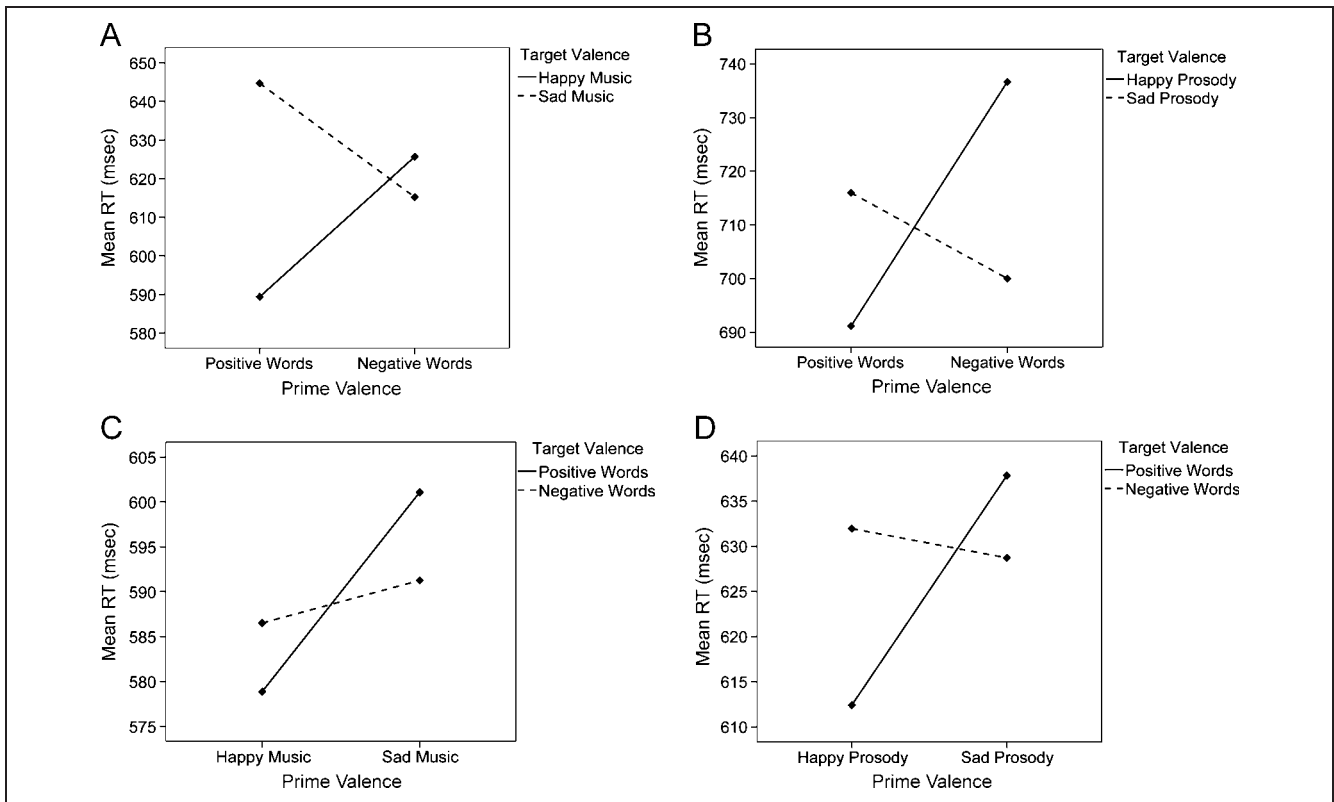
#### *ProsodyPrime*

No affective priming effect was found during semantic/phonological categorization of target words preceded by prosody primes. RM-ANOVA revealed a nonsignificant

