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Review

Towards a neural basis of processing musical semantics

Stefan Koelsch

Cluster of Excellence der Freien Universität Berlin, Languages of Emotion, Habelschwerdter Allee 45, 14195 Berlin, Germany

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Abstract

Processing of meaning is critical for language perception, and therefore the majority of research on meaning processing has focused on the semantic, lexical, conceptual, and propositional processing of language. However, music is another a means of communication, and meaning also emerges from the interpretation of musical information. This article provides a framework for the investigation of the processing of musical meaning, and reviews neuroscience studies investigating this issue. These studies reveal two neural correlates of meaning processing, the N400 and the N5 (which are both components of the event-related electric brain potential). Here I argue that the N400 can be elicited by musical stimuli due to the processing of extra-musical meaning, whereas the N5 can be elicited due to the processing of intra-musical meaning. Notably, whereas the N400 can be elicited by both linguistic and musical stimuli, the N5 has so far only been observed for the processing of meaning in music. Thus, knowledge about both the N400 and the N5 can advance our understanding of how the human brain processes meaning information.

1. Introduction

To communicate, an individual has to utter information that can be interpreted and understood by another individual. Thus far, the majority of research on meaning processing has focused on semantic, lexical, conceptual, and propositional processing of language. This article deals with neural correlates of the processing of meaning emerging from the interpretation of musical information. As I will show in this article, the investigation of these neural correlates can substantially broaden our understanding of how the human brain processes meaning across domains.

In addition to previous accounts on musical meaning (which usually deal with questions such as "does music have meaning?", "which types of meaning can music convey?", "what are the differences between music and language with regard to meaning?") this article deals with the *psychological reality* of musical meaning as reflected in neurophysiological indices of semantic processing: While listening to music, the human mind constantly, and automatically attributes meaning to musical information, regardless of whether or not a composer intended to convey exactly the meaning information that is interpreted by a mind (and regardless of whether or not the information is more or less ambiguous compared to the conceptual processing of language). That is, the term *meaning* is not used here to refer only to (directional) relations between signifier and signified, and – even when dealing with reference of signifier to signified – the term meaning is not used here to refer only to the intentional use of a signifier to refer to something

E-mail address: stefan.koelsch@fu-berlin.de.

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signified. This is reminiscent of the musical aspects of speech (such as pitch contour, pitch range, pitch variation, timbre, tempo, pauses, etc.), which are also understood here as source of information from which (musical) meaning emerges (note that, in addition, non-linguistic acoustic information of speech also provides information that can be interpreted with regard to gender, size, distance, location, etc. of a speaker).

As will be illustrated below, musical meaning can emerge from extra-musical sign qualities, from intra-musical structural relations, from musicogenic effects, from the establishment of a unified coherent sense out of "lower-level" units, and from musical discourse. Thus, processing of musical meaning includes storage of meaningful information, activation of representations of meaningful information, selection of representations of meaningful information, and integration of the semantic information of these representations with the previous semantic context. Therefore, the term "musical semantics" is used in this article, although this term is not used here to refer to binary (true-false) truth conditions.

In the following, some previous accounts on musical meaning will be summarized with regard to three fundamentally different classes of meaning emerging from musical information, referred to here as extra-musical meaning, intra-musical meaning, and musicogenic meaning. It will be suggested that processing of extra- and intra-musical meaning is reflected electrically in two different event-related brain potentials (ERPs): The *N400* component of the ERP can be elicited by musical stimuli due to the processing of extra-musical meaning, whereas the *N5* component can be elicited due to the processing of intra-musical meaning. Notably, whereas the N400 can be elicited by both linguistic and musical stimuli, the N5 has so far only been reported for the processing of music. Thus, knowledge about both the N400 and the N5 can advance our understanding of how the brain understands the world.

2. Extra-musical meaning

Extra-musical meaning emerges from the interpretation of musical information with *reference to the extra-musical world*; Leonard Meyer [48] referred to this class of musical meanings as *designative meaning*. Extra-musical meaning comprises three dimensions: musical meaning due to (1) iconic, (2) indexical, and (3) symbolic sign qualities of music. These sign-qualities are reminiscent of those introduced by Charles Sanders Peirce (although not with reference to music [57]), and to my knowledge first applied to music by Vladimir Karbusicky [29].

Iconic musical meaning emerges from (the interpretation of) musical patterns or forms (e.g., musical sound patterns) that resemble sounds of objects, qualities of objects, or even qualities of abstract concepts. For example, a musical passage may sound "like a bird", "like a thunderstorm", "like wideness", etc., and acoustic events may sound "warm", "round", "sharp", "colourful", etc. The acoustic properties of such sound qualities, however, have not been specified yet.

Indexical musical meaning emerges from (action-related) sound patterns that index the presence of a psychological state of an individual, for example the presence of an emotion, or the presence of an intention (Susanne Langer used the term "iconic" for what is referred to here as "indexical musical meaning" [44,45]). Ian Cross [7] refers to this dimension of musical meaning as "motivational-structural" (in reference to [54]) due to the relationship between affective-motivational states of individuals on the one side, and the structural-acoustical characteristics of (species-specific) vocalizations on the other.

