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When emotional prosody and semantics dance cheek to cheek: ERP evidence

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ABSTRACT

To communicate emotionally entails that a listener understands a verbal message but also the emotional prosody going along with it. So far the time course and interaction of these emotional 'channels' is still poorly understood. The current set of event-related brain potential (ERP) experiments investigated both the interactive time course of emotional prosody with semantics and of emotional prosody independent of emotional semantics using a cross-splicing method. In a probe verification task (Experiment 1) prosodic expectancy violations elicited a positivity, while a combined prosodic–semantic expectancy violation elicited a negativity. Comparable ERP results were obtained in an emotional prosodic categorization task (Experiment 2). The present data support different ERP responses with distinct time courses and topographies elicited as a function of prosodic expectancy and combined prosodic-semantic expectancy during emotional prosodic processing and combined emotional prosody/emotional semantic processing. These differences suggest that the interaction of more than one emotional channel facilitates subtle transitions in an emotional sentence context.

1. Introduction

Human communication entails many facets. One of them is to convey the emotional state of a speaker. This requires the listener to integrate a number of emotional information sources such as semantics, facial, postural, gestural and vocal expressions within a short time frame to derive a proper interpretation. Thus, emotional comprehension depends on how successfully one integrates and evaluates verbal and non-verbal emotional cues. This is particularly relevant when these cues are ambiguous. To say, "I am really happy" with an angry tone of voice, for example, signals that emotional prosody and semantics do not have to "dance cheek to cheek". Therefore, it is of special interest to investigate the relative contribution of each of these channels to understand their interaction as an utterance unfolds in time.

Here, we focus on two emotional channels, prosody and semantics. Emotional prosody is the non-verbal vocal expression of emotion and carries salient acoustic–phonetic cues (i.e., F0, duration, and intensity). Emotional semantics convey verbal information that allows the listener to derive meaning from an utterance and may or may not differ from semantics in general (Hermans et al., 1994; Fazio et al., 1986). While there is ample and controversial discussion on how and when these emotional channels interact, there is general agreement that emotional processing may be highly automatic due to its

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evolutionary significance (Schupp et al., 2004a). In order to understand the time course and processing nature of these channels individually and in an interactive manner, it is crucial to study the processes as they unfold in time. ERPs are an excellent tool to do so as they provide high temporal resolution.

Several ERP components have been identified as correlates of non-emotional verbal and non-verbal information processing. For example, the integration of meaning in a sentence is linked to the well-known N400 component across a variety of domains (for recent reviews, see Van Petten and Luka, 2006; Kutas and Federmeier, 2000), while prosodic information processing has been linked to a number of positivities such as the closure-positive shift (CPS; Steinhauer et al., 1999) and the P800 (Astésano et al., 2004). Overall, effortful meaning integration elicits a negativity (N400), while prosodic reanalysis or reprocessing has yielded a number of positivities (CPS, P800). As these ERP components differ morphologically, it has been suggested that components related to these processes are functionally distinct.

1.1. ERP evidence on emotional verbal and non-verbal processes

In the context of emotion processing, both positivities and negativities are reported for different modalities (e.g., Schirmer et al., 2005; Wambacq and Jerger, 2004; Bostanov and Kotchoubey, 2004; Schirmer and Kotz, 2003; Schupp et al., 2004a; Schupp et al., 2000; Carretié et al., 1996). For example, investigations of auditory emotional word processing (Wambacq and Jerger, 2004) and of emotional picture processing (e.g., Schupp et al., 2004a,b) reported positivities with varying latencies as a function of task. In particular, Schupp and colleagues (2004a) related the positivity to attention-regulated motivation, not unlike the P300 elicited to rare, unexpected stimuli (e.g., Donchin and Coles, 1988). However, Schirmer and Kotz (2003) reported an N400 to incongruent words in an auditory emotional word Stroop task. Furthermore, using prosody as context, Schirmer and colleagues (2002, 2005) found an N400 elicited by visual targets in a cross-modal priming paradigm. Participants listened to emotionally intoned sentences with neutral semantics followed by a matching or mismatching emotional visual target word. Mismatching visual targets elicited a larger N400 than matching targets. This effect was qualified by the listeners' sex as a function of stimulus onset asynchrony (SOA) in a lexical decision task (LDT; Schirmer et al., 2002) but not in a combined LDT/prosodic–semantic matching task (Schirmer et al., 2005). Crucially, when emotional processing is attended, both an N400 and positivity are reported (see Schirmer et al., 2005). Thus, it appears that task demands influence the respective processing pattern as well as the interaction of emotional prosody with semantics. However, while cross-modal priming is a valuable and controlled approach to study the interaction of processes, it does not reflect the temporal dynamics of interactive processes as they unfold in time. Therefore, it is of special interest to investigate the online contribution of respective emotional information in order to understand their interaction in an utterance.

1.2. Motivation for the current set of experiments

Adapting an approach previously used by Steinhauer et al. (1999) and Astésano et al. (2004), we extended the method of cross-splicing auditory signals to investigate the temporal unfolding of emotional prosodic processing and of combined emotional prosodic/semantic processing after expectancy violations. One major challenge to investigate any interaction between prosody and language-specific functions is that they are not synchronized (e.g., Marslen-Wilson et al., 1992). While prosody consists of suprasegmental parameters that extend over time, syntax and semantics can be processed as local phenomena (e.g., Eckstein and Friederici, 2006). To specify whether transitions from neutral prosody into emotional prosody in a neutral semantic context differ from transitions from neutral prosody into emotional prosody in an emotional semantic context we applied cross-splicing to induce comparable transitions in a temporally and acoustically controlled manner. Given the sensitivity of the ERP measure to latency jitter, this procedure also allows to synchronize the interaction of emotional prosody and emotional semantics comparably to the interaction of emotional prosody with neutral semantics. As the temporal unfolding of sentence prosody depends on the continuous integration of primary acoustic parameters (e.g., perceived pitch, duration and intensity), prosodic expectancy builds up. To this end, the cross-splicing approach allows violating prosodic expectancy and should elicit a positivity comparable to previously reported positivities after prosodic expectancy violations (Steinhauer et al., 1999; Astésano et al., 2004). What remains to be shown is whether transitions into emotional prosody elicit a morphologically different positivity given the emotional quality of the signal and whether the predicted positivity varies by valence (angry, happy). Furthermore, parallel transitions into combined emotional prosody and emotional semantics may be similarly constrained by context (i.e., acoustic correlates in concert with semantics) as semantic expectancy in a sentence (e.g., Van Petten et al., 1999). Thus, a combined expectancy violation should elicit a negativity that may be comparable to the well-known N400 and has been reported in emotional cross-modal paradigms (Schirmer et al., 2002, 2005). This effect could be biphasic, consisting of a negativity and a positivity as both prosodic and semantic expectancy are violated, but may be influenced by task demands (see Schirmer et al., 2005).