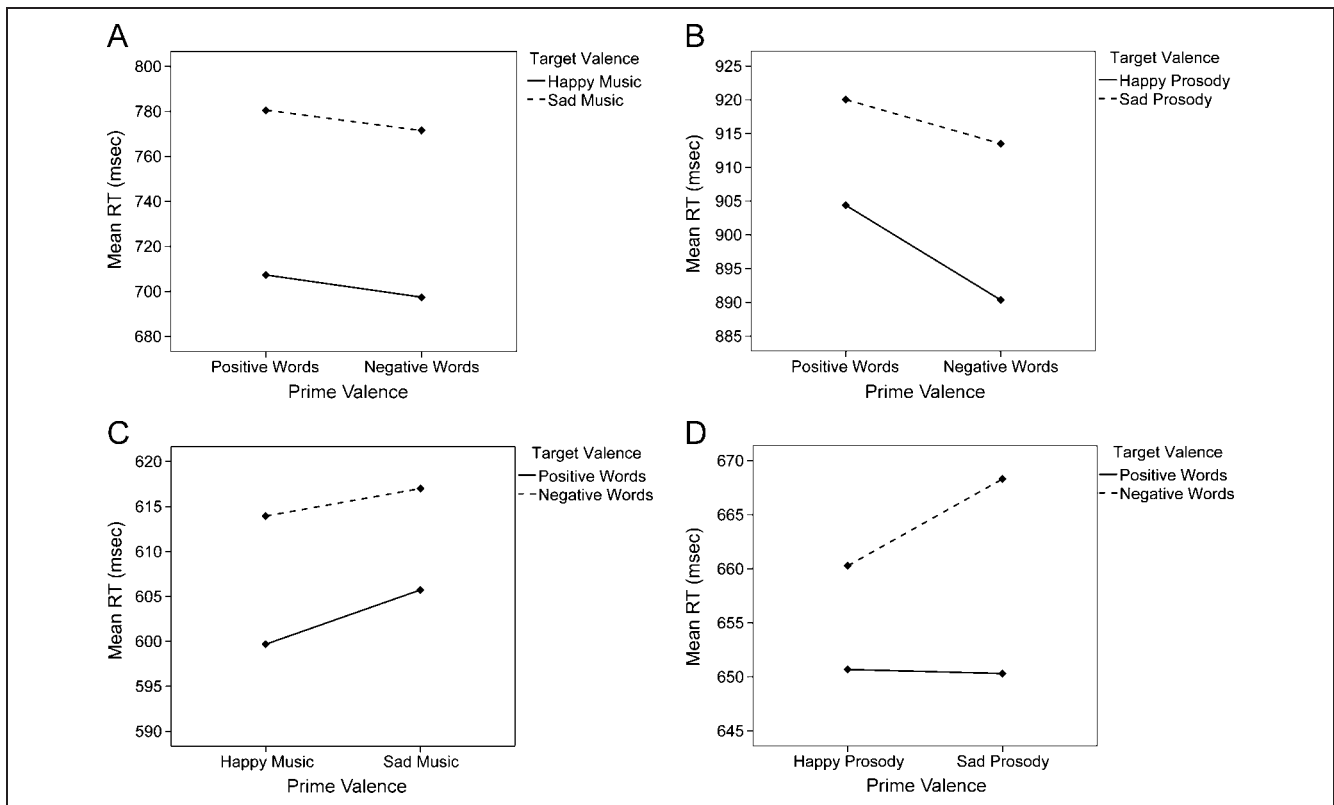
**Table 5.** Frequency of Affective Priming Effects in the 49 Participants of Experiment 2

Condition	Frequency (%)	Mean (msec)	SD (msec)
Music Target	55.00	13.35	14.32
Prosody Target	41.00	25.55	20.56
Music Prime	57.00	11.25	12.67
Prosody Prime	55.00	25.84	19.85

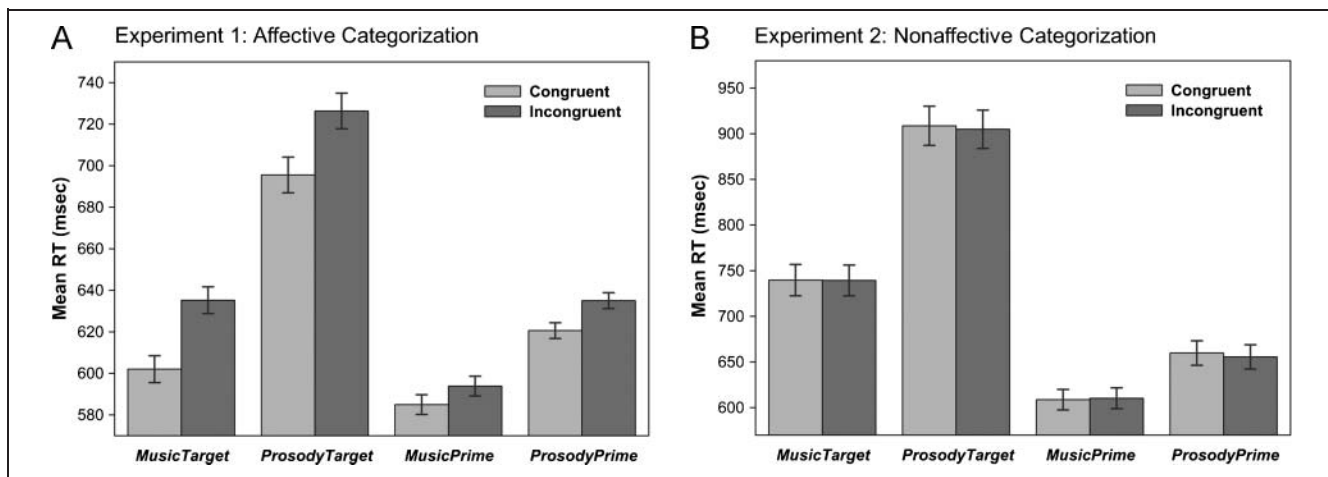
Mean and standard deviations (SD) of the difference in RTs between affectively congruent and incongruent conditions are shown.



