

## Shared Neural Resources between Music and Language Indicate Semantic Processing of Musical Tension-Resolution Patterns

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**Harmonic tension-resolution patterns have long been hypothesized to be meaningful to listeners familiar with Western music. Even though it has been shown that specifically chosen musical pieces can prime meaningful concepts, the empirical evidence in favor of such a highly specific semantic pathway has been lacking. Here we show that 2 event-related potentials in response to harmonic expectancy violations, the early right anterior negativity (ERAN) and the N500, could be systematically modulated by simultaneously presented language material containing either a syntactic or a semantic violation. Whereas the ERAN was reduced only when presented concurrently with a syntactic language violation and not with a semantic language violation, this pattern was reversed for the N500. This is the first piece of evidence showing that tension-resolution patterns represent a route to meaning in music.**

**Keywords:** ERP, language, music, semantics

### Introduction

A fundamental question in musicology has been to what extent music is capable of communicating meaning and, if at all, whether this is achieved merely by association or actually by its own unique set of symbols. A recent experiment (Koelsch et al. 2004) has shown that music can prime semantic concepts as well as language. However, the material used allows this claim only to be made for pieces explicitly referring to something other than music, such as an object, a mood, or an association (i.e., national anthem), thus merely providing evidence that music is capable of activating associated concepts, which in turn are semantically meaningful. The present study on the other hand investigates music material, which does not refer to anything outside itself, relying solely on the interplay of formal musical structures. This interplay has also been referred to as tension-resolution patterns and constitutes a basic hallmark of all tonal compositions. Even though it has been theoretically considered as a semantic pathway (Meyer 1956), no such evidence has been provided so far. Here we demonstrate that basic structural features of musical compositions are capable of communicating meaning without reference to anything outside their context, which could be semantic.

Tension-resolution patterns can be described in terms of the relationship between musical elements (i.e., harmonies), which are based on hierarchical organization (i.e., Western major-minor tonal system). Previous studies have shown that the perceived closeness between 2 tones strongly depends on their belonging to the same key or not and that even within the same key some tones will be judged as more stable, or final sounding, than others (Krumhansl 1979). Chords built on the keys of a scale are experienced in much the same manner (Krumhansl

and Kessler 1982), and for both single tones and chords, the harmonic distance between the perceived elements, which can be illustrated by means of the circle of fifths, mediates this stability. This perceptual phenomenon was argued to be subserved by a rule known as the “hierarchy of stability” (Bharucha and Krumhansl 1983), whereby in an established harmonic context, chords closer to the context will sound as more stable or final than those further away. It has been proposed that the representation of such musical rules is acquired implicitly by mere exposure to Western music in daily listening situations (Tillmann et al. 2000).

Harmonic priming experiments have shown that listeners come to have expectations of subsequent harmonies when presented with a single chord (Bharucha and Stoeckig 1986). These expectations were shown to correlate with the harmonic distance between the target chord and the prime chord. Listeners evidently have implicit expectations of the harmonic course of events, which in turn are related to their perception of musical tension (Bigand et al. 1996, 1999; Krumhansl 1996, 2002; Steinbeis et al. 2006). It was found that listeners rate harmonic events as increasingly tense, the further these events occur away from the tonal root, in both chord sequences (Bigand et al. 1996, 1999) as well as musical pieces (Krumhansl 1996; Toivianinen and Krumhansl 2003; Steinbeis et al. 2006). Music listeners hence directly link the perceptual phenomenon of harmonic stability to the psychological construct of tension by means of their acquired expectations.

Meyer (1956) was the first to embrace the possible link between the kind of tension-resolution patterns described above and meaning in music. He endorsed the possibility of absolute musical meaning, which refers to the music’s intrinsic structural properties, a form that can be juxtaposed against meaning arising from extramusical associations. It follows that single musical entities do not symbolize anything (even though they can) but rather that they point to a musical consequence. In other words, one type of meaning of a musical event is borne out of its implicit suggestion of a number of possible subsequent musical events. This of course applies to all types of meaning that are driven by expectations. These possibilities are constrained by the expectations, which have been implicitly learned and are subject to particular rules and hierarchies impinging on the perceptual system. It can thus be argued that the meaning arising out of tension-resolution patterns in music is of a similar sort as that derived from hierarchical relations of linguistic utterances (Ullman 2001). For instance, in the sentence “Clementia licked the plug,” we know that Clementia performed an action on an object, from the hierarchical composition of the utterance, without being aware of either the action or the object (example taken from

Ullman 2001). The type of meaning that can be derived from tension-resolution patterns is thus not unlike the one extracted from language structure. Structural hierarchies in music are therefore required by listeners to make sense of the music as it unfolds over time (Patel 2003). So far, the only piece of evidence in favor of such a notion was provided by Poulin-Charronat et al. (2005), who showed unexpected harmonies to increase response times on a lexical decision task in a semantic priming paradigm. This interaction was interpreted in terms of the increased allocation of attentional resources to an unexpected event.

Tension-resolution patterns have been studied for nigh on 20 years; however, the main body of research has focused on the structural organization of music and comparing it with language in terms of syntax (Lerdahl and Jackendoff 1983). The strongest evidence supporting an overlap in musical and linguistic syntax has come mostly from the neuroimaging literature. Patel et al. (1998) investigated the neural correlates of rule violations underlying linguistic syntax and harmonic structure. An event-related potential (ERP) known as the P600 and typically found for syntactic integration difficulties (Osterhout and Holcomb 1992; Hagoort et al. 1993) was found to be indistinguishable for both the language and the musical structure violation. Using MEG, the dipole of an early right anterior negativity (ERAN) was found to be located in Broca's area and in most subjects more strongly in its right hemispheric homotope (Maess et al. 2001), the former representing a structure also implicated in the processing of language syntax (Friederici 2002). These findings provide strong support for the syntactic analogy, and coupled with other failed attempts to elicit an N400 for either melodic (Besson and Macar 1987) or harmonic (Janata 1995) violations, it was concluded that these patterns do not represent an instance of musical semantics.