With regard to the expression of emotions, Juslin and Laukka [27] compared in a meta analysis the acoustical signs of emotional expression in music and speech, showing that the acoustic properties that code emotional expression in speech are highly similar to those coding these expressions in music (for the universality of such features see Fritz et al. [17]). Numerous of these features can also be found in the *Affektenlehre* of the seventeenth century. The Affektenlehre prescribed certain musical methods and figures for imitating, or portraying (and thus, according to the Affektenlehre, summoning) individual emotions, and aimed at differentiating the relationships between the various individual elements of musical form and technique as well as individual affections such as joy, sadness, love, hate, desire, and admiration.[1]

As mentioned above, psychological states indexed by sound information also include intentions. An fMRI study by Steinbeis and Koelsch [70] showed that listeners automatically engage social cognition during listening to music, in an attempt to decode the intentions of the composer or performer (as indicated by activations of the cortical

[1] In contrast to the concept of *imitation* of emotion, Hanslick [23] introduced in the 19th century the term *expression*, with the controversial claim that instrumental music cannot express definite emotions (for an extensive discussion see, e.g., Davies [12]).

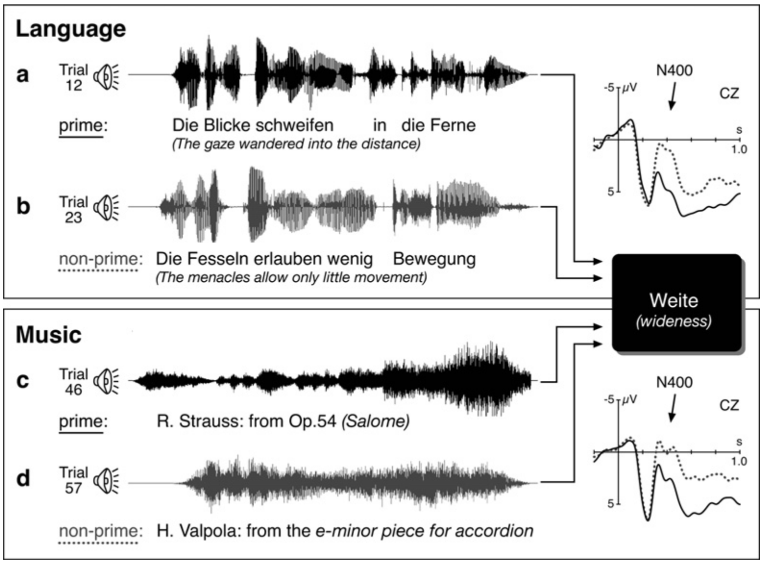

Fig. 1. Left: Examples of the four experimental conditions preceding a visually presented target word. Top panel: Prime sentences that are semantically related (**a**), and unrelated (**b**) to the target word *wideness*. The diagram on the right shows grand-averaged ERPs elicited by target words after the presentation of semantically related (solid line) and unrelated prime sentences (dotted line), recorded from a central electrode. Unprimed target words elicited a clear N400 component in the ERP (compared to the primed target words). Bottom panel: Musical excerpts that are semantically related (**c**), and unrelated (**d**) to the same target word. The diagram on the right shows grand-averaged ERPs elicited by target words after the presentation of semantically related (solid line) and unrelated musical excerpts (dotted line). As after the presentation of sentences, unprimed target words elicited a clear N400 component (compared to primed target words). Each trial was presented once, conditions were distributed in random order, but counterbalanced across the experiment. Note that the same target word was used for the four different conditions. Thus, condition-dependent ERP effects elicited by the target words can only be due to the different preceding contexts.

theory-of-mind network). That study also reported activations of posterior temporal regions implicated in semantic processing [46], presumably because the decoding of intentions has meaning quality.

Symbolic musical meaning emerges from explicit (or conventional) extra-musical associations (e.g. any national anthem; see also Nattiez [50]).[2] Note that the meaning of the majority of words is due to symbolic meaning. Cross [7] refers to this dimension of musical meaning as *culturally enactive*, emphasizing that symbolic qualities of musical practice are shaped by (and shape) culture. Symbolic musical meaning also includes social associations such as associations between music and social or ethnic groups; such associations have been shown to influence behaviour (reviewed in Patel [55]).

2.1. Extra-musical meaning and the N400

The following section will illustrate that processing of extra-musical meaning is reflected in the N400 component of the event-related potential (ERP). The N400 is an electrophysiological index of the processing of meaning information, particularly conceptual/semantic processing or lexical access, and/or post-lexical semantic integration (for details see Friederici and Wartenburger [16], Lau et al. [46]). The N400 has negative polarity and is maximal over centro-parietal electrode sites when elicited by auditory stimuli. It usually emerges at about 250 ms after the onset of a word and reaches its maximal amplitude at around 400 ms. The N400 elicited by words is highly sensitive to manipulations of semantic relations, being attenuated for words that are preceded by a semantically congruous context, compared to when preceded by a semantically incongruous context [30]. That is, when a word is preceded by a semantic context, the amplitude of the N400 is inversely related to the degree of semantic fit between the word and its preceding semantic context (for an example see upper panel of Fig. 1).

[2] Davies [12] uses the term *arbitrary stipulation of stand-alone meaning* [12, p. 34], and provides a number of interesting examples for symbolic musical meaning [12, pp. 40–47].

There is ample evidence that the N400 elicited by words is sensitive to conceptual analysis, and it is assumed that the N400 reflects that readers and listeners immediately relate the word to a semantic representation of the preceding contextual information. That is, the N400 elicited by words is particularly sensitive to the processing of meaning information, both in prime-target and in sentential contexts [14,43]. More generally, an N400 effect can be elicited by the processing of almost any type of semantically meaningful information, such as faces and pictures (e.g. Lau et al. [46]), environmental sounds [2,9,51,52,74], and odours [21]; importantly, the N400 can also be elicited by music, and the N400 elicited by a word can be modulated by the meaning of musical information preceding that word.