To summarize, the current experiments aimed at specifying the relative contribution of emotional prosody and semantics during the temporal unfolding of an emotional utterance. To answer the primary research question, that is, what is the brain response of prosodic transitions into emotional prosodic context and into combined emotional prosodic/semantic context, two types of prosodic expectancy violations were created through cross-splicing. Given the exploratory nature of the current investigation we first opted for effect-unspecific hypotheses in Experiment 1 (see Handy, 2004). However, based on sparse previous evidence (e.g., Schirmer et al., 2002, 2005; Astésano et al., 2004) these effect-unspecific hypotheses were constrained in two ways: (1)

quantitative procedures (i.e., mean amplitude) were adapted in accord with previous evidence in the literature, and (2) a follow-up experiment was conducted to test the theoretical implications of the first experiment. If the respective ERP effects are replicated independent of task (probe verification in Experiment 1 and emotional prosodic categorization in Experiment 2), effect-specific hypothesis can be formulated and further explored.

2. Results

2.1. Experiment 1

2.1.1. Behavioral analyses

Accuracy scores were calculated for each participant and corrected by 2.5 SD of the mean. Accuracy data for the two different conditions were calculated in separate repeated measures ANOVAs. The analysis of the prosodic condition included the within-subjects factor P (happy, angry and neutral) only, while the analysis of the combined condition included the factors M (ATCH) (match/mismatch) and P (ROSODY; happy, angry). In both conditions, SEX (female/male) was treated as a between-subjects factor.[1]

2.1.2. ERP analyses

The mean amplitude for matching and mismatching sentences in the prosodic condition was calculated with the between-subjects factor SEX (female/male) and the repeated within-subjects factors: P (happy, angry, neutral), scalp regions of interest (SROI; anterior: F7, F5, F3, FT7, FC5, FC3, F8, F6, F4, FT8, FC6, FC4; central: T7, C5, C3, TP7, CP5, CP3, T8, C6, C4, TP8, CP6, CP4; posterior: P7, P5, P3, PO7, PO3, O1, P8, P6, P4, PO8, PO4, O2; for regional averaging, see Dien and Santuzzi, 2004) and HEMI (left, right). The analysis of the combined condition was calculated accordingly, but including the additional factor M (match, mismatch) and the modified factor P (happy, angry). The null-hypothesis was rejected for *p*-values smaller than 0.05. The Geisser–Greenhouse correction (Geisser and Greenhouse, 1959) was applied to all repeated measures with greater than one degree of freedom in the numerator. In order to decrease Type I errors, *p*-values for multiple post hoc comparisons were corrected using a modified Bonferroni procedure (see Keppel, 1991). Only interactions involving the critical factor M were followed up by step-down analyses in the combined condition. Significant results are reported as ≤0.05.

2.1.3. Behavioral results

2.1.3.1. Prosodic condition. Statistical analysis of accuracy scores yielded a significant P effect, $F(2, 64)=30.61$, $p<0.0001$. Post hoc comparison revealed slightly lower accuracy for mismatching angry sentences when compared to matching neutral sentences (94% vs. 98%), $F(1, 32)=38.49$, $p<0.0001$. No other main effect or interaction was significant (all $p>0.05$). Latter result extended to the analysis of the combined condition (all $p>0.05$).

2.1.4. ERP results

2.1.4.1. Prosodic condition. ERPs in the prosodic condition display an N1 that is larger at posterior than anterior electrode sites, and a larger P2 amplitude at anterior than posterior electrode sites. Following these early components, matching prosody develops a long-lasting negativity while mismatching prosody follows a more positive time course. Based on a 50-ms timeline analysis and a criterion of at least 4 consecutive significant time steps, a critical time window for mean amplitude quantification was defined between 600–950 ms post-sentence onset.

There was a significant main effect of P, $F(2, 64)=5.56$, $p<0.01$, confirming a more positive-going waveform for both happy, $F(1, 32)=4.40$, $p<0.05$, and angry mismatching, $F(1, 32)=8.57$, $p<0.01$, sentences than for neutral matching sentences. A three-way interaction between P × HEMI × SEX, $F(2, 64)=4.32$, $p<0.05$, supported a P × HEMI interaction in female, $F(2, 34)=3.33$, $p=0.05$, but not in male participants, $F(2, 30)=3.19$, $p>0.05$. Female participants displayed a P effect in the left, $F(2, 34)=5.92$, $p<0.01$, and in the right hemisphere, $F(2, 34)=4.39$, $p<0.05$. Post hoc comparisons of P revealed a left-lateralized, positive-going waveform for angry, $F(1,17)=9.65$, $p<0.01$, and happy, $F(1,17)=5.11$, $p<0.05$, mismatching sentences compared to neutral matching sentences as well as a right-lateralized positivity for angry mismatching sentences, $F(1,17)=6.61$, $p<0.05$.

Taken together, the present results confirm that a prosodic expectancy violation elicits a positivity with an apparently whole-head distribution in male participants, but with a more varied distribution in female participants—a left-lateralized positivity in response to happy mismatching sentences and a bilaterally distributed positivity elicited by angry mismatching sentences (see Table 1 for a list of all significant effects of the omnibus analysis and Fig. 1a for a graphical display of ERP effects).

Table 1 – Experiment 1: Summary of ERP *F* values for both conditions in both time windows for all significant or marginally significant effects

Prosodic expectancy violation 600–950 ms			Combined expectancy violation 350–550 ms		
Source	df	F value	Source	df	F value
P	2,64	5.56**	M × P	1,32	5.25*
HEMI	1,32	10.58**	SROI	2,64	22.39****
SROI	2,64	6.19*			
P × HEMI × SEX	2,64	4.32*			

**** $p<0.0001$.
*** $p<0.001$.
** $p<0.01$.
* $p<0.05$.
# $p<0.1$.

[1] The present study investigated the time course of emotional prosody and combined emotional prosody with semantics. As previous research (e.g., Schirmer et al., 2002) has suggested that listeners' sex influences implicit emotional prosody processing, SEX was included as a between-subject factor.