The present study aims to redress the question whether tension-resolution patterns are capable of carrying meaning by investigating another ERP known from the literature on harmonic expectation, the N500 (or N5; Koelsch et al. 2000; Koelsch and Siebel 2005; Loui et al. 2005). This bilateral potential with a frontal distribution is usually observed in response to final chords in a harmonic sequence failing to fulfill harmonic expectations by not returning to the tonic, a constraint placed on the sequence by the preceding dominant chord. This violation is reflected by the aforementioned ERAN as well as an N5, which hitherto has been interpreted as reflecting harmonic integration (Koelsch et al. 2000; Poulin-Charronat et al. 2006). Observations of similarities between the N5 and the N400 (Koelsch et al. 2000, 2003) have entertained the possibility that this component may have something to do with the processing of meaning. The present study set out to test this hypothesis. We used an interaction paradigm that has been successfully implemented in the past (Koelsch et al. 2005) to assess the relative influence of various types of language violations (syntactic or semantic) on the processing of harmonic expectancy violations (i.e., chord sequences which represent abstract entities of tension-resolution patterns). The fundamental assumption underlying the use of this paradigm was that of shared processing resources between the language and the music domain (Patel 2003). This model argues that language and music share processing resources dedicated to structural aspects of the auditory input. Even though the extent of available processing is difficult to quantify, the evidence

presented above (Koelsch et al. 2005), as well as recent behavioral studies (Slevc LR, Rosenberg JC, and Patel AD, in preparation), suggest that there are bounds to the resources available.

With regards to the present study, given that the N5 is reliably elicited in response to harmonic expectancy violations, it was hypothesized that if it reflects semantic processes associated with the violations, it ought to be reduced when occurring simultaneously with a semantic violation in the language material. Alternatively, if the N5 simply reflects more general working memory demands placed on the cognitive system as a result of any type of unexpected event, then a reduced N5 was hypothesized similarly for both types of language violations. Because the function of the ERAN has long been assumed to be of syntactic nature (for a review, see Koelsch 2005), it was hypothesized that it would be modulated only by simultaneously presented syntactic language violations.

## Materials and Methods

### Participants

Participants were 26 right-handed musically untrained adults (13 males) with a mean age of 24.4 years, normal hearing, and normal or corrected-to-normal vision.

### Stimuli

Musical stimuli consisted of 78 five-chord sequences. Sequences were built in the following fashion in order to create maximal expectation toward the final chord: the first chord was the tonic of the ensuing sequence, the second chord was a tonic, mediant, submediant, or subdominant chord, the third chord was either a subdominant, dominant, or dominant 6-4 chord, the fourth chord was always a dominant seventh chord, and the final chord was either a tonic chord or a Neapolitan chord. The tonic chord at fifth position represents the most expected chord, whereas the Neapolitan chord represents a highly unexpected harmonic event. Tonic and Neapolitan chord occurred with equal probability (39 times in each language condition). The sequences were composed in different voicings and part writing occurred according to the classical rules of harmony. The chord sequences were generated with a piano sound (General MIDI No. 1) under computerized control via MIDI on a Roland JV-2080 synthesizer (Hamamatsu, Hirakuchi, Japan). The first 4 chords were presented for 600 ms each, whereas the final chord was presented for 1200 ms. Sequences directly followed one another with no pause in between. Final chords had an approximate loudness of 55 dB, which was kept constant across all final chords. Each chord was played simultaneously with a single visually presented word. To ensure that participants would listen closely to the chord sequences, 30 chords deviating in timbre (harpichord) were inserted pseudorandomly into the auditory presentation. It was assumed that this would be sufficient to retrieve the N5 absent from the previous study (Koelsch et al. 2005), the design of which we replicated in the present study. The timbre deviants were not analyzed further.

The same sentence material as the one used in previous studies (Gunter et al. 2000; Koelsch et al. 2005) was employed by the present study, which consisted of 39 sentences with 5 elements each. Each sentence was presented in 3 different versions, a syntactically correct and semantically expected one, a syntactically incorrect and semantically expected one, and a syntactically correct and semantically unexpected one. The incorrect syntactic event consisted of a syntactic gender violation described in previous studies (Gunter et al. 2000), whereas the unexpected semantic event consisted of a low-cloze probability sentence completion at the final word, representing a very mild type of semantic expectancy violation. For the sake of simplicity, low-cloze probability sentences will be referred to as semantically unexpected or semantically incorrect throughout the manuscript even though they were not semantically implausible.

Each version of the sentence was presented with a tonic chord and a Neapolitan chord sequence (see Figure 1), producing 234 experimental sequences in total. The order of sentences was pseudorandomized so that neither the same sentence nor its altered version was presented in direct succession. To ensure that participants paid attention to the language material, 16 memory questions were inserted pseudorandomly, so that the experimental sequences were divided into 16 nonequally sized blocks.

### Procedure

The experiment was conducted in an acoustically and electrically shielded electroencephalographic (EEG) cabin. Subjects were seated in a comfortable chair facing a computer screen placed at approximately 1 m distance. Participants were instructed to carry out 2 tasks: They were told to detect chords played on a deviant instrument and signal this detection by pressing a button as soon as they heard the chord. Additionally, they were instructed to pay attention to the global meaning of each sentence, which they would be tested on infrequently during the experiment. Sixteen times a sentence appeared on the screen with the question underneath whether participants had already read the sentence before. Eight of the sentences had been presented before and the remaining 8 had not. The experimental session lasted approximately 28 min.