An initial study investigating this issue [37] used a classical semantic priming paradigm in which target words (presented visually) were preceded by (auditorily presented) prime stimuli that were either sentences or musical excerpts (Fig. 1). The prime stimuli were semantically either related or unrelated to the target word. In the language condition, for example, participants heard the sentence: “The gaze wandered into the distance” and then saw the target word “wideness”, which is semantically more closely related to the prime sentence than to a prime sentence like “The manacles allow only little movement” (Fig. 1). Target words ($n = 44$) were both concrete (e.g., needle, river, staircase, blossom, king, bird, pearls, sun) and abstract words (e.g., wideness, limitedness, devotion, mischief, reality, illusion, arrival, leave).

In the ERP experiment, participants made a two-alternative relatedness judgement for each target word. In the music condition, participants judged 78% of the related target words as “related”, and 82% of the unrelated target words as “unrelated”; hit rates in the language condition were higher (93 and 91%, the difference between language and music condition was significant). The upper panel of Fig. 1 shows the ERPs of the target words following prime sentences to which the target words were semantically either related or unrelated. ERPs elicited by the target words showed the classical N400 priming effect: The N400 was clearly larger for the semantically unrelated compared to the semantically related target words (as to be expected). Importantly, the conditions of primary interest in that study were the conditions in which the target words were preceded by musical excerpts. These excerpts were believed to be meaningfully (or “semantically”) un/related to the target words, and it was of interest whether a musical excerpt could have the same effect on the semantic processing of a target word as a sentence. In the example presented in the lower panel of Fig. 1, the target word “wideness” was in one trial preceded by a musical excerpt in which the intervals of chords were set in wide position (therefore assumed to prime the concept of wideness), and in another trial by a musical excerpt in which the intervals were often dissonant, and set in close position (therefore used as a non-prime for the word wideness). Note that the ordering of related and unrelated primes was balanced across the experiment, and that any emotional content (such as pleasantness/unpleasantness) was controlled for.

Like in the language condition, the ERPs elicited by target words that were meaningfully unrelated to the preceding musical excerpt showed an N400 (compared to the ERPs of target words that were meaningfully related to the preceding excerpt). That is, these results showed a modulation of the N400 elicited by the target words as a function of the semantic fit between musical excerpt and target word. That was the first empirical evidence that musical information can prime representations of meaningful concepts, and that music can systematically influence the semantic processing of a word (for probably the first behavioural experiment on this topic see Hevner [24]). The priming of meaning by musical information was due to (a) iconic sign qualities, i.e. common patterns or forms (such as ascending interval steps priming the word staircase), (b) indexical sign quality, such as the suggestion of a particular emotion due to the resemblance to movements and prosody typical for that emotion (e.g., saxophone tones sounding like derisive laughter), or (c) symbolic sign quality due to meaning inferred by explicit extra-musical associations (e.g. a church anthem priming the word devotion). Unfortunatly, is was not investigated in that study whether N400 responses differed between these dimensions of musical meaning (and, so far, no subsequent study has investigated this). However, the results still allow to conclude that processing of extra-musical meaning is associated with N400 effects.

Results of that experiment were obtained when participants judged the relatedness of prime-target pairs. In an additional experiment, participants performed a memory task on the stimulus items (thus being oblivious of the true purpose of the experiment). Even with this task, the N400 was clearly modulated by the semantic fit between musical excerpts and target-words. That is, musical information can prime representations of meaningful concepts even when participants do not judge the semantic relatedness between prime and target word. This argues for the notion that the musical information activated conceptual representations, and not covert verbalization of words (which then could have led to the observed N400 effects).

The N400 effects elicited in the language condition (in which the target words followed sentences) did not differ from those observed in the music condition (in which the target words followed musical excerpts), with regard to amplitude, latency, and scalp distribution (and N400 effects did not differ between concrete and abstract words). In addition, a source analysis localized the main sources of the N400 effects, in both conditions, in the posterior part of the medial temporal gyrus bilaterally (Brodmann's areas 21/37), in proximity to the superior temporal sulcus. These regions have been implicated in the processing of semantic information during language processing (reviewed, e.g., in Lau et al. [46]): Functional neuroimaging studies indicate that the posterior STS and the mid-posterior middle temporal gyrus host conceptual/semantic representations (representation of non-linguistic visual object features seem be stored in ventral parts of the inferior temporal cortex [46]), and (with regard to language production) the (left) MTG is also activated in tasks that require lexical selection [26].

Due to the length of musical excerpts (∼10 s), musical information could not be used as target stimulus in the study by Koelsch et al. [37], thus only words were used as target stimuli (and the N400 was only elicited on words, not on musical information). Hence, a question emerging from that study was whether musical information can also elicit N400 responses. One study addressing this issue [10] used short musical excerpts (duration was ∼1 s) that could be used either as primes (in combination with word targets), or as targets (in combination with word primes). Fig. 2a shows that when the musical excerpts were used as primes, meaningfully unrelated target words elicited an N400 (compared to related target words, as in the study from Koelsch et al. [37]). Importantly, when musical excerpts were used as target stimuli (and words as primes), an N400 was observed in response to excerpts that the participants rated as meaningfully unrelated to the preceding target word (compared to excerpts that were rated as related to the preceding word). This was the first evidence that musical information can also elicit N400 responses. Note that the musical excerpts were composed for the experiment, and thus not known by the participants. Therefore, musical meaning was not due to symbolic meaning, but due to indexical (e.g., "happy") and iconic (e.g., "light") meaning. In the data analysis used in that study [10], the relatedness of prime-target pairs was based on the relatedness judgements of participants. In another article [11] it was shown that even if the data are analyzed based on the un/relatedness of prime-target pairs as pre-defined by the experimenters, a significant N400 was elicited (in the latter study a lexical decision task was used, whereas in the former study participants were asked to judge the conceptual relatedness of prime and target stimuli).