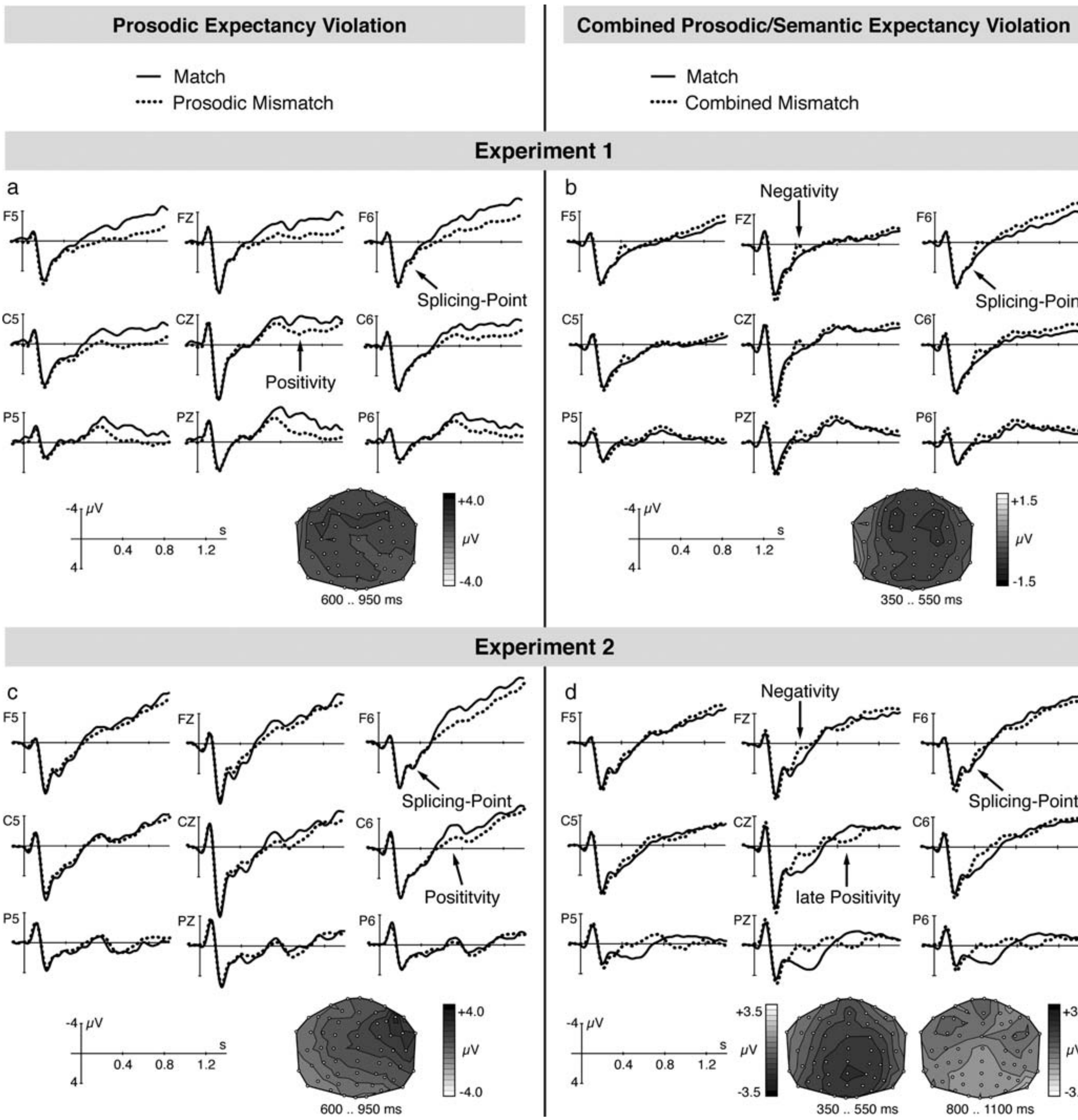

Fig. 1 – (a ,b, c, d) The illustration shows ERPs elicited by matching and mismatching sentences at selected electrode sites in addition to ERP difference maps comparing the matching and mismatching sentences. Panels a and c show ERPs and ERP difference maps elicited in the prosodic expectancy violation condition of Experiments 1 (panel a) and 2 (panel c). For the prosodic expectancy violation in Experiment 2 (panel c), the ERP difference map shows the time course that was statistically significant for both happy and angry spliced items, i.e., from 600 to 950 ms. Panels b and d show ERPs and ERP difference maps elicited in the combined prosodic and semantic expectancy violation condition of Experiments 1 (panel b) and 2 (panel d). Waveforms show the average for matching (black) and mismatching (dotted) sentences from 200 ms prior to stimulus onset up to 1400 ms post-stimulus onset.

2.1.4.2. Combined condition. The development of early components was comparable to those reported in the prosodic condition. However, following these early components the matching sentences (happy and angry) develop a short-lasting positivity while mismatching sentences (happy and angry) follow a more negative time course. A critical time window (350–550 ms post-sentence onset) was defined based on a 50-ms consecutive timeline analysis.

Table 2 – Experiments 1 and 2: Summary of mean accuracy scores for neutral, happy, angry, prosodically spliced happy (CSNP), prosodically spliced angry (CSNN), semantically and prosodically happy (SNP) and semantically and prosodically spliced angry (SNN) sentences

	Accuracy scores Experiment 1 (probe verification)		Accuracy scores Experiment 2 (emotional prosodic categorization)	
Condition	Accuracy (%)	SD	Accuracy (%)	SD
Neutral	98.43	3.09	87.93	24.30
Happy	98.82	1.62	95.31	8.62
Angry	99.23	1.99	96.29	6.71
CSNP	98.03	3.19	93.12	11.38
CSNN	94.11	2.60	93.95	15.03
SNP	98.91	1.94	96.75	7.08
SNN	98.72	2.01	95.31	6.97

A significant interaction of M and P, $F(1, 32)=5.25$, $p<0.05$, revealed that happy, $F(1, 32)=6.56$, $p<0.05$, but not angry mismatching sentences show a negative brain response. No further interaction was significant.[2]

Overall, these results substantiate a whole-head distributed negative brain response to mismatching sentences in the combined condition (see Table 1 for a list of all significant effects and Fig. 1b for a graphical display of effects).

2.1.5. *Summary and rationale for Experiment 2*

Experiment 1 set out to investigate the temporal unfolding of emotional prosodic processing as well as of combined emotional prosodic/semantic processing after cross-slicing in a probe verification task. The results show that (1) mismatching emotional prosody in neutral semantic context elicits a positivity (600–950 ms) independent of valence (happy or angry). However, the distribution of the positivity is influenced by the listeners' sex. Male participants show a positivity distributed across the scalp while female participants show a bilateral positivity to angry mismatching sentences and a left-lateralized positivity to happy mismatching sentences. Furthermore, in the combined condition we find a negativity (350–550 ms) independent of valence (happy or angry) and sex (female, male). These data support a first successful differentiation of the respective contribution of emotional channels in an online investigation through cross-splicing. Furthermore, the results allow describing a precise time course of the respective processes. In order to replicate these results and to support effect-specific hypotheses, we tested the very same material in an emotional categorization task. Thus, we expected to find a positivity (600–950 ms) elicited in the prosodic condition and a negativity (350–550 ms) in the combined condition.