### Recordings and Data Analysis

The EEG was recorded from 64 Ag-AgCl electrodes placed on the head according to the extended 10–20 system and referenced to the left mastoid. An additional electrode was placed on the nose tip and another on the sternum. The EEG was sampled at a rate of 500 Hz. Horizontal and vertical electrooculograms were also recorded. Electrode resistance was kept below 5  $\Omega$ . The EEG data were filtered off-line using a band-pass filter with a frequency range of 0.25–25 Hz (3001 points, fir) to eliminate slow drifts as well as muscular artifacts. To remove eye movement-related artifacts from the EEG data, data were excluded if the standard deviation of the horizontal eye channel within a gliding window of 200 ms exceeded 25  $\mu$ V. To eliminate movement-related artifacts and drifting electrodes, data were excluded if the standard deviation within a gliding window of 800 ms exceeded 30  $\mu$ V. For statistical evaluation, ERPs were analyzed by repeated measures analyses of variance (ANOVAs) as univariate tests of hypotheses for within-subject effects. Mean ERP values were computed for 4 regions of interest (ROIs): left anterior (F7, F5, F3, FT7, FC5, and FC3), right anterior (F8, F6, F4, FT8, FC6, and FC4), left posterior (TP7, CP5, CP3, P7, P5, and P3), and right posterior (TP8, CP6, CP4, P8, P6, and P4). The factors entering the ANOVAs were the following: chord type (expected [tonic]  $\times$  unexpected [Neapolitan]), syntax (correct  $\times$  incorrect), cloze (high  $\times$  low), hemisphere (right  $\times$  left), and antpost (anterior  $\times$  posterior). The time windows used for the analyses were largely in accordance with those used in previous studies (Gunter et al. 2000; Koelsch et al. 2005), such as 160–260 ms (ERAN), 600–800 ms (N5), 300–400 ms (LAN and N400), and 500–700 ms (P600).

## Results

### Behavioral

Participants detected 88.8% of the timbre deviants and answered over 82.8% of the memory questions correctly. This suggests that sufficient attention was directed to both information channels to process the input accurately.

### ERP Main Effects

#### Language

**Syntax.** The syntactic gender violations elicited a LAN, which was followed by a globally distributed P600 (see Fig. 2). An ANOVA for the time window 300–400 ms with the factors

syntax (correct and incorrect), hemisphere, and antpost revealed a significant 3-way interaction ( $F_{1,25} = 10.78$ ,  $P < 0.005$ ), showing a stronger negativity over left anterior sites than right posterior sites as well as a significant 2-way interaction between factors syntax and hemisphere ( $F_{1,25} = 5.58$ ,  $P < 0.05$ ), indicating a stronger negativity over the left hemisphere. As a result of these interactions and the a priori hypothesis of an increased negativity over left anterior sites, another ANOVA was conducted over the left anterior ROI with the factor syntax, which showed to be significant ( $F_{1,25} = 5.46$ ,  $P < 0.05$ ). Another ANOVA for the time window 500–700 ms with the factors syntax, hemisphere and antpost revealed a significant main effect of syntax ( $F_{1,25} = 21.17$ ,  $P < 0.0001$ ) and no further interactions.

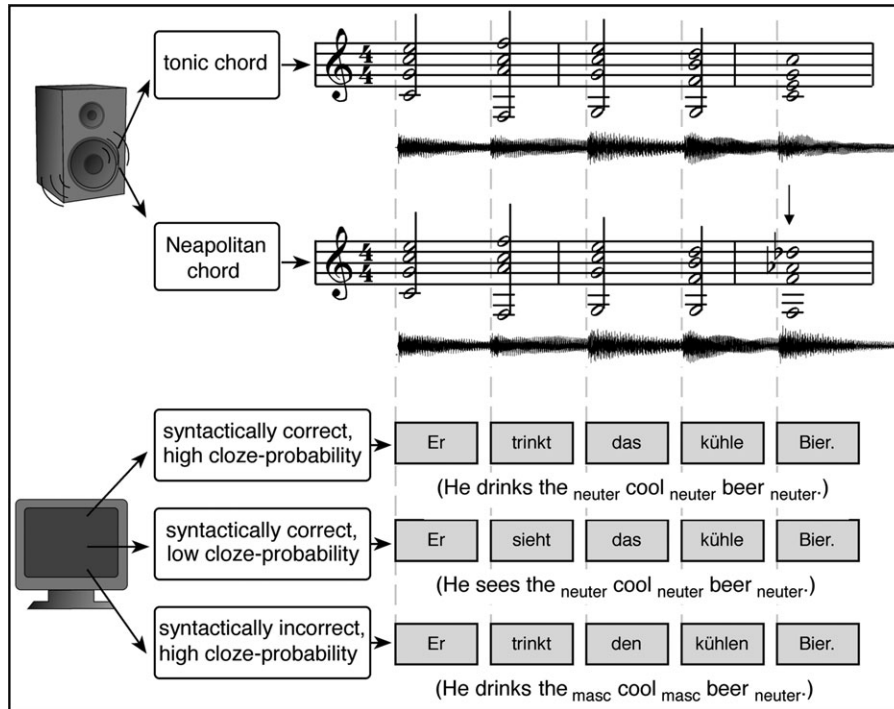
**Semantics.** The low-cloze probability sentences elicited an increased N400 compared with the high-cloze probability sentences. An ANOVA for the time window 300–400 ms with the factors cloze (high and low), hemisphere, and antpost revealed a significant main effect of cloze ( $F_{1,25} = 7.24$ ,  $P < 0.05$ ) and no further interactions. In addition, an increased P600 was found for the low-cloze compared with the high-cloze sentences. An ANOVA for the time window 500–700 ms with the factors cloze (high and low), hemisphere, and antpost revealed a significant main effect of cloze ( $F_{1,25} = 8.83$ ,  $P < 0.01$ ) and no further interactions.