Further studies investigated the processing of musical meaning using only single chords or single tones: One study [68] used an affective priming paradigm with single chords (presented auditorily) and words (presented visually). Chords were either consonant or dissonant, and perceived by the participants (all musicians) as either more pleasant or more unpleasant. Words were either pleasant or unpleasant due to their positive or negative affective content (for example "love" and "hate"). Unrelated targets elicited an N400 effect, both when chords were primes and when words were targets, as well as when words were primes and chords were targets. The N400 elicited by words had a posterior, whereas the N400 elicited by chords had an anterior scalp distribution. The difference in scalp distribution perhaps reflects different semantic processes, such as more strategic processes (including integrating and relating the meaning between target and prime) during the music-evoked targets; such strategic processes have been shown to involve (inferior) frontal areas [15,46]. However, the different scalp distributions of the observed N400 effects could also be due to the fact that words were presented visually, and chords auditorily.

In any case, the study by Steinbeis and Koelsch [68] revealed that a single musical stimulus (a chord that is more or less pleasant) can influence the semantic processing of a word (in this study presumably due to a chord's indexical qualities). Note that participants were musicians; using the same experimental paradigm with non-musicians also showed an N400 when words were targets [67], but not when chords were targets.

We [68] also obtained fMRI data using the same experimental paradigm, and found that the semantic processing of words was related primarily to activity in temporal lobe structures, namely the posterior portion of the middle temporal gyrus (MTG) extending into the superior temporal sulcus (STS), again corresponding to Brodmann's areas BAs 21/37 (there were also sub-threshold activations of inferior frontal cortex in both conditions that were presumably due to controlled selection and retrieval of conceptual representations, see also above and Leu et al. [46]). As mentioned before, these temporal regions play a role for the storage and activation of lexical representations [46]. Nearby (presumably within the same cytoarchitectonic areas), activation maxima were observed for the semantic processing of the chords. The topographical difference of activations between the processing of chords and words in this study was perhaps due to the fact that words (such as "love") have different lexico-conceptual entries than, for example, a consonant major chord. It is likely that spreading activation is a mechanism underlying these priming effects: Single chords may activate affective representations, which spread onto affectively related lexical representations. This