**Figure 3.** Affective priming effects during affective categorization in Experiment 1. RTs for happy and sad music and prosody targets and for positive and negative word targets following affectively congruent and incongruent primes are depicted. (A) MusicTarget,  $p < .001$ ; (B) ProsodyTarget,  $p < .001$ ; (C) MusicPrime,  $p < .073$ ; (D) ProsodyPrime,  $p < .001$ .



**Figure 4.** Lack of affective priming effects during nonaffective categorization in Experiment 2. RTs for happy and sad music and prosody targets and for positive and negative word targets following affectively congruent and incongruent primes are depicted. (A) MusicTarget,  $F < 1$ ; (B) ProsodyTarget,  $p < .476$ ; (C) MusicPrime,  $F < 1$ ; (D) ProsodyPrime,  $p < .200$ .



**Figure 5.** Comparison of the overall effect of affective congruence on RTs between affective categorization in Experiment 1 (A) and nonaffective categorization in Experiment 2 (B) for the four experimental conditions. Error bars indicate 95% confidence intervals.

two-way Prime Valence  $\times$  Target Valence interaction for RT [ $F(1, 47) = 1.7, p = .200$ ]. Table 5 shows that the frequency of affective priming effects in the four conditions of Experiment 2 was at chance level.

## ERP RESULTS

First, a full RM-ANOVA was conducted on mean voltages within the N400 time-window including the factors Condition (*MusicTarget* vs. *ProsodyTarget* vs. *MusicPrime* vs. *ProsodyPrime*), Prime Valence (positive vs. negative), Target Valence (positive vs. negative), Region (anterior vs. central vs. posterior), and Hemisphere (left vs. right), with Sex (male vs. female) and Experiment (1 vs. 2) as between-subject factors. Mean N400 amplitudes served as the dependent measure.

Results showed that the prime–target interactions significantly differed between Experiment 1 (see Figure 6) and Experiment 2 (see Figure 7) at the N400 time-window, indicated by a significant three-way interaction Prime Valence  $\times$  Target Valence  $\times$  Experiment [ $F(1, 77) = 11.39, p < .001$ ]. This interaction was further qualified by the factor Condition, as suggested by a significant four-way interaction Prime Valence  $\times$  Target Valence  $\times$  Experiment  $\times$  Condition [ $F(3, 231) = 3.38, p < .02$ ]. Follow-up ANOVAs were subsequently performed for each of the four conditions in Experiment 1 (affective categorization) and Experiment 2 (nonaffective categorization).

### Experiment 1: Affective Categorization

#### *MusicTarget*

RM-ANOVA revealed a significant two-way Prime Valence  $\times$  Target Valence interaction for music targets at the N400 time-window [ $F(1, 30) = 4.8, p = .036$ ], indicating larger negativities for incongruent compared with congruent

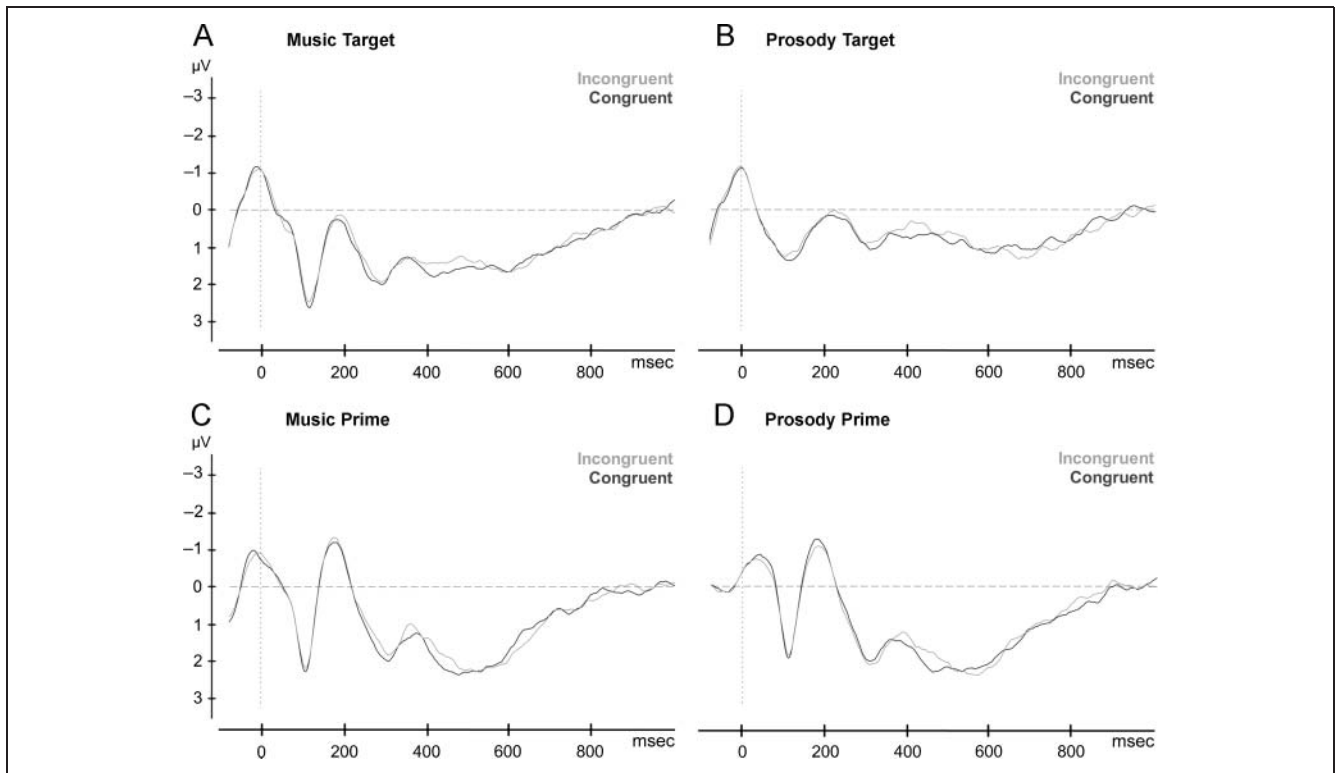
music targets. The data also showed a significant three-way interaction Prime Valence  $\times$  Target Valence  $\times$  Sex for music targets [ $F(1, 30) = 7.6, p = .010$ ], suggesting that this effect was stronger in female than in male participants. However, sex as between-subject factor did not reach significance [ $F(1, 30) < 1$ ]. The Prime Valence  $\times$  Target Valence interaction was not qualified by region or hemisphere, suggesting a global scalp distribution of the N400-like effect. See Figure 8 for a comparison between topographies of this N400-like effect between the four conditions of Experiment 1.