### Music

**ERAN.** The Neapolitan chord elicited a distinct ERAN maximal around 210 ms at right anterior sites (see Fig. 3). An ANOVA for the time window 160–260 ms with the factors chord type, hemisphere, and antpost revealed a significant 3-way interaction ( $F_{1,25} = 10.29$ ,  $P < 0.005$ ), indicating an increased negativity over right anterior sites compared with left posterior ones, a significant 2-way interaction with the factors chord type and hemisphere ( $F_{1,25} = 9.81$ ,  $P < 0.005$ ), indicating an increased negativity over the right hemisphere than over the left, a significant 2-way interaction with the factors chord type and antpost ( $F_{1,25} = 39.01$ ,  $P < 0.0001$ ), indicating an increased negativity over anterior sites than over posterior ones, as well as a significant main effect of chord type ( $F_{1,25} = 98.14$ ,  $P < 0.0001$ ).

**N5.** The Neapolitan chord also elicited a clear N5, with an onset at around 450 ms and lasting up to around 900 ms and a maximum at 650 ms, with an anterior distribution and a slight right hemispheric weighting. For statistical analysis, however, the time window of 600–800 ms was opted for, which was motivated by an inspection of interactions with the language material in this particular latency band of the N500. As a result, we also chose this time window to report the main effects pooled over all sentence types. An ANOVA for the time window 600–800 ms with the factors chord type, hemisphere, and antpost revealed a significant 3-way interaction ( $F_{1,25} = 9.08$ ,  $P < 0.01$ ), indicating an increased negativity over right anterior sites compared with left posterior ones, a significant 2-way interaction with the factors chord type and antpost ( $F_{1,25} = 30.1$ ,  $P < 0.0001$ ), indicating an increased negativity over anterior sites compared with posterior ones, and a significant main effect of chord type ( $F_{1,25} = 8.86$ ,  $P < 0.01$ ).





**Figure 1.** Design: sentences and musical material were combined in a way that each sentence type was presented with each harmonic sequence type creating a  $3 \times 2$  design. Thus, the following 6 experimental conditions were investigated: sentences, which were both syntactically correct and semantically expected, presented 1) with a regular or 2) with an irregular harmonic chord sequence; sentences, which were syntactically incorrect and semantically expected, presented 3) with a regular or 4) with an irregular harmonic chord sequence; sentences, which were syntactically correct and semantically unexpected (low cloze), presented 5) with a regular or 6) with an irregular harmonic chord sequence. It is important to note that the event indicating whether the presented material was regular or irregular always occurred at the end of the sequence (i.e., final word for sentences and final chord for chord sequences). Both sentences and chord sequences contained 5 elements, which were presented simultaneously; the final element represents the time-locked point of investigation to test the influence of sentence type on harmonic processing.

### *Interactions between Language Violations and Music—ERAN and N5*

**Syntax and ERAN.** When the Neapolitan chord was presented simultaneously with the syntactic gender violation, the ERAN amplitude was reduced compared with when presented with syntactically correct sentences (see Figs 4 and 5). An ANOVA for the time window 160–260 ms with the factors chord type and syntax revealed a significant interaction ( $F_{1,25} = 6.44$ ,  $P < 0.05$ ).

**Syntax and N5.** No such interaction however was observed in the time window of the N5 ( $P > 0.5$ ).

**Semantics and ERAN.** When the Neapolitan chord was presented simultaneously with the semantically unexpected sentences, there was no significant reduction of the ERAN. This was confirmed in an ANOVA with the factors chord type and cloze ( $P > 0.3$ ).

**Semantics and N5.** There was a clear interaction between factors chord type and cloze in the N5 time window, showing a reduced N5 when the Neapolitan chord was presented with semantically unexpected sentences compared with when presented with semantically expected sentences ( $F_{1,25} = 8.26$ ,  $P < 0.01$ ).

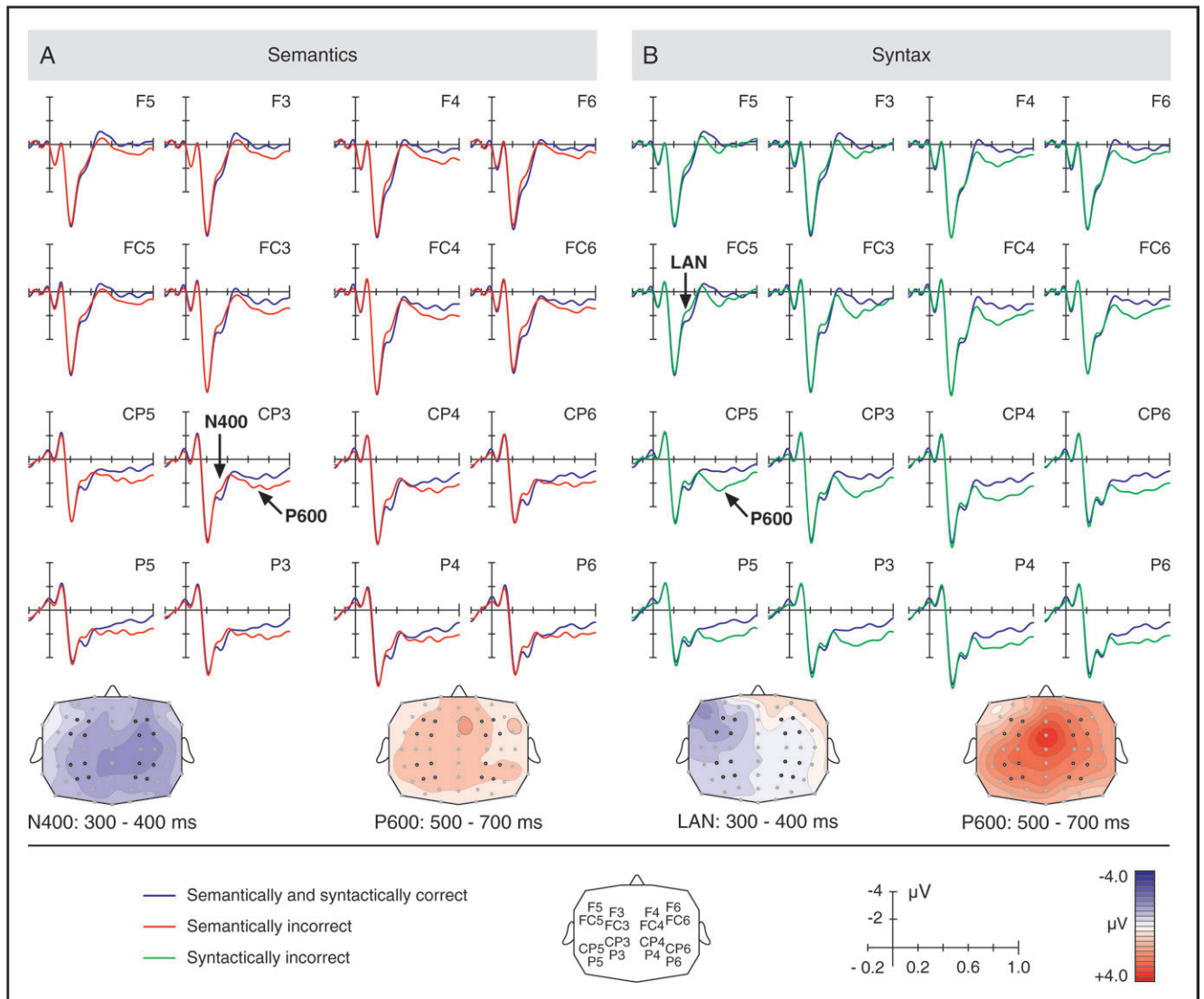
**Functional specificity of ERAN and N5.** To test for a functional dissociation between the 2 components, another ANOVA was