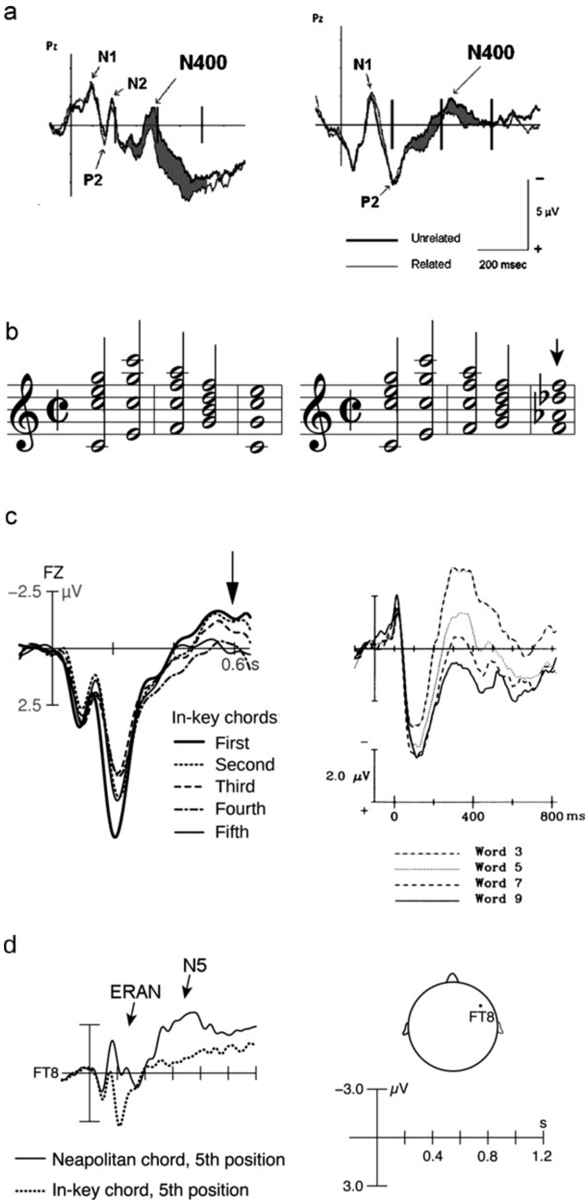

Fig. 2. (**a**) Data from the experiments by Daltrozzo and Schön [10], the left panel shows ERPs elicited by target words (primed by short musical excerpts), the right panel shows ERPs elicited by musical excerpts (primed by target words). The thick line represents ERPs elicited by unrelated stimuli, the thin line represents ERPs elicited by related stimuli. Note that the difference in N1 and P2 components is due to the fact that words were presented visually, and musical excerpts auditorily. Both meaningfully unrelated words and meaningfully unrelated musical excerpts elicited N400 potentials. (**b**) Chord sequences used in the experiment by Koelsch et al. [35], the left sequence ends on a regular tonic chord, the right sequence ends on an irregular chord function. (**c**) Left: Grand-average ERPs of in-key chords (first to fifth position), elicited by sequences such as the sequence shown in the left panel of (**b**). The amplitude of the N5 (indicated by the arrow) was dependent on the position of the chords in the cadence: The amplitude of the N5 decreases with increasing harmonic context build-up (modified from Koelsch et al. [35]). Right: A similar amplitude-decline can be observed for the N400 elicited by semantically correct open class words during sentence comprehension (modified from Van Petten and Kutas [73]). The amplitude-decline was inversely correlated with the word's ordinal position in relatively simple English sentences, reflecting the build up of constraints imposed by a partial sentence upon individual succeeding words. (**d**) Grand-average EPRs elicited by the final chords of sequences such as those shown in (**b**), separately for regular (dotted line) and irregular (solid line) chords. Compared to the ERPs of regular chords, irregular chords elicited ERAN and N5 potentials.
Modified from Koelsch et al. [35].

hypothesis of purported underlying mechanisms could be tested by varying the SOA and observing the persistence or absence of the effects.

Further experiments using the affective priming developed in the study by Steinbeis and Koelsch [68] used chords with pleasant and unpleasant timbres, as well as chords in major and minor mode as prime stimuli (i.e., target stimuli were always words [71]). Moreover, that study investigated both musicians and non-musicians. N400 effects for target words that did affectively not match with the prime chords were observed in the timbre, as well as in the major/minor mode experiment, with no statistical difference between musicians and non-musicians. These results showed that for both musicians and non-musicians a single chord is sufficient to communicate affective meaning (the meaning of the chords was presumably due to a mixture of indexical and symbolic sign qualities, but this was not specified in that study).

In another study [20], it was investigated whether similar semantic priming effects can also be observed when single tones are used as primes and/or targets. Tones had different timbres, and target words were adjectives (for example, "tense", "open", "fast", "strong", "colourful"). Unrelated target words elicited the N400 effect, both when primed by tones, and when primed by words. Likewise, unrelated target tones elicited the N400 effect, both when primed by words, and even when primed by tones (none of the participants had received any professional musical training). That study [20] also compared N400 effects between stimulus pairs that were pre-defined by the experimenters as related or unrelated, and stimulus pairs that were judged by the participants as related or unrelated. Although there was no statistically significant difference between these two conditions, the N400 was visible much more clearly in the ERPs of sound targets when the ERPs were analyzed according to the ratings of each participant. It should also be noted that the effect size of all N400 effects was rather small; therefore, future studies should replicate those effects, preferably using larger numbers of trials, and subjects. Such studies should also aim to differentiate between different sign qualities of sounds.

In summary, the mentioned studies show that musical information (musical excerpts, single chords, and single tones), can systematically prime representations of meaningful concepts (as indicated on modulatory effects on the N400 elicited by words). Moreover, the studies show that musical excerpts, single chords, and single tones can elicit N400 effects that are modulated by the semantic fit with a preceding word. The N400 effects are due to extra-musical meaning, that is, meaning emerging from musical information referring to the extra-musical world of concepts.

3. Intramusical meaning and the N5

The previous section dealt with extra-musical meaning and the N400. However, musical semantics extends beyond the relations between concepts and the (extra-musical) world in that musical meaning can also emerge from (the interpretation of) intra-musical references, that is, from the structural reference of one musical element, or unit, to at least one other musical element, or unit (without reference to the extra-musical world of concepts).[3] The term "intra-musical" was also used by Malcom Budd [4], other theorists have used the terms "formal meaning" [1], "formal significance" [12], or "embodied meaning" (note that the term "embodied" has nowadays a different meaning than the one meant by Meyer [48]). Similar distinctions as the one drawn here between extra- and intra-musical meaning have been made by several theorists (for a review see Koopman and Davies [41]).

The following will provide empirical evidence for the hypothesis that the processing of intra-musical meaning is reflected electrically in the N5 (or N500) component of the ERP: It will first be described that the N5 is sensitive to harmonic context build-up, and to harmonic incongruity. Then, evidence is presented that the N5 specifically interacts with the processing of the semantic incongruity of a word (which indicates that the processes underlying the generation of the N5 are related to semantic processes). At the end of this section, I will also provide some theoretical considerations, including other phenomena that can give rise to intra-musical meaning.

Harmonic context buildup. The N5 was first described in reports of experiments using paradigms in which chord sequences consisting of five chords ended either on a music-syntactically regular or a music-syntactically irregular chord function (Koelsch et al. [35], see Fig. 2b). Regular chords at positions 1 to 5 elicited an N5 (see arrow in the left panel of Fig. 2c), and the amplitude of the N5 declined towards the end of a chord sequence. This amplitude decline

[3] The German word for *meaning* is *Bedeutung*, and *deuten* has two meanings, namely *to point* (to something), and *to interpret*. In major–minor tonal music, intra-musical meaning can emerge from chord functions pointing to the musical context, and listeners interpreting the function of a chord.

is taken to reflect the decreasing amount of harmonic integration required with progressing chord functions during the course of the cadence. A small N5 elicited by the (expected) final chord of a chord sequence presumably reflects that only a small amount of harmonic integration is required at this position of a chord sequence. This phenomenology of the N5 is similar to that of the N400 elicited by open-class words (i.e., nouns, verbs, etc.): With progressing position of words in a sentence, the N400 amplitude also declines towards the end of a sentence (Van Petten and Kutas [73], see right panel of Fig. 2c). That is, during sentence processing, a semantically correct final open-class word usually elicits a rather small N400, whereas the open-class words preceding this word elicit larger N400 potentials. This is due to the semantic expectedness of words, which is rather unspecific at the beginning of a sentence, and which becomes more and more specific towards the end of the sentence (where readers already have a hunch of what the last word will be). Thus, a smaller amount of semantic integration is required at the end of a sentence, reflected in a smaller N400. If the last word is semantically unexpected, then a large amount of semantic integration is required, which is reflected in a larger amplitude of the N400.