#### *ProsodyTarget*

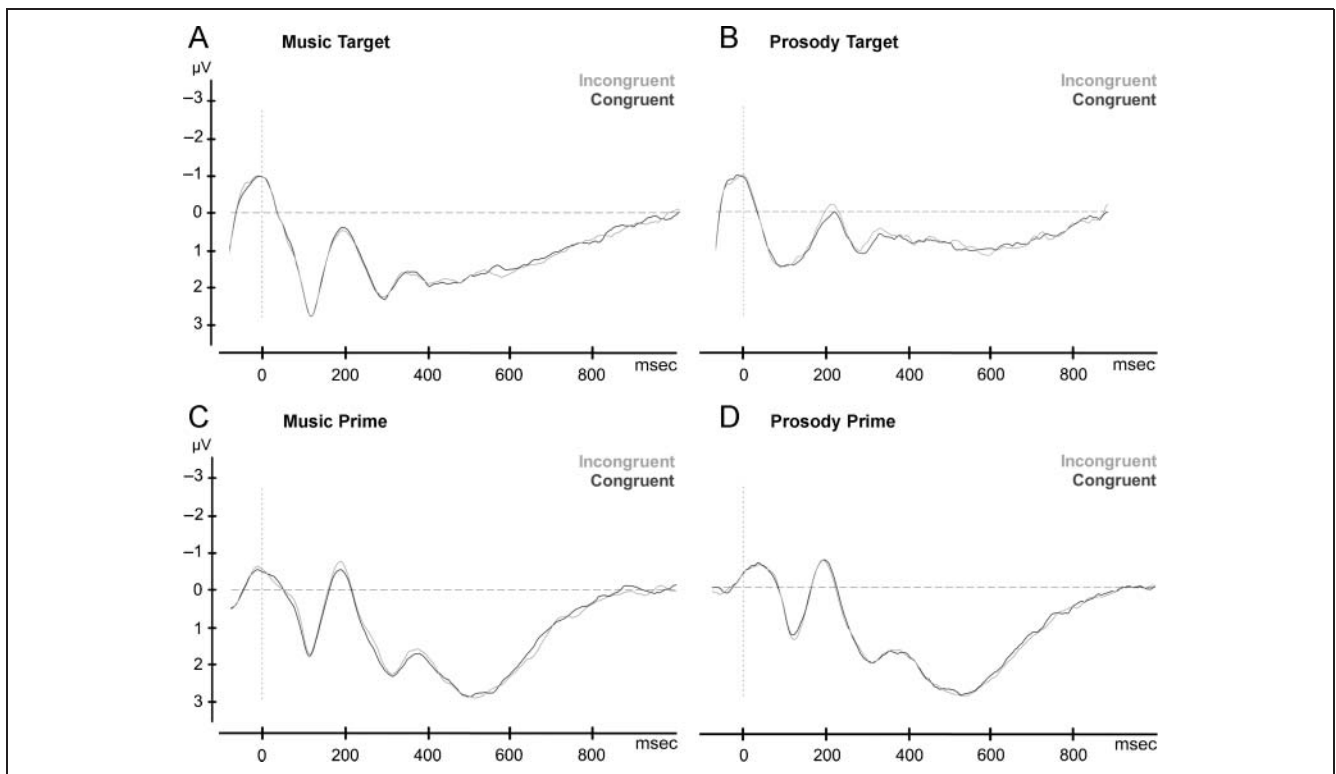
A significant two-way Prime Valence  $\times$  Target Valence interaction was observed for prosody targets at the N400 time-window [ $F(1, 30) = 4.8, p = .036$ ], indicating larger negativities for incongruent compared with congruent prosody targets. The Prime Valence  $\times$  Target Valence interaction was not qualified by region or hemisphere, suggesting a global scalp distribution of the N400-like effect.