conducted using time window (ERAN/N5), chord type, and language violation (syntax/cloze) as factors. A significant 3-way interaction was found ( $F_{1,25} = 7.41$ ,  $P < 0.05$ ), reflecting that the ERAN was modulated more by the incorrect language syntax than by the unexpected language semantics and that the opposite was the case for the N5.

An additional test for a functional specificity of both the ERAN and the N5 is to compare their responsiveness with either type of violation. This test was performed with an additional ANOVA over the time windows of both the early (160–260) and the late (600–800) component using type of language violation (syntax/cloze) as an additional factor. Conducting an ANOVA with factors chord type and language violation over the ERAN time window, no interaction was found, suggesting that the ERAN was not significantly more reduced for the syntactic violation than for the semantically unexpected sentences ( $P > 0.2$ ). Running the same type of ANOVA over the later time window, however, it showed that the N5 was significantly smaller when the Neapolitan chord occurred concurrently with the semantically unexpected sentences than the syntactic gender violations ( $F_{1,25} = 5.73$ ,  $P < 0.05$ ).

### *Interactions between Music Violation and Language—LAN and N400*

The fact that the present experiment employed a dual task compels to look at the effect of the harmonic expectancy on the language ERPs (see Fig. 6).



**Figure 2.** Low-cloze probability sentences elicit an N400 with a central scalp distribution and a P600 (A); syntactic gender violations elicit a LAN and a P600 (B).

**LAN.** The LAN was reduced when presented concurrently with the Neapolitan chord compared with when presented with the tonic chord. An ANOVA with factors chord type and syntax over the time window 300–400 ms revealed a significant 2-way interaction ( $F_{1,25} = 7.07, P < 0.05$ ). This replicates previous results (Koelsch et al. 2005).

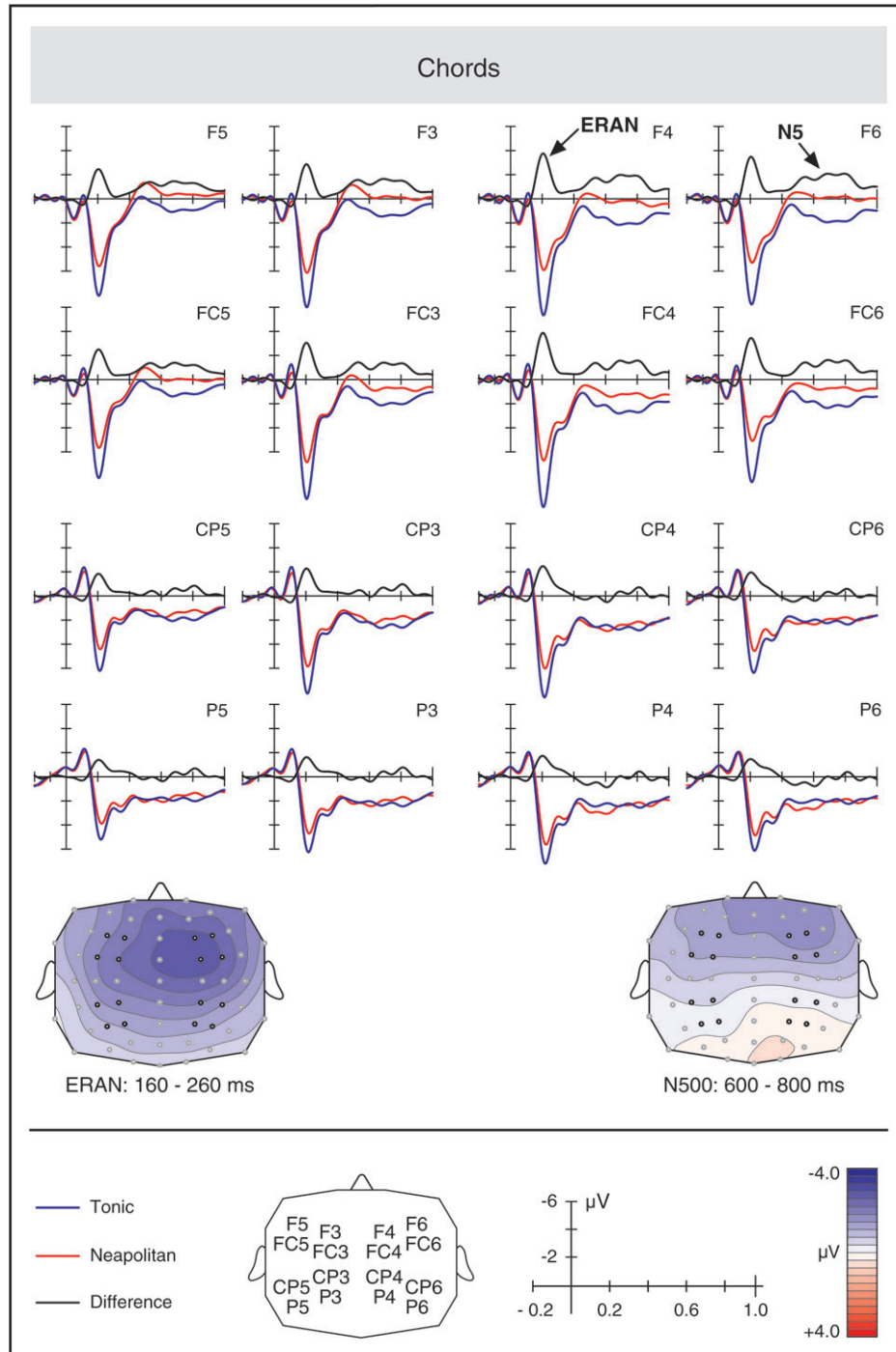
**N400.** No reduction of the N400 could be found when presented simultaneously with the Neapolitan chord ( $P > 0.3$ ). This also replicates previous results (Koelsch et al. 2005) and is possibly more surprising in this case, as a clear N5 was elicited unlike in the previous study. This, however, suggests that whereas the syntactic interaction (LAN–ERAN) works both ways, the semantic interaction (N400–N5) only works in the direction of music.