Harmonic incongruity. Fig. 2d shows ERPs elicited by regular and irregular chords at the final position of the chord sequences shown in Fig. 2b. Compared to regular chord functions, irregular chord functions typically elicit an early right anterior negativity (ERAN, which is usually maximal around 150–200 ms, and taken to reflect neural mechanisms related to syntactic processing; for a review see Koelsch [31]). In addition, irregular chords elicit an N5 with a larger amplitude than the N5 of regular chord functions (for studies reporting such N5 effects for melodies see Miranda and Ullman [49], Koelsch and Jentschke [36]). This increase of the N5 amplitude is taken to reflect the increased amount of harmonic integration, reminiscent of the N400 reflecting semantic integration of words. That is, at the same position within a chord sequence the N5 is modulated by the degree of fit with regard to the previous harmonic context, analogous to the N400 (elicited at the same position within a sentence) which is modulated by the degree of fit with regard to the previous semantic context (see also Fig. 1). Therefore, the N5 was proposed to be related to the processing of musical meaning, or semantics, although the type of musical meaning had remained unclear [35].

Notably, the N5 can be elicited even when individuals do not pay attention to the music (e.g., while listeners read a book, or a play a video game, for a review see Koelsch [31]). That is, the neural mechanisms underlying the generation of the N5 operate partly automatically. Thus, similar to the processing of extra-musical meaning reflected in the N400 priming effects, intra-musical meaning is processed even when individuals do not pay attention to musical information (an exception is the synchronous processing of words and chords under the instruction to ignore the music and to pay attention to the syntax and semantics of the words [34]).

N5 and N400. The following will present evidence for the hypothesis that the earlier brain response to irregular chords (the ERAN) is related to syntactic processing, and the later response (the N5) to the processing of meaning information. With regard to the ERAN reflecting syntactic processes, two ERP studies [34,69] showed an interaction between the ERAN and the left anterior negativity (LAN; the LAN is an ERP component elicited by morpho-syntactic violations in language). In these experiments, chord sequences and sentences were presented together synchronously, that is, the onset of each chord coincided in time with the onset of a word of a sentence (Fig. 3). The chord sequences ended either on a regular tonic, or on a music-syntactically irregular "Neapolitan" chord (as in Fig. 2b). The last word of each sentence was (a) either syntactically correct, with a high semantic cloze probability (a high semantic cloze probability means that the last word of the sentence was semantically highly expected, for example the word "beer" in the sentence "He drinks the cold beer"), or (b) syntactically correct, but with a low semantic cloze probability (which means that the last word of the sentence was semantically less expected, for example the word "beer" in the sentence "He sees the cold beer"), or (c) it was morpho-syntactically incorrect (due to a gender disagreement), with a high semantic cloze probability (e.g. "Er trinkt den kühlen Bier"/"He drinks the$_{masc}$ cold$_{masc}$ beer$_{neuter}$").

Results showed three main effects: (1) Music-syntactic irregularities elicited the ERAN (consistent with the results of previous experiments investigating ERP responses to chords only, e.g., Koelsch et al. [35]). (2) Language-syntactic irregularities elicited the LAN, consistent with studies investigating ERP responses to words only (e.g., Gunter et al. [22]). (3) Semantically less expected words elicited an N400 (compared to the semantically highly expected words), consistent with previous studies showing that words with semantic low-cloze probability elicit an N400 compared to words with semantic high-cloze probability (e.g., Gunter et al. [22]).

Of particular interest in that study were, however, not the main effects, but the interactions between these effects, because such interactions indicate that the underlying processes are driven at least partly by shared neural resources. That is, it was investigated whether the processing of irregular chord functions has any effects on the simul-

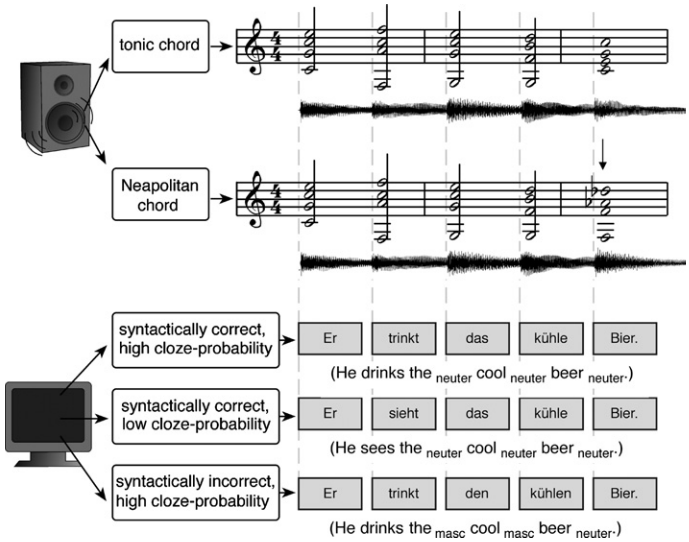

Fig. 3. Examples of experimental stimuli used in the studies by Koelsch et al. [34] and Steinbeis and Koelsch [69]. Top: examples of two chord sequences in C major, ending on a regular (upper row) and an irregular chord (lower row, the irregular chord is indicated by the arrow). Bottom: examples of the three different sentence types, the critical word is the last word of each sentence. Onsets of chords (presented auditorily) and words (presented visually) were synchronous.
Reprinted from Steinbeis and Koelsch [69].