#### *MusicPrime*

A significant three-way interaction Prime Valence  $\times$  Target Valence  $\times$  Region was found for visual word targets preceded by music primes at the N400 time-window [ $F(1.1, 33.1) = 8.3, p = .006$ ], accompanied by a main effect of region [ $F(1.1, 33.5) = 45.7, p < .001$ ], whereas the two-way interaction Prime Valence  $\times$  Target Valence did not reach significance [ $F(1, 30) < 1$ ]. This indicates significantly larger negativities for word targets following incongruent music primes compared with congruent primes only at anterior regions, as separate ANOVAs for each region revealed: at anterior regions, the two-way interaction Prime Valence  $\times$  Target Valence was significant [ $F(1,$

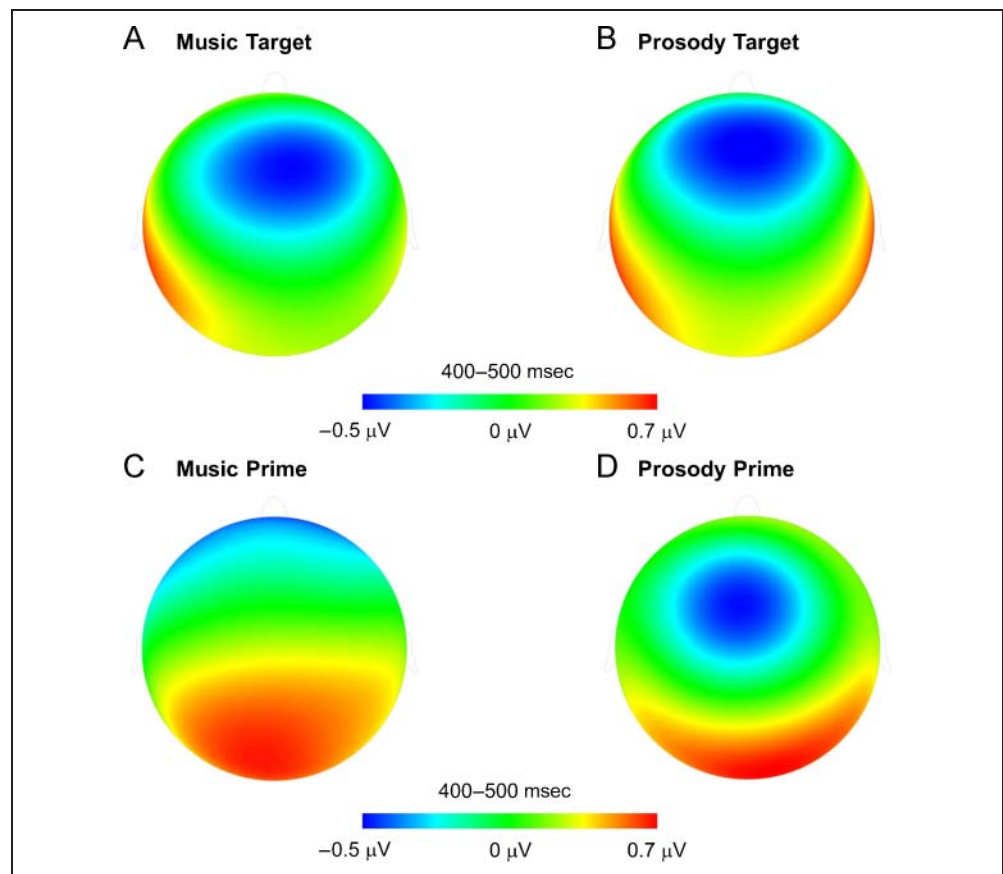


**Figure 6.** N400-like effect in response to affectively incongruent targets (gray) versus affectively congruent targets (black) during affective categorization in Experiment 1. Grand averages of 32 participants for a 1000 msec time-window post target onset at electrode site P3 are shown for (A) MusicTarget, (B) ProsodyTarget, (C) MusicPrime, and (D) ProsodyPrime.