### Discussion

The present study reports several significant main effects all in accordance with the main hypotheses. The LAN and P600

elicited by the syntactic violations and the N400 and P600 elicited by the semantically unexpected sentences demonstrate that the sentence material was processed sufficiently to allow for an observation of its effect on the music material. This is confirmed by the relatively high accuracy performance in the memory test. The harmonic expectancy violations elicited both a clear ERAN and an N5, their time course, and scalp distribution conforming to previous results (Koelsch et al. 2000, 2005). The fact that the N5 was at all present can be attributed to task requirements. We therefore succeeded in retrieving the N5, a primary component of interest.

The main finding of the present study, however, is that the N5 was modulated only by the semantically unexpected sentences and not by the syntactic gender violations. Because we consider the semantically and the syntactically anomalous material to make comparable demands on attentional and working memory resources and the fact that the N400, the semantic component, and the LAN, the syntactic component, occur in identical time windows, the 2 anomalous sentence

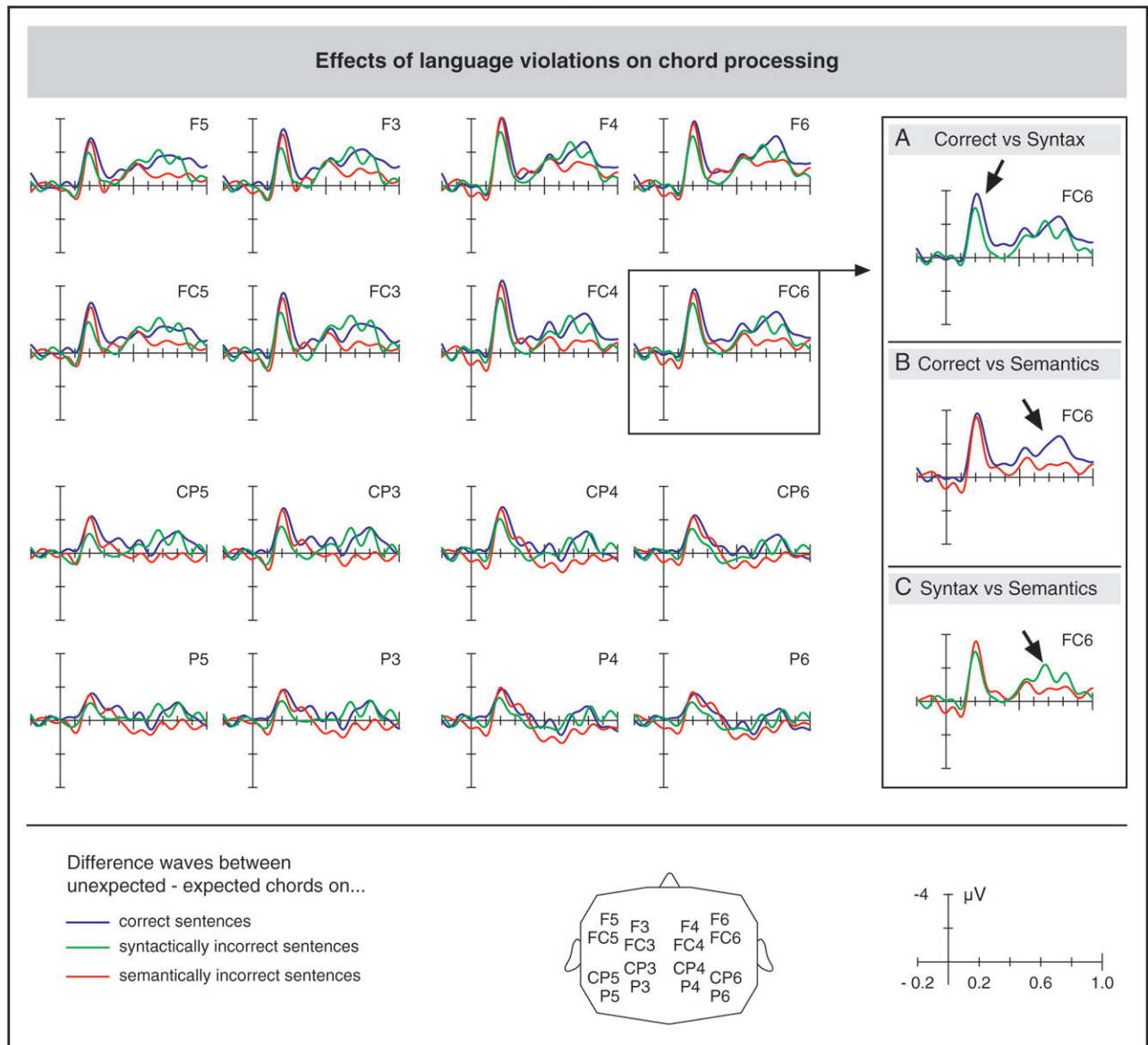


**Figure 3.** Harmonically unexpected chords elicit an ERAN and an N5 with a bilateral frontal scalp distribution.

types represent optimal control conditions with regard to more general cognitive mechanisms. Also, this effect cannot be interpreted in terms of overlapping scalp topographies between the P600 elicited for the low-cloze probability sentences and the N500 in the music condition, as the syntactic violation also elicited a P600 and should therefore have reduced the N500, which it did not. Therefore, the fact that there was a significant interaction between sentence violation and N5 amplitude suggests that this modulation is specific to semantic processing and cannot be attributed to more general attentional or working memory demands.

The N5 can be therefore interpreted as reflecting the processing of semantic aspects of tension-resolution patterns. It should be emphasized that the semantically unexpected material used in the present study was very mild and not semantically implausible, which makes the finding of an interaction with the N5 even more noteworthy. This is therefore the first piece of evidence that the processing of musical elements relies on resources that are typically associated with the processing of meaning in language.