[2] To verify that the mismatch effect is independent of valence, a 30-ms shorter time window from 380 to 550 ms was analyzed after close visual inspection at single electrodes. Within this time window, a significant main effect of M was found, $F(1, 32)=4.11$, $p=0.05$. Mismatching sentences irrespective of valence showed a more negative-going waveform than matching sentences.

2.2. *Experiment 2*

2.2.1. *Behavioral results*

2.2.1.1. Prosodic condition/combined condition. No statistically significant accuracy effects were found in either condition (all $p>0.05$; see Table 2 for a summary of mean accuracy scores for matching and mismatching sentences in both experiments).

2.2.2. *ERP results*

In Experiment 2 three latency windows, 600 to 950 ms in the prosodic condition and 350 to 550 ms and 800 to 1100 ms in the combined condition, were analyzed in separated ANOVAs with the same factors as in Experiment 1 (see Table 3 for an extended overview of all significant effects from the respective omnibus analyses). The late time window (800–1100 ms) was calculated as a negativity in the combined condition was followed by a positivity.

2.2.2.1. Prosodic condition. As in the previous experiment the early components (N1, P2) followed a classical development. After the cross-splicing point a positive brain response to mismatching sentences was larger than for matching sentences. A significant main effect of P, $F(2, 60)=3.40$, $p=0.05$, confirmed that angry mismatching prosody, $F(1, 30)=4.89$, $p<0.05$, but not happy mismatching prosody ($p>0.05$) elicited a positivity. In addition, P interacted with SROI, $F(4, 120)=5.77$, $p<0.01$, and with HEMI, $F(2, 60)=9.21$, $p<0.001$. Both interactions where qualified by a three-way interaction of P, HEMI and SROI, $F(4, 120)=4.77$, $p<0.01$, that confirmed a significant interaction of P and SROI only over right hemi-

Table 3 – Experiment 2: Summary of ERP *F* values of the 350- to 550-ms and the 600- to 950-ms time windows analyses for all significant or marginally significant effects

Prosodic expectancy violation, 600–950 ms			Combined expectancy violation, 350–550 ms		
Source	*df*	*F* value	Source	*df*	*F* value
P	2,60	3.40*	M	1,30	14.61***
SROI	2,60	5.65***	SROI	2,60	5.05*
P×HEMI	2,60	9.21***	M×HEMI	1,30	5.24*
P×SROI	4,120	5.77**	M×SROI	2,60	9.33**
HEMI×SROI	2,60	9.34***	P×SROI	2,60	3.85*
P×HEMI×SROI	4,120	4.77**			

Combined expectancy violation, 800–1100 ms

Source	*df*	*F* value
M	1,30	4.65*
P	1,30	37.70****
HEMI	1,30	7.64**
SROI	2,60	12.89***
M×SROI	2,60	9.49**

* $p<0.05$.
** $p<0.01$.
*** $p<0.001$.
**** $p<0.0001$.

sphere electrode sites, $F(4, 120)=9.47$, $p<0.0001$. Here, P was significant in anterior, $F(2, 60)=15.73$, $p<0.0001$, and in central regions, $F(2, 60)=6.11$, $p<0.01$. Post hoc comparisons revealed both, an effect of angry, $F(1, 30)=28.06$, $p<0.0001$, and happy mismatching sentences, $F(1, 30)=6.31$, $p<0.05$, in the right anterior region, whereas there was only an effect of angry mismatching sentences, $F(1, 30)=11.05$, $p<0.01$, in the right central region (happy mismatching prosody, $p>0.05$).

Furthermore, a three-way interaction of P × SROI × SEX, $F(4, 120)=4.38$, $p<0.05$, revealed a significant P × SROI effect for male participants only, $F(4, 69)=10.25$, $p<0.001$. At anterior electrode sites, there were effects of both angry, $F(1, 15)=38.75$, $p<0.0001$, and happy mismatching sentences, $F(1, 15)=6.92$, $p<0.05$, while at central sites only angry mismatching sentences were significant, $F(1, 15)=7.92$, $p<0.05$.

Overall, results confirm a positivity elicited by mismatching emotional prosody over right hemisphere electrode sites. However, the positivity in response to happy mismatching prosody was only found in the right anterior region, while the positivity elicited by angry mismatching prosody was found over right anterior and central electrode sites. Furthermore, the positivity had a more bilateral distribution in male than female participants.

2.2.2.2. Combined condition. A main effect of M, $F(1, 30)=14.61$, $p<0.001$, confirmed a larger negative brain response to mismatching than matching sentences irrespective of valence. This effect varied in distribution (M × SROI, $F(1, 30)=9.33$, $p<0.001$; M × HEMI, $F(1, 30)=5.24$, $p<0.05$) but confirmed a negativity in central, $F(1, 31)=16.60$, $p<0.001$, and posterior regions, $F(1, 31)=21.06$, $p<0.0001$, as well as in both hemispheres (left: $F(1, 31)=11.02$, $p<0.001$; right: $F(1, 31)=17.16$, $p<0.001$).

The negativity was followed by a positivity between 800 and 1100 ms, $F(1, 30)=4.65$, $p<0.05$, that also varied across regions (M and SROI, $F(2, 60)=9.49$, $p<0.01$), which confirmed that the positivity was maximally distributed over central, $F(1, 31)=4.77$, $p<0.05$, and posterior regions, $F(1, 31)=10.49$, $p<0.01$. Lastly, a highly significant P effect, $F(1, 30)=37.70$, $p<0.0001$, showed that happy sentences elicited a more negative-going waveform than angry sentences.

Taken together, the data confirm a negative ERP response at centroparietal electrode sites. Also, a bilaterally distributed valence difference between the happy and angry sentences irrespective of sentence type (i.e., matching and mismatching) was found in a positivity following the negativity (see Table 3 for all significant effects).

2.2.3. *Between-task analyses*

To prove that the respective ERP effects in Experiment 1 and Experiment 2 are indeed comparable, a between-task ANOVA was calculated. Results that directly relate to the posed research questions are reported in the following paragraphs.

2.2.4. *Prosodic condition*

A main effect of TASK did not reach significance ($p>0.1$) but varied in distribution (TASK × HEMI × SROI, $F(2, 124)=6.19$, $p<0.01$). Overall, in Experiment 2 waveforms followed a more positive development at posterior regions, $F(1, 62)=13.94$, $p<0.001$, in both the left, $F(1, 62)=11.48$, $p<0.01$, and right, $F(1, 62)=14.96$, $p<0.001$, hemispheres. The positivity elicited by mismatching sentences also varied in distribution, P × HEMI × SROI, $F(4, 248)=3.25$, $p<0.05$, and confirmed a right-lateralized positivity elicited by angry, $F(1, 62)=37.57$, $p<0.001$, and happy, $F(1, 62)=8.88$, $p<0.01$, mismatching sentences in anterior regions as well as in central regions (angry: $F(1, 62)=17.32$, $p<0.0001$, happy: $F(1, 62)=4.62$, $p<0.05$).