taneous processing of language-syntactic and language-semantic incongruities. It was found that music-syntactic and language-syntactic processing interacted with each other: When elicited on irregular chords, the amplitude of the LAN was reduced (compared to the LAN elicited on regular chords). This suggests that the processing of irregular chords interfered with the syntactic processing of words (see also Slevc et al. [66], Fedorenko et al. [13], for behavioural studies reporting interactions between syntactic processing of music and language). Importantly, the N400 response (elicited by the semantically less expected words) did not interact with the ERAN, indicating that music-syntactic analysis does not affect language-semantic processing.

No N5 was elicited by the irregular chords in that study [34], therefore no potential interactions between the N5 and the N4 (nor between the N5 and the LAN) could be investigated. The absence of an N5 after the presentation of an irregular chord function was new, and presumably due to the task, in which participants were instructed to read the sentences and judge whether the sentences were correct (the chord functions were task-irrelevant). That is, under this instruction, and when participants process chords and words simultaneously, no N5 is elicited.

To investigate potential interactions between N5 and N400, we conducted another study [69] that used the same experimental paradigm as the previous study [34], except that ∼12% of the chord sequences contained a timbre deviant (harpsichord instead of the regular piano). Participants were instructed to read the sentences, judge their correctness, and to detect the infrequently occurring timbre deviants. Thus, participants had a task that was related to both the sentences and the musical sequences. With this task, the irregular chords elicited the N5 (in addition to the ERAN), which enabled us to study both ERAN and N5, as well as their possible interactions with the LAN and the N400 elicited by the words.

Results replicated the previous finding of the interaction between ERAN and LAN (that is, the LAN was reduced when elicited on irregular compared to regular chords). Moreover, it was found that the ERAN was smaller when elicited on syntactically incorrect words (compared to the ERAN elicited on syntactically correct words, see Fig. 4A). The fact that such an ERAN modulation was not observed in our previous study [34] was presumably related to the task, which required participants to pay attention to the chord sequences (for effects of attention on the ERAN see Koelsch [31]).

However, the interesting and most relevant finding with regard to the processing of musical meaning was that the N5 interacted with the semantic cloze-probability of words: The N5 was smaller when elicited on words with a low semantic cloze probability ("He sees the cold beer") compared to when elicited on words with a high semantic cloze probability ("He drinks the cold beer"; see Fig. 4B). Importantly, the N5 did not interact with the syntactic processing

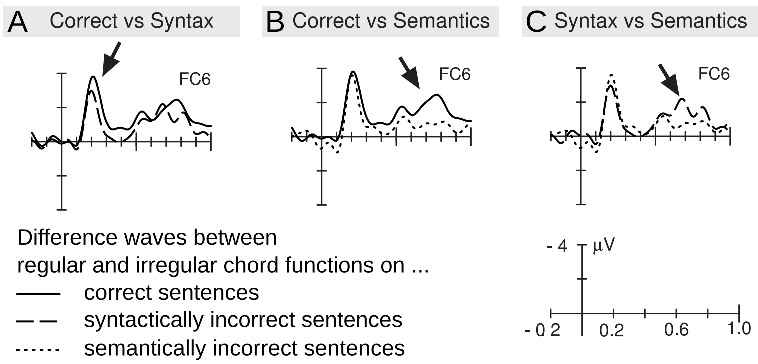

Fig. 4. Grand-average ERPs elicited by the stimuli shown in Fig. 3, participants ignored the musical stimulus, concentrated on the words, and answered in 10% of the trials whether the last sentence was correct or (syntactically or semantically) incorrect; in addition they monitored the timbre of the chord sequences and detected infrequently occurring timbre deviants. ERPs were elicited on chords and are shown for the different word conditions (note that only difference waves are shown). (**A**) The solid difference wave shows ERAN (indicated by the arrow) and N5 elicited on syntactically and semantically correct words. The dashed difference wave shows ERAN and N5, elicited when chords are presented on morpho-syntactically incorrect (but semantically correct) words. Under the latter condition, the ERAN (but not the N5) is reduced. (**B**) The solid difference wave is identical to the solid difference wave of (**A**), showing the ERAN and the N5 (indicated by the arrow) elicited on syntactically and semantically correct words. The dotted difference wave shows ERAN and N5, elicited when chords are presented on semantically incorrect (but morpho-syntactically correct words). Under the latter condition, the N5 (but not the ERAN) is reduced. (**C**) shows the direct comparison of the difference waves in which words were syntactically incorrect (dashed line) or semantically incorrect (dotted line). These ERPs show that the ERAN is influenced by the morpho-syntactic processing of words, but not by the semantic processing of words. By contrast, the N5 is influenced by the semantic processing of words, but not by the morpho-syntactic processing of words.
Data from Steinbeis and Koelsch [69].

of words, indicating that the N5 is not simply modulated by any type of deviance, or incongruency, but that the N5 is specifically modulated by neural mechanisms underlying semantic information processing (see also Fig. 4C). That is, the N5 potential can be modulated by semantic processes, namely by the activation of lexical/conceptual representations of words with different semantic fit to a previous context. This modulation indicates that the N5 is related to the processing of meaning. Note that the harmonic relation between the chord functions of a harmonic sequence is an intra-musical reference (i.e., a reference of one musical element to another musical element, and not a reference to anything belonging to the extra-musical world). Therefore, we have reason to believe that the N5 reflects the processing of intra-musical meaning.