**Figure 7.** Lack of N400-like effect in response to affectively incongruent targets (gray) versus affectively congruent targets (black) during nonaffective categorization in Experiment 2. Grand averages of 48 participants for a 1000 msec time-window posttarget onset at electrode site P3 are shown for (A) MusicTarget, (B) ProsodyTarget, (C) MusicPrime, and (D) ProsodyPrime.

**Figure 8.** Topographic maps of N400-like effects during affective categorization in Experiment 1. Scalp distributions are shown for the difference waves of affectively incongruent conditions subtracted by affectively congruent conditions in the time-window 400–500 msec post target onset. N400-like effects showed a global scalp distribution for MusicTarget (A), ProsodyTarget (B), and ProsodyPrime (D), and an anterior locus of the N400-like effect for MusicPrime (C).



30) = 10.3,  $p = .003$ ], but not at central [ $F(1, 30) < 1$ ] and posterior regions [ $F(1, 30) = 2.3, p = .137$ ].

#### *ProsodyPrime*

A significant two-way Prime Valence  $\times$  Target Valence interaction was observed for visual word targets preceded by prosody primes at the N400 time-window [ $F(1, 30) = 6.6, p = .015$ ], indicating larger negativities for incongruent compared with congruent targets. The *Prime Valence  $\times$  Target Valence* interaction was not qualified by region or hemisphere, suggesting a global scalp distribution of the N400-like effect.

### **Experiment 2: Nonaffective Categorization**

#### *MusicTarget*

RM-ANOVA revealed a significant two-way Prime Valence  $\times$  Target Valence interaction for music targets at the N400 time-window [ $F(1, 47) = 6.2, p < .001$ ]. In contrast to Experiment 1, the effect was reversed: larger negativities were found for affectively congruent compared with affectively incongruent music targets during semantic classification. A significant three-way interaction Prime Valence  $\times$  Target Valence  $\times$  Sex [ $F(2, 47) = 6.2, p = .004$ ] indicated that this effect was significantly larger in female than in

male participants. No other interactions qualified the Prime Valence  $\times$  Target Valence interaction.

#### *ProsodyTarget*

In contrast to Experiment 1 (affective categorization), the two-way Prime Valence  $\times$  Target Valence interaction for prosody targets was not significant at the N400 time-window [ $F(1, 47) = 1.1, p = .300$ ], indicating that the same affectively incongruent prosody targets did not elicit larger negativities during semantic/phonological categorization.

#### *MusicPrime*

The two-way Prime Valence  $\times$  Target Valence interaction was not significant at the N400 time-window during semantic/phonological categorization of word targets preceded by music primes [ $F(1, 47) < 1$ ].

#### *ProsodyPrime*

In contrast to Experiment 1, the two-way Prime Valence  $\times$  Target Valence interaction was not significant at the N400 time-window [ $F(1, 47) = 1.4, p = .241$ ], indicating that the word targets preceded by affectively incongruent prosody



primes did not elicit larger negativities during nonaffective categorization.

## DISCUSSION

This study was designed to systematically test the mechanisms underlying cross-modal affective priming between music, speech, and visually presented words. In Experiment 1, participants categorized music, prosody, and word targets on the basis of their valence (affective categorization). In this experiment, both spreading of activation and response competition may underlie the affective priming effect. In Experiment 2, participants categorized the targets based on non-affective characteristics. This design rendered affective prime characteristics irrelevant to the response dimension, excluding response competition as a possible mechanism of the affective priming effect, while leaving the possibility of spreading of activation to occur.

Our results revealed a consistent pattern at the behavioral and the electrophysiological level. During affective categorization (Experiment 1), both music and prosody targets were evaluated faster when preceded by affectively congruent word primes, and vice versa. This affective priming effect was observed for prosodic primes and targets as well as for music targets. Significantly larger N400-like effects were observed for incongruent compared with congruent targets during affective categorization in each of the four conditions of Experiment 1. In contrast, during nonaffective categorization of the same stimuli in Experiment 2, an affective priming effect observed neither at the behavioral nor at the electrophysiological level in any of the four conditions.

The results of Experiment 1 confirm previous findings of priming effects between musical and linguistic stimuli (Daltrozzo & Schön, 2008, 2009; Steinbeis & Koelsch, 2008, 2011; Sollberger et al., 2003). Affective priming effects between music, prosody, and visually presented words at the behavioral level were accompanied by significantly larger negativities at the N400 time-window for affectively incongruent versus congruent targets during affective categorization.