Overall, these results confirm a positivity elicited by mismatching prosody sentences over right anterior and central electrode sites irrespective of task and valence. Moreover, the TASK analysis revealed that in Experiment 2 ERP amplitudes at posterior regions were generally more positive going than in Experiment 1 irrespective of prosodic valence.

2.2.5. *Combined condition*

A TASK effect approached significance, $F(1, 62)=3.53$, $p<0.07$, confirming a more positive-going waveform development in Experiment 2 than in Experiment 1. A significant main effect of M, $F(1, 62)=14.73$, $p<0.001$, confirmed that the amplitude rise of mismatching sentences was more negative than for matching sentences. This effect was qualified by a three-way interaction between M × SROI × TASK, $F(2, 124)=6.97$, $p<0.01$,

Table 4 – Experiments 1 and 2: Summary of ERP *F* values of the 350- to 550-ms and the 600- to 950-ms time windows analyses for all significant effects with task as a between-subjects factor

Prosodic expectancy violation, 600–950 ms			Combined expectancy violation, 350–550 ms		
Source	*df*	F value	Source	*df*	F value
P	2,124	8.14^{***}	M	1,62	14.73^{***}
HEMI	2,124	12.92^{***}	SROI	2,124	23.27^{****}
SROI × TASK	2,124	17.97^{****}	M × P	1,62	7.65^{**}
P × HEMI	2,124	6.55^{**}	M × HEMI	1,62	4.44^{*}
P × SROI	4,248	5.32^{**}	M × SROI	2,124	6.01^{*}
HEMI × SROI	2,124	6.41^{**}	M × SROI × TASK	2,124	6.97^{**}
HEMI × SROI × TASK	2,124	6.19^{**}	P × HEMI × SROI × TASK	2,124	4.28^{**}
P × HEMI × SROI	4,248	3.25^{*}	M × P × HEMI × SROI	2,124	3.35^{*}

* $p<0.05$.
** $p<0.01$.
*** $p<0.001$.
**** $p<0.0001$.

that confirmed that matching sentences differed in amplitude at posterior regions between the two experiments, $F(1, 62) = 12.62$, $p < 0.001$. In Experiment 1 ERPs were more negative-going (−0.4 μV) than in Experiment 2 (1.6 μV) (see Table 4 for all significant effects).

In summary, a negativity extending across the scalp was elicited independent of valence in both tasks in the combined condition. As in the prosodic condition, task affected the overall amplitude size of the effect independent of the critical experimental condition.

3. Discussion

The current set of experiments investigated the temporal unfolding of emotional prosodic processing and that of combined emotional prosodic/semantic processing as a function of expectancy violations realized by cross-splicing. Based on sparse previous evidence we hypothesized that prosodic expectancy violations should elicit a positivity while combined prosodic/semantic expectancy violations should elicit a negativity. Indeed, as evidenced by the between-task analysis two morphologically distinct effects were elicited by the respective expectancy violation: a right-lateralized frontocentral positivity to prosodic expectancy violations and a broadly distributed negativity to combined expectancy violations irrespective of task demands and valence. Task effects only became apparent as a function of overall amplitude size in both experimental conditions and a late positivity following the negativity in the combined expectancy violation condition during emotional prosodic categorization. Taken together, the results confirm that the time course, polarity and topographical distribution of prosodic and combined expectancy violations reflect different processing dynamics. In the following general discussion results for each experimental condition will be discussed separately in the realm of both experiments but with a strong accent on the commonalities as evidenced by the between-task analysis.

3.1. *Prosodic expectancy in emotional context-just a P300 or a prosody specific positivity?*

Up to date the literature provides a strong assumption that emotional processing is highly automatic due to its evolutionary significance (e.g., Schupp et al., 2004a). Furthermore, there are accounts of emotional prosody that characterize the process as “automatic” (Hird and Kirsner, 1998) or non-voluntary (Wambacq and Jerger, 2004; Buck and Van Lear, 2002). To test the influence of attention on the ERP response elicited by prosodic expectancy violations in the ongoing speech signal, we investigated the brain response with and without an attentional spotlight on the process. Under both processing conditions, a predominantly right frontocentral positivity was elicited which suggests that the positivity cannot solely be a P300 response (e.g., Schupp et al., 2004a). If this was the case, the positivity should have only been elicited when emotional prosody was task relevant (e.g., Carretié et al., 1996). Furthermore, several authors reported that negative rather than positive emotional pictures elicited a larger P300-like positivity (e.g., Schupp et al., 2004a; Keil et al., 2002; Cuthbert et al., 2000). If negative stimuli are attended to because they are more salient the current results do not support such an interpretation as the amplitude size in response to negative and positive emotional stimuli was equivalent. Lastly, in both processing conditions the distribution of the positivity was maximal at anterior and central right hemisphere electrode sites. This distribution is atypical for the P300. So if the current positive brain response to prosodic expectancy violations is not a P300, what alternative explanation can be provided for this effect?

Right-lateralized positivities have been reported in the context of sentential prosodic processing in adults with ERPs (Pannekamp et al., 2005; but see Astésano et al., 2004) and infants with near-infrared spectroscopy (fNIRS; Homae et al., 2006) as well as with DC potentials measuring emotional prosody (Pihan et al., 1997, 2000). These data reports require a note of caution. If right-lateralized positivities are elicited in both prosodic and emotional prosodic contexts, then this component possibly reflects a response to a transition phenomenon (i.e., after the splicing point) that signals a deviance in a predicted acoustic pattern development. This would signal a conglomerate of complex acoustic changes that cannot be easily divorced from acoustic pattern changes inherent to emotional prosodic unfolding. Systematic variations of transition types (i.e., from neutral to emotional or vice versa) and acoustic parameters (i.e., varying one parameter while keeping others constant) are needed to further clarify this issue. Finally, lateralization of emotional prosodic effects may vary as a function of task demands (see Pihan et al., 2000; Kotz et al., 2006). In both DC potential studies (Pihan et al., 2000) and fMRI studies (Kotz et al., 2003, 2006) emotional prosodic processing could result in left-lateralized or bilateral prosodic effects rather than right-lateralized effects dependent on whether the evaluation of emotional prosody engaged the lexical–semantic processing system in parallel or not. Such an interpretation is clearly not warranted for the present data, even though emotional prosody was processed in lexical–semantic context. In addition, functional lateralization of linguistic and emotional prosody is also controversially discussed in the neuroimaging and clinical literature (see Kotz et al., 2006; Pell and Baum, 1997; Van Lancker and Sidtis, 1992). However, there is converging consensus that some aspects of pitch processing involve the right hemisphere (Meyer et al., 2004; Johnsrude et al., 2000; Zatorre et al., 1992). Following a similar line of argument as taken by Astésano and colleagues (2004), the prosodic expectancy violation used here is closely linked to an F0 deviation (see Table 5 for specifics on acoustic analyses and respective statistics) by changing the emotional pitch pattern. Given that we investigated emotional rather than linguistic prosody we cannot exclude the possibility that other more fine-grained acoustic parameters may have contributed to the current results. The present data, however, may support the idea of lateralized pitch change detection in vocal emotional expression. As a consequence, while functionally speaking the CPS (see Pannekamp et al., 2005), the P800 (Astésano et al., 2004) and the positivity reported here are induced by different sentential contexts and prosodic constraints, these components may be at least partially modulated by pitch variations