It appears that intra-musical meaning is modulated by musical expression (e.g., emphasizing an irregular musical event by playing it with an accent), and that such modulation is also reflected in N5-potentials: In a study in which excerpts of classical piano sonatas were played either with musical expression (played by a pianist) or without expression (i.e., without any variations in tempo and attack), chords played in the condition with expression elicited a larger N5 than the same chords played in the condition without expression [38].

Neural generators of the N5. The locations of the neural generators of the N5 have remained elusive. This is in part due to the difficulty that in most experiments the N5 follows the ERAN (but see also Poulin-Charronnat et al. [60]), making it difficult to differentiate the neural correlates of N5 and ERAN in experiments using functional magnetic resonance imaging. The N5 usually has a clear frontal scalp distribution, thus the scalp distribution of the N5 is more anterior than that of the N400, suggesting at least partly different neural generators. Perhaps the N5 originates from combined sources in the temporal lobe (possibly overlapping with those of the N400 in BAs 21/37) and the frontal lobe (perhaps in the posterior part of the inferior frontal gyrus). This needs to be specified, for example using EEG or MEG source localization in a study that compares an auditory N400 with an auditory N5 within subjects.

Further intra-musical phenomena. The previous sections described two intra-musical phenomena from which (intra-musical) meaning can emerge: Harmonic context build-up, and harmonic incongruity. However, it is unlikely that these are the only two intra-musical phenomena that give rise to meaning; therefore, the following will suggest further phenomena, on a more abstract level (so that these principles can also be related to musical aspects other than harmonic structure; examples are, however, given with regard to chord functions so that the examples can be related to the previous text). It is proposed here that intra-musical meaning can emerge from representations of (1) the build-up of structure (for example, harmonic context build-up), (2) the extent of a structure (for example, a harmonic structure can be confined to a single key, or span several keys), (3) the stability of a structure (for example, a harmonic structure consisting of chords of the harmonic core is more stable compared to a structure consisting mainly of chords not belonging to the harmonic core), (4) a structural breach (for example due to a harmonic incongruity, such as in a deceptive cadence), (5) post-breach structure (for example, a chord function leading to a resolution has a different intra-musical meaning than in another harmonic context), (6) resolution of a structural breach (for example, the tonic resolving a structural breach at the end of a harmonic sequence is harmonically integrated in a different way than a tonic at the end of a harmonic sequence without a structural breach), and (7) large-scale structural relations (for example, meaning may arise from the recognition of the entirety of the structure of a movement, a symphony, a suite, etc.; but see also Cook [5], for a critical account on the perception of large-scale structures).

These principles of meaning emerging from structural relations (build-up of a structure, extent of structure, etc.) are not confined to music, but reflect rather general principles, parts of which have been described, for example, with regard to lyric poetry, rhetoric, aesthetics, visual arts, and linguistics. Music-psychological research could further test and investigate these principles using the N5 as dependent variable.

It is important to understand that intra-musical meaning is not the iconic meaning (or a metaphorical meaning) of extra-musical concepts such as "build-up", "extent", "stability", etc., but the meaning emerging from *harmonic integration* due to the establishment of a structural model, its modifications, etc. This does, however, not exclude that representations of such extra-musical concepts are activated during the processing of musical structure. For example, in music analysis, music theorists often use such extra-musical metaphorical concepts to describe intra-musical structural principles (see also Cook [6]), suggesting that (at least in those individuals) such intra-musical phenomena give rise to extra-musical meaning.

Furthermore, it is important to note that harmonic integration is implicitly also related to musical expectancy, and that the violation, or fulfillment of expectancies has emotional effects (such as tension, suspense, and relaxation; for an extensive account on this issue see Huron [25]). Meyer [48] stated that "as soon as the unexpected, or for that matter the surprising, is experienced, the listener attempts to fit it into the general system of beliefs relevant to the style of the work. [...] Three things may happen: (1) The mind may suspend judgement, so to speak, trusting that what follows will clarify the meaning of the unexpected consequent. (2) If no clarification takes place, the mind may reject the whole stimulus and irritation will set it. (3) The expected consequent may be seen as a purposeful blunder. Whether the listener responds in the first or third manner will depend partly on the character of the piece, its mood or designative content. The third response might well be made to continuing music whose character was comic or satirical" [48, pp. 29–30]. "From this point of view what a musical stimulus or series of stimuli indicate and point to are not extra-musical concepts and objects but other musical events which are about to happen. This is, one musical event (be it a tone, a phrase, or a whole section) has meaning because it points to and makes us expect another musical event" [48, p. 35]. Thus, the structural relations of musical events can also lead to emotional responses (such as surprise, increase in tension, etc.), which can, in turn, have meaning for the individual; I will differentiate between these two dimensions, and thus deal with the dimension of emotional meaning in the following section on musicogenic meaning.

4. Musicogenic meaning

The previous sections dealt with meaning emerging from the interpretation of musical information; this section deals with meaning emerging from the interpretation of (physical, emotional, and self-related) effects *elicited by* music (see also the concept of "meaning for the subject" by Koopman and Davies [41, p. 268]). That is, listeners do not only interpret musical information expressed by another individual, but also the effects evoked by the music in themselves. There is scarcity of empirical data on these dimensions of meaning, therefore the following sections on musicogenic meaning mainly provide rather theoretical, and partly speculative, considerations.

4.1. Physical musicogenic