The present finding of an interaction between harmonic structure processing and semantic language material



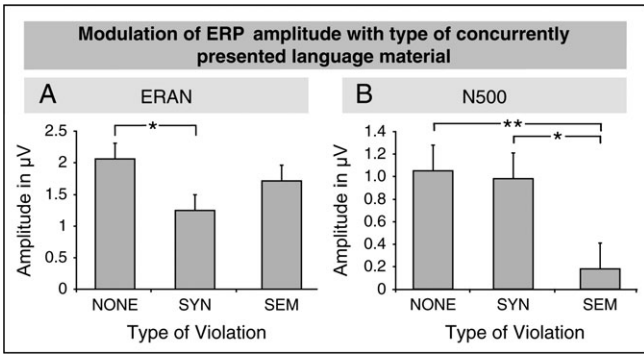
**Figure 4.** Sentences with a gender violation reduce the ERAN, but not the N5 (A); semantically unexpected sentences reduce the N5, but not the ERAN (B); semantically unexpected sentences reduce the N5 more than syntactic gender violations (C), providing the strongest evidence for semantic specificity of the N5.

suggests that structure in music is a key feature leading to semantic processing and making sense of music. As already illustrated in the example mentioned in the introduction, the structure of a normal linguistic utterance, can give rise to certain semantic expectations (i.e., resulting from word class), even in the absence of specific lexical knowledge. The analogy to language is expedient in as far as we can now conceive of the theoretical possibility that structural violations may be of both a syntactic and a semantic nature. We are not suggesting that music is capable of specifying truth conditions but rather that meaning and understanding of music is achieved by means of its structure and that the knowledge and perception of structure is the listener's predominant means of making sense of the musical input.

It has been previously shown that music and language share neural resources on the level of syntactic structure building

(Koelsch 2005) and syntactic integration (Patel et al. 1998; see also Patel 2003; Koelsch et al. 2005). Our data are the first to show that the 2 domains also share neural resources on a semantic level. Recent neuroscientific reviews on language processing (Bookheimer 2002; Friederici 2002) have argued for a "dual system" of semantic processing, with procedures, such as contextual integration, on the one hand and the representation of semantic knowledge on the other. Because the N5 has been shown to reflect sensitivity to the buildup of harmonic context (Koelsch et al. 2000), much like the N400 reflects the establishment of a semantic context (Van Petten and Kutas 1990), it is likely that the reduction of the N5 with semantically unexpected material results from the shared neural processes dedicated to building a semantic context. Recent reviews on semantic language processing and the function of the N400 (Kutas and Federmeier 2000) have highlighted contextual integration as a crucial contributor to the generation of this