Table 5 – Shows acoustical analyses for all presented conditions from sentence onset to sentence offset

Condition	Duration mean (s)	Intensity mean (dB)	F0 mean (Hz)
(a) Acoustic measurements from sentence onset to sentence offset			
Prosodically and semantically matching happy sentences	1.8 (0.1)	67.3 (2.2)	226.6 (15.0)
Prosodically and semantically matching angry sentences	1.7 (0.1)	70.0 (2.4)	191.5 (9.5)
Prosodically and semantically matching neutral sentences	1.6 (0.1)	68.6 (2.1)	157.0 (8.3)
Prosodically mismatching—happy sentences	1.8 (0.2)	67.0 (2.4)	213.8 (14.3)
Prosodically mismatching—angry sentences	1.7 (0.1)	70.0 (2.3)	189.3 (10.5)
Prosodically and semantically mismatching—happy sentences	1.8 (0.1)	66.8 (2.3)	213.0 (12.6)
Prosodically and semantically mismatching—angry sentences	1.7 (0.1)	70.5 (2.0)	189.8 (5.9)
(b) Acoustic measurements up to mean splicing point			
Prosodically and semantically matching happy sentences	0.26	66.0 (2.6)	224.2 (16.7)
Prosodically and semantically matching angry sentences	0.26	70.5 (2.4)	194.4 (8.2)
Prosodically and semantically matching neutral sentences	0.26	68.1 (2.9)	155.0 (12.8)
Prosodically mismatching—happy sentences	0.26	66.2 (3.1)	223.7 (18.2)
Prosodically mismatching—angry sentences	0.26	70.0 (2.9)	195.0 (13.7)
Prosodically and semantically mismatching—happy sentences	0.26	66.1 (2.7)	223.2 (16.1)
Prosodically and semantically mismatching—angry sentences	0.26	70.7 (2.4)	194.3 (7.6)
(c) Acoustic measurements after mean splicing point			
Prosodically and semantically matching happy sentences	1.5	72.6 (2.0)	224.3 (12.5)
Prosodically and semantically matching angry sentences	1.4	69.2 (2.5)	177.0 (15.4)
Prosodically and semantically matching neutral sentences	1.3	70.8 (1.5)	163.4 (3.9)
Prosodically and semantically mismatching—happy sentences	1.5	70.9 (1.2)	168.8 (0.9)
Prosodically and semantically mismatching—angry sentences	1.4	70.3 (1.3)	170.0 (2.4)

Acoustical analyses comparing prosodically happy and prosodically angry spliced sentences to neutral sentences after the splicing point (cf. (c)) revealed significantly different pitch values (Scheffe's test, all $p<0.05$) for prosodically happy spliced (mean: 223.7 Hz) and angry spliced (mean: 194.9 Hz) sentences in comparison to neutral sentences (mean: 154.9 Hz). In addition, acoustic analyses up to splicing point (cf. (b)) revealed significantly different pitch values (Scheffe's Test, all $p<0.05$) for semantically and prosodically happy spliced sentences (mean: 170.0 Hz) compared to happy sentences (mean: 224.3 Hz) as well as for semantically and prosodically angry spliced sentences (mean: 168.8 Hz) compared to angry sentences (mean: 177.0 Hz).

and thus may belong to the same family of positivities. Naturally, given task constraints and processing strategies these pitch effects may differ in distribution and latency in the ERP (Astésano et al., 2004; Pihan et al., 2000) and the fMRI (Kotz et al., 2006, 2003) as well as a function of context (emotional, non-emotional).

Lastly, in both processing conditions the lateralization of the positivity differed for male and female participants. While both listeners were sensitive to prosodic expectancy violations, distributional effects varied as a function of sex. As we have previously only reported sex-related ERP condition effects that varied as a function of task but did not differ in topography (Schirmer and Kotz, 2003; Schirmer et al., 2005), the current results need to be further investigated before drawing strong conclusions. In particular, as the between task-analysis did not reveal any sex-related differences, topographic differences as reported in Experiment 1 may indeed rather be inter-individual than sex-related.

To conclude, we suggest that the positivity elicited by prosodic expectancy violations reflects a prosodic transition process that extracts auditory/acoustic emotion-related parameters in order to assign significance during emotional speech comprehension.

3.2. *Combined prosodic and semantic expectancy in emotional context—an N400-like response?*

The negativity obtained by cross-splicing a semantically and prosodically neutral start of a sentence to a semantically and prosodically emotional end of a sentence suggests that the effect is predominantly guided by semantic information. However, the component characteristics of the negativity deviate from the morphology of a classical N400 effect. While the component duration is comparable to the N400 (200 ms) in both tasks, the latency onset (relative to the splicing point) and distribution of the effect differ. Comparable to previous investigations with larger N400 amplitudes for semantically fitting items than for non-fitting items, both in non-emotional (e.g., Van Petten and Kutas, 1988) and emotional contexts (e.g., Schirmer et al., 2005), we report an online mismatch effect in emotional sentence context. Thus, the current data deliver new online evidence that mismatches in an emotional context elicit a negativity similar to an N400. However, in the paradigm used here, emotional semantic expectancy was time locked to emotional prosodic expectancy in the on-going speech signal. As emotional prosodic expectancy violations elicited a positivity in neutral semantic context, we conclude that semantic processing may override emotional prosodic processing when both information types interact in time. Similarly, Besson and co-workers (2002) reported that semantics cannot be ignored when participants focus their attention on linguistic prosody, while prosody can be ignored when attention is focused on semantics. Our results nicely complement these data as a negativity was present in both tasks. What remains to be discussed is the early onset of the negativity, the relative small amplitude rise and why combined emotional prosodic/semantic expectancy violations seem to elicit an earlier brain response than emotional prosodic expectancy violations.