### The Role of Response Conflict

Previous findings of affective priming effects accompanied by negativities at the N400 time-window have often been interpreted to reflect interference at the conceptual level, that is, in terms of the spreading of activation account (Daltrozzo & Schön, 2008, 2009; Steinbeis & Koelsch, 2008, 2011; Zhang, Lawson, Guo, & Jiang, 2006). Indeed, in a previous cross-modal affective priming study by Steinbeis and Koelsch (2008) using fMRI, words preceded by affectively incongruent music chords elicited activity in the right medial-temporal gyrus, and music chords preceded by affectively incongruent words were found to be related to

activity in the right posterior STS, areas that are associated with semantic processing and which have been found in ERP studies using source localization to identify the locus of the N400 (Khateb, Pegna, Landis, Mouthon, & Annoni, 2010; Koelsch et al., 2004). In contrast, the N450 observed in ERP studies employing Stroop paradigms has been suggested to arise in the ACC, an area related to error processing and conflict monitoring by studies using source localization techniques (Szűcs & Soltész, 2010; Hanslmayr et al., 2008; Liotti, Woldorff, Perez, & Mayberg, 2000).

However, a body of empirical evidence is accumulating that argues against spreading of activation to be the sole cause of affective priming effects. The occurrence of affective priming seems to depend on the nature of the task employed: when participants are asked to evaluate targets based on their valence, affective priming effects are readily observed (e.g., De Houwer et al., 2002; Klauer & Musch, 2002; Klinger et al., 2000). When asked to evaluate targets based on nonaffective features or to pronounce the targets, however, affective priming is less reliably found (e.g., Spruyt et al., 2004; Klauer & Musch, 2001; De Houwer et al., 1998; but see Spruyt, De Houwer, et al., 2007; De Houwer & Randell, 2004; Hermans et al., 2004, for positive evidence of affective priming in such tasks). Task-induced modulation of affective priming was also reported by Daltrozzo and Schoen (2009) using musical and linguistic stimuli. These authors observed that affectively incongruent targets elicited a much smaller N400 effect during a more implicit lexical decision task than during affective categorization.

Taken together, the results of these studies suggest that spreading of activation may not be the only mechanism underlying affective priming, but that conflict at the response level may contribute to priming effects in the affective evaluation task. Bartholow and colleagues (2009) were the first to directly show with electrophysiological measurements that response competition contributes to affective priming between words in the evaluative categorization task by demonstrating the occurrence of preferred response activation after prime onset in motor cortex. Confirming a contribution of response competition during evaluative categorization, Eder and coworkers (in press) concluded that response priming as well as semantic priming contributes to affective priming effects between words and pictures, as indicated by an earlier occurring stimulus-locked LRP in affective congruent conditions and a larger N400 in affective incongruent conditions, respectively. Our findings of N400-like effects for music, prosody, and word targets in a task allowing for response conflict (Experiment 1) but not in a task eliminating response conflict (Experiment 2) are in line with a role of response conflict during affective priming.

### The N400 and the N450

Affective priming tasks such as used in this study are quite similar to stimulus-response compatibility tasks such as

the Stroop task, which induces a high level of response competition (e.g., De Houwer, 2003; Klauer et al., 1997; for a review, see Klauer, Voss, & Stahl, 2011). In the classical Stroop paradigm, participants are asked to name the color a color word is printed in. A mismatch between the color word and the color it is printed in slows down RTs (Stroop effect). Interestingly, a number of ERP studies employing Stroop paradigms have also reported negativities at the N400 time-window (Szűcs & Soltész, 2007, 2010; Hanslmayr et al., 2008; Liotti et al., 2000; Rebai, Bernard, & Lannou, 1997). Although those negativities have sometimes been interpreted as N400 effects (e.g., Rebai et al., 1997), the authors of these studies tend to interpret them as a different effect, the N450, which has been proposed to reflect conflict at the response level (Szűcs & Soltész, 2007, 2010; Qiu, Luo, Wang, Zhang, & Zhang, 2006; West & Alain, 2000). ERP studies using source localization techniques corroborated this conclusion by showing that the source of the N450 is the ACC, an area known to be involved in conflict monitoring and error processing (Hanslmayr et al., 2008; Liotti et al., 2000).

In summary, although a contribution of conceptual level interaction cannot be excluded in those studies, the results of ERP studies employing Stroop paradigms provide indirect evidence for negativities at the N400 time-window being sensitive to conflict at the response level. This is in line with the present finding of N400-like effects in a task allowing for response conflict (Experiment 1), but an absence of such effects when eliminating response conflict as a contributing factor to affective priming (Experiment 2).

Given previous findings of conflict at the response level as a contributor to affective priming in the evaluative categorization task (Eder et al., in press; Bartholow et al., 2009) on the one hand and negativities in the N400 time-window elicited by response conflict in Stroop tasks on the other hand, the question emerges whether negativities in the N400 range during affective priming reflect interference at the conceptual level (N400 interpretation), whether they are caused by conflict at the response level (N450 interpretation) or whether both mechanisms contribute to such negativities. The negativities in the N400 range observed in Experiment 1 of the current study do not correspond to the centro-parietal (sometimes more right-hemispheric) topographic distribution of the classical N400 (e.g., Kutas & Federmeier, 2011) but show a global topography, indicated by the fact that neither the factor Region nor the factor Hemisphere qualified the *Prime Valence* × *Target Valence* interaction. For musical excerpts presented as primes, however, the N400-like effect had an anterior locus, as suggested by a significant three-way interaction *Prime Valence* × *Target Valence* × *Region* (see Figure 8 for scalp topographies of the N400-like effects for the four conditions).