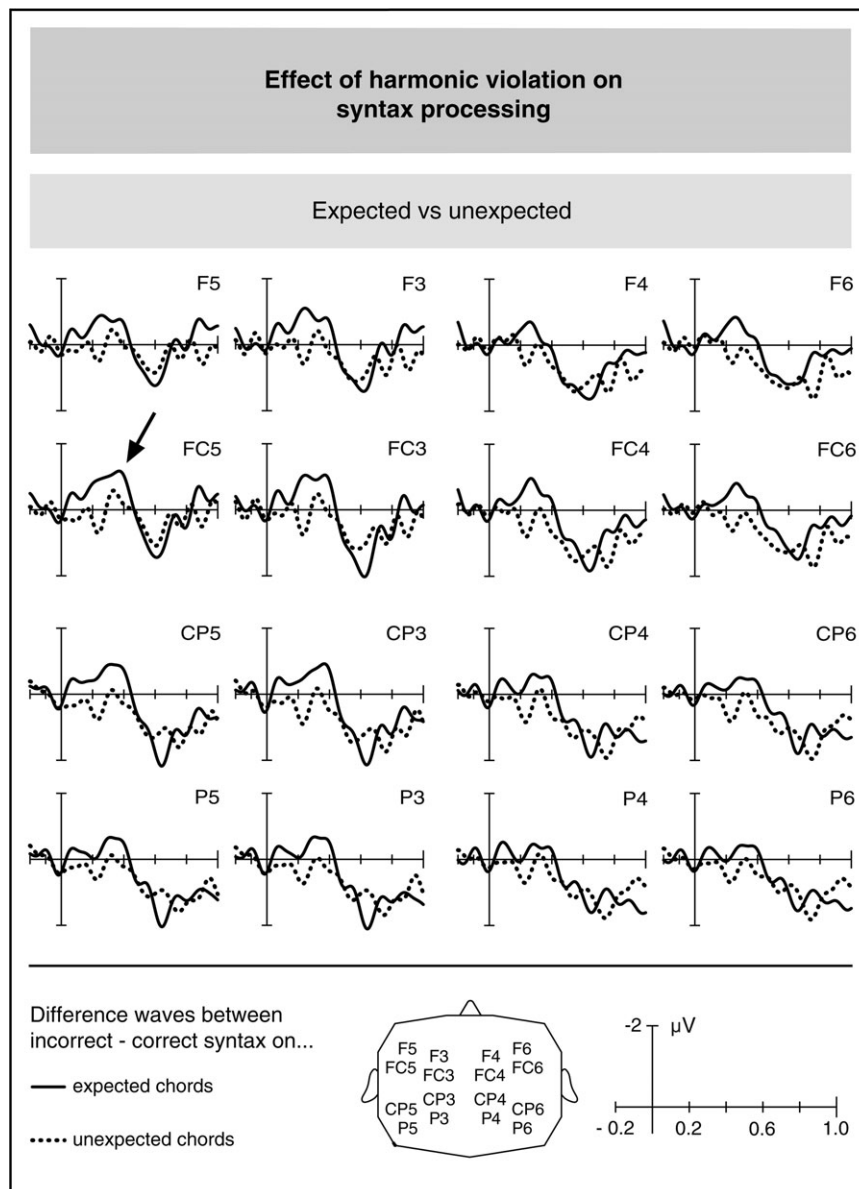


**Figure 5.** The ERAN is significantly reduced when presented concurrently with a syntactic violation compared with when presented with correct sentences, but not semantically unexpected sentences (A); the N5 is significantly reduced when presented concurrently with a semantically unexpected sentence compared with both correct sentences and syntactically incorrect sentences (B).

component, making the possibility of an overlap between music and language on a level of contextual integration plausible. We would therefore argue that the shared resources are dedicated to semantic procedures (i.e., context building), which echoes theoretical accounts of the nature of shared resources dedicated to syntactic structure building between music and language (Patel 2003).

We speculate the involvement of the pars orbitalis (BA47) of the inferior frontal gyrus to be involved in such operations. Language studies have systematically shown a role of BA47 in semantic processing (Bookheimer 2002), whereas recent studies have shown increased activations of this region when processing musical structure compared with auditory input without any coherent temporal structure (Levitin and Menon 2005).

The present study provides evidence for one of several pathways in music capable of generating meaning. Presumably



**Figure 6.** The LAN is significantly reduced when presented concurrently with a harmonically unexpected chord compared with when presented with a harmonically expected chord.



there are differences in the underlying mechanisms of the kind of pathway reported here and other pathways reported in previous studies (Koelsch et al. 2004). As described above, it is most likely that tension-resolution patterns are meaningful in that they represent instances of highly constrained context-building mechanisms. The musical stimuli used by Koelsch et al. (2004), however, seem to tap into semantic representations of music more directly by means of imagery, association, or emotion. Therefore, it appears as if the multitude of pathways to meaning in music may be subserved by different mechanisms, which are indicated by differing ERP components, the N400 and the N500.

The additional finding of a specific interaction between the ERAN and the syntactic language violations only confirm a considerable string of previous results surmising the ERAN to reflect the processing of musical syntax (Koelsch 2005; Koelsch and Siebel 2005; Koelsch et al. 2005). The fact that the ERAN was only reduced when presented concurrently with the syntactic language violation and not the semantically unexpected sentences suggests that the ERAN is modulated by the recruitment of syntactic processing resources required by the language system and not influenced by general working memory demands. The observation that the latency of the LAN (300–400 ms) is later than that of the ERAN (160–260 ms) and yet the latter was reduced when reading material that typically elicits a LAN is not simple to interpret. We assume that other neural processes not detected by scalp electrodes might play a role in such an interaction; however, further evidence is required in order to substantiate such claims. The fact that we can observe the same pattern as reported in a previous study (Koelsch 2005), whereby the LAN is significantly reduced by concurrently presented harmonic irregularities, provides further evidence that the ERAN may reflect syntactic processing. This supports the hypothesis that music and language share syntactic integration resources (Patel 2003; Koelsch et al. 2005).

The finding that musical and linguistic syntax mutually affect one another, whereas only linguistic semantics affects musical semantics and not the other way round confirms previous studies (Koelsch et al. 2005). This presumably reflects the fact that the semantic aspects of language are considerably more salient than those of harmonic irregularities, which would predict a more one-sided interaction. Whereas there are so far no studies to support this assumption, one might predict a 2-sided interaction when using more semantically salient musical material, such as the one used in the study by Koelsch et al. (2004). Behavioral evidence in support of harmonic influences on semantic aspects of language processing (Poulin-Charronat et al. 2005) could be interpreted in terms of differing task requirements and stimulus material and presentation modality of the language stimuli. A more complete investigation taking varying attention to the concurrently presented stimulus material and task requirements into account might be a better candidate for responding to this particular issue. Future research might also want to consider the possibility of presenting both language violations within the same sentence material and to observe the effects of music violations on both the LAN and the N400.

The present study investigated whether a basic characteristic of Western tonal musical compositions can be meaningful to music listeners. The finding of shared neural resources involved in semantic processing between language and musical

structure suggests that this is indeed the case. This implies that in some way, all musical pieces can be meaningful to listeners familiar with the basic structural properties of music (Meyer 1956). This meaning can be, but need not be, mediated via feelings or emotions (Meyer 1956) but more likely arises out of a knowledge of musical rules and regularities, which can be implicitly learned through exposure to music (Tillmann et al. 2000). We have provided a clear piece of evidence showing that intrinsic musical properties and formal musical structures are understood as meaningful by listeners and that meaning in music can occur without any reference or association to other meaningful events, objects, or sounds.

## Notes

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