Comparable to the results in the probe verification task, the combined expectancy violation in the emotional prosodic categorization task elicited a negativity with a very early onset and a small amplitude rise. Trying to link these results to an N400, it is important to note that the N400 has been reported to occur with an onset as early as 200 ms after stimulus onset during auditory presentation (Holcomb and Neville, 1991). In addition, some data support the notion that emotional information may be stored in the mental lexicon similarly as lexical information (Wurm et al., 2001). If one considers the possibility that a monophasic N400 reflects both lexical access and semantic integration (Kutas and Federmeier, 2000; but for an alternative account, see Van den Brink et al., 2001), then the negativity elicited by the combined emotional prosodic/semantic expectancy violation may belong to the N400 family. Extending this idea, an early N400 amplitude rise may be linked to a critical moment during sentence processing at which an acoustic input first deviates from an emotional semantic expectancy (for non-emotional semantic expectancy, see Van Petten et al., 1999). Along this line of argumentation one could speculate that when expectancy of emotional prosodic and emotional semantic information is time locked, deviations of semantic expectancy can be detected earlier as (1) semantic processing can begin before an expected word is fully processed and (2) the emotional prosodic deviance may clearly signal that an expected word in the sentence context is not a good fit. This in turn would also support the idea that the more emotional channels a stimulus encodes the quicker the system can respond to deviancy (for a comparison, see Vuilleumier, 2005).

Alternatively, the early onset of the negativity could reflect an N200 that has been linked to lexical selection (Van den Brink et al., 2001). However, the present negativity is at odds with latter interpretation as it displays a whole-head distribution with an increase in amplitude size in central and posterior regions relative to anterior regions.

Lastly, in the emotional prosodic categorization task the negativity was followed by a positivity. If this positivity is prosody related, then it only occurs when attention is explicitly focused on emotional prosody (see also Schirmer et al., 2005). In both tasks, the combined expectancy violation resulted in a similar and early negative brain response. Carretié et al. (1997) argued that an N300 elicited during emotional picture processing reflects a more reliable emotion-sensitive component than the P300, as it is less influenced by cognitive variables. For example, the amplitude of the P300 increases when subjects consider a stimulus as task relevant (e.g., Bashore and van der Molen, 1991; Johnson, 1986; Picton and Hillyard, 1988). This "relevance-for-task effect" has also been discussed in the context of P300 emotional valence effects. Comparing emotional stimuli to neutral stimuli results in an increased P300 amplitude for emotional stimuli when participants process the emotional stimulus as task relevant. This effect may vary as a function of valence as negative stimuli can elicit larger positivities than positive stimuli (e.g., Schupp et al., 2004a). Here, we would like to argue that the late positive ERP component found in the combined expectancy violation condition was only elicited because emotional prosody was mandatory during emotional prosody categorization. Surprisingly, the negativity in response to combined expectancy violations, if driven by semantics, precedes the positivity, even though emotional prosody was of primary importance to the task. This clearly suggests that emotional semantic information cannot be ignored even if the task requires participants to do so.

In sum, it can be concluded that emotional semantic information processing can override emotional prosodic processing irrespective of task demands when the two information types are time locked. Even though the amplitude rise of the negativity was small, an effect that can be related to the online integration of auditory stimuli in a sentence context, these results suggest that the negativity found in

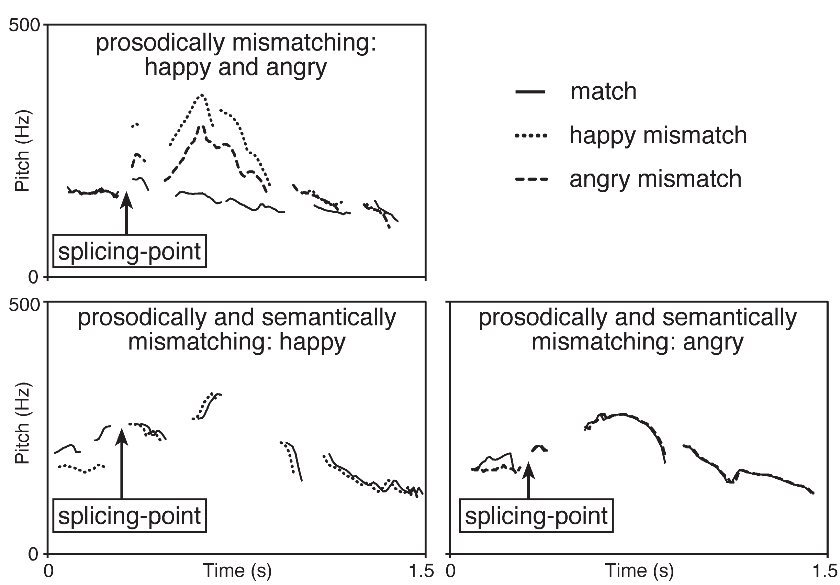

Fig. 2 – The illustration shows an example pitch contour for prosodically happy (dotted) and angry (dashed) mismatching sentences in comparison to neutral sentences (solid; upper box) as well as an example pitch contour for semantically and prosodically happy (dotted; left) and angry (dashed; right) mismatching sentences in comparison to their emotional counterpart (solid).

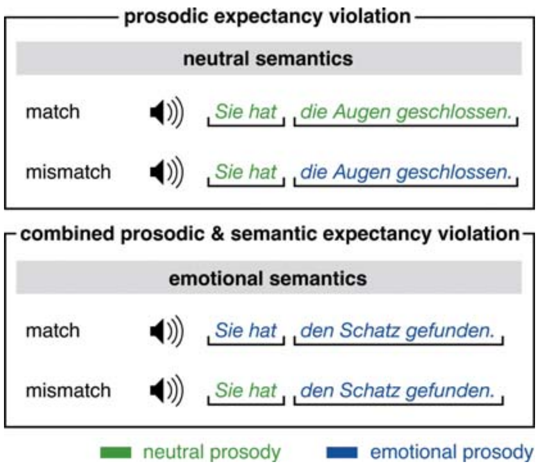

Fig. 3 – The illustration explains the splicing procedure. The first two examples display sentence examples from the prosodic expectancy violation, whereas the last two examples display sentence examples from the combined prosodic/semantic expectancy violation. German examples have the following literal translations: "Sie hat die Augen geschlossen" = "She has closed her eyes"; "Sie hat den Schatz gefunden" = "She has found the treasure".

the current experiments may subsume both emotional prosodic and semantic processing. However, it seems that emotional prosody comes back into focus when task demands, i.e., the attentional focus on emotional prosody, force the system to do so.