The current results do not allow for an unambiguous classification of the observed negativities in the N400 range (Experiment 1) as corresponding to the classical N400

effect or to an N450. For this reason, we refer to the negativities observed here as an “N400-like effect.”

### Reversed Priming Effects

The only condition in Experiment 2 that elicited significant differences at the N400 time-window was *MusicTarget*. In contrast to the negativities observed during affective categorization in Experiment 1, this negativity pattern was reversed: Larger negativities were found in response to affectively congruent conditions as compared with incongruent ones. This effect was found to be larger in female participants and did not surface at the behavioral level. Reversed N400-like priming effects such as observed in Experiment 2 of the current study have been reported previously (Paulmann & Pell, 2010; Bermeitinger, Frings, & Wentura, 2008a). These effects have been interpreted in the light of the center-surround inhibition theory (Carr & Dagenbach, 1990), arguing that briefly presented primes only weakly activate the concept associated with the prime; to increase activation of the prime concept surrounding concepts become inhibited, which leads to hampered access of the related targets, reversing the priming effect.

However, considering that the reversed N400-like effect in this study occurred only during nonaffective categorization (Experiment 2) of music instruments (participants decided whether a music excerpt was played on the piano or with the guitar) and that the effect was significantly larger in female than in male participants, another explanation appears to be more plausible. Gender differences have been frequently observed in semantic tasks such as object decision or semantic fluency tasks (e.g., Barbarotto, Laiacona, Macchi, & Capitani, 2002, for biological versus man-made objects; Capitani, Laiacona, & Barbarotta, 1999, for naming fruits versus tools; Laws, 2004, for tools and vehicles). Specifically, females seem to have a processing advantage for natural objects, whereas males show an advantage for artifactual objects (e.g., Laws & Hunter, 2006; Laws, 1999). Bermeitinger, Wentura, & Frings (2008b) tested this gender difference for natural versus artifactual objects in a semantic priming paradigm. In two experiments, they found that female participants showed positive priming effects for natural categories but reversed priming effects for artifactual categories. The men, however, showed positive priming for both natural and artifactual categories. A third experiment further showed that this priming pattern in females could be manipulated by focusing their attention on perceptual versus functional features. The authors interpreted these results as evidence for specific default processing modes that differ between women and men. Such a difference in processing modes could account for the reversed N400-like priming effects during the categorization of music instruments (= artifactual categories) observed in Experiment 2 of this study, which we found to be significantly larger in female compared with male participants. However, this interpretation remains speculative until future research replicates such reversed

priming effects in the different genders during music processing.

### Limitations

An important limitation of the current study is that the presence of response competition was confounded by attention directed to the affective dimension of the targets. Attentional factors have indeed been shown to influence affective priming effects in the evaluative categorization task (Gawronski et al., 2010). Therefore, we cannot exclude the possibility that in Experiment 2, the absence of attention to the affective dimension prevented affective processing of the targets, undermining affective priming effects to occur (see, e.g., Spruyt, De Houwer, & Hermans, 2009; Spruyt, De Houwer, et al., 2007). Future studies should attempt to control for the amount of attention devoted to the affective dimension to elucidate to what extent attention influences cross-modal affective priming between music and language and the accompanying N400-like effects.

Although our results quite consistently showed effects for Experiment 1 but not for Experiment 2, we inferred a contribution of response competition as a mechanism driving affective priming from the absence of an effect, rendering our evidence indirect. Although our findings are in line with recent studies that have found direct evidence for response competition during evaluative categorization, it may well be the case that both interference at the conceptual level and at the response level could contribute to affective priming effects. Future studies should investigate the relative contribution of each mechanism to affective priming.

Furthermore, on the basis of the current data it remains unclear whether the observed N400-like effect for affective incongruence between music, speech, and words with emotional connotations resembles more closely the classical N400 effect or the N450 effect observed in ERP studies using Stroop paradigms. Future studies should use neuroimaging methods that allow localization of the brain regions mediating affective incongruency in music, prosody, and linguistic stimuli.

### Conclusions

The results of this study support the notion that affective music and speech prosody are capable of interfering with the processing of words with affective connotations, and vice versa. Affective incongruence seems to be associated with N400-like effects during evaluative categorization. Our findings further suggest a role of response competition during the affective categorization of music, prosody, and words with emotional connotations.

### Acknowledgments

Niels O. Schiller was supported as a Fellow-in-Residence 2010/11 at the Netherlands Institute for Advanced Study. We thank

Jos Pacilly for designing computer scripts for this study and Linda Geerligns for her support in ERP data analysis. This work was supported by a European Science Foundation EURYI grant (NWO 044035001) awarded to André Aleman.

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