The results of the current set of experiments further specify the time course and differential processing of emotional prosody and the interaction of emotional prosody and emotional semantics. In sum, emotional prosodic processing is an automatic process driven by auditory/acoustic extraction of emotion-related parameters that is not primarily influenced by emotional valence or by task demands. Furthermore, the interaction of emotional channels as evidenced in the combined emotional prosodic/semantic expectancy violation occurs rapidly and independent of attention allocation. However, it is apparent that the detection of a combined expectancy violation in sentential context favors a brain response linked to processing emotional meaning that is faster than emotional prosodic processing in neutral semantic context. In particular, a fast reaction to violations in a more defined auditory signal (i.e., prosody and semantics) as evidenced by the ERP suggests rapid and effective emotional processing as hypothesized in so called feedback models (for comparison see, Vuilleumier, 2005), which may occur long before a behavioral response.

4. Experimental procedures

4.1. Participants

Thirty-four volunteers (18 female) participated in the first experiment. The mean age of female participants was 24.7 years (SD 2.6) and of male participants 25.6 years (SD 2.1). Thirty-two right-handed volunteers (16 female, mean age of 26.1 (SD 3.1); 16 male, mean age of 25.7 (SD 3.0)) that had not participated in Experiment 1 were paid to participate in Experiment 2. All listeners were native speakers of German, students attending the local university, right-handed, and had no hearing impairment.

4.2. Stimuli

The base stimulus material consisted of 30 happy, 27 angry and 30 semantically and prosodically neutral sentences, respectively. A trained native female speaker of German produced all sentences. Sentences were recorded with a DAT recorder and digitized at 16-bit/44.1 kHz sampling rate. The stimulus material was prosodically analyzed (i.e. pitch, intensity and duration of the sentences were extracted) using *Praat* (Boersma and Weenink, 2003). Results of the acoustical analyses are reported in Table 5. Emotional valence of the sentences was obtained in an earlier rating study. Twenty-three participants (eight female) that did not participate in the ERP experiments rated all sentences on a 5-point scale that ranged from −2 to +2 for emotional valence (where −2 equaled "very angry" and +2 equaled "very happy"). Participants rated 62% (SD 35.1) of the sentences as angry, 81% (SD 21.7) as happy and 66% (SD 22.6) as neutral. The lower number of angry sentences resulted from a critical cut off. Additionally, nouns and verbs were controlled for word frequency (Baayen et al., 1995). Prosodic and combined expectancy violations of intonation contours were created by cross-splicing (for precise methodological procedures, see Steinhauer et al., 1999). In order to balance the number of matching and mismatching sentences, 30 matching sentences were added as filler sentences resulting in a total of 117 matching and 117 mismatching sentences. Filler sentences did not enter statistical evaluation of the experimental conditions. In the following, a short description of each respective violation condition is given.

4.3. Prosodic expectancy violation

In this condition, neutral sentences were manipulated. A semantically and prosodically neutral first half of a sentence was cross-spliced to a semantically neutral but prosodically emotional (happy, angry) second half of a sentence. This procedure resulted in 30 mismatching semantically neutral but happy emotional sentences and 30 mismatching semantically neutral but angry emotional sentences (see Fig. 2 for an example pitch contour for prosodically spliced sentences and Fig. 3 for a graphical illustration of splicing procedure).

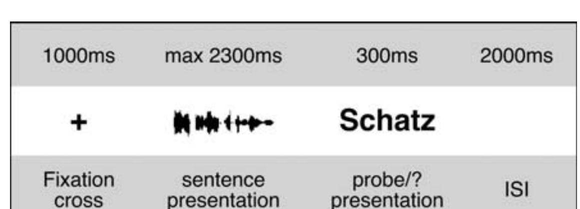

Fig. 4 – Trial sequence.

4.4. *Combined expectancy violation*

In this condition, emotional sentences (happy, angry) were manipulated. A semantically and prosodically neutral first half of a sentence was cross-spliced to a semantically and prosodically emotional (happy, angry) second half of a sentence. This splicing procedure resulted in 30 cross-spliced happy sentences and 27 cross-spliced angry sentences (see Figs. 2 and 3).

Trials were pseudo-randomized and distributed over six blocks containing 39 trials each. In order to determine the splicing point, the mean duration (measured in ms) of the neutral start of the sentences that were used as a splicing template ("Er hat"/"Sie hat") was calculated. The mean duration calculated from sentence onset to splicing point was 260 ms (see Table 5 for acoustic analyses and Fig. 2).

4.5. *Procedure*

Each participant was comfortably seated in an electrically shielded room at a distance of 115 cm from a computer screen. Sentences were presented via loudspeakers located to the left and right side of the computer. After sentence offset, a visual probe was presented for 300 ms. Participants had to respond as quickly and accurately as possible if the visual probe word had occurred in the previous sentence or not. Half of the participants pressed the "yes" button with their right hand and the "no" button with their left hand on a three-button response panel. The *Experimental Run Time System* (ERTS; Beringer, 1993) was used to run the experiment. Participants were asked to avoid eye movements during sentence presentation. The inter-trial interval was 2000 ms (see Fig. 4 for trial sequence).

The same procedure was applied in Experiment 2. However, in Experiment 2, participants engaged in a prosodic categorization task. Volunteers were asked to listen to the sentence prosody and then press the button for the corresponding prosodic valence as quickly and accurately as possible. Half of the participants pressed the "happy" button with their right index finger and the "angry" button with their left index finger. The remaining participants had the reverse button assignment. Neutral responses were always assigned to the middle button.

4.6. *ERP recording and data analysis*

The electroencephalogram (EEG) was recorded from 59 Ag-AgCl electrodes mounted on a custom-made cap (Electro-Cap International) according to the modified expanded 10–20 system (Nomenclature of the American Electroencephalographic Society, 1991). Signals were recorded continuously with a band pass between DC and 70 Hz and digitized at a sampling rate of 250 Hz. The reference electrode was the tip of the nose. Bipolar horizontal and vertical EOGs were recorded for artifact rejection purposes. Electrode resistance was kept under 5 K-Ω. Data was re-referenced offline to linked mastoids. ERPs were averaged for epochs of 1700 ms starting 200 ms before sentence onset thus including a 200-ms pre-stimulus baseline. Trials contaminated by EOG or movement artifacts were rejected with a threshold of 30.00 μV (7.97% rejected trials in Experiment 1 and 12.13% rejected trials in Experiment 2). Given the exploratory nature of the investigation in Experiment 1, data quantification was constrained by a timeline analysis (50 ms) of the whole epoch. Based on these systematic statistical tests and close visual inspection, two time windows were defined for further ERP analyses of mean amplitudes. ERPs in the emotional prosodic condition were analyzed between 600 and 950 ms after sentence onset and in the combined emotional prosodic/semantic condition between 350 and 550 ms after sentence onset. All statistical analyses were computed including correct trials only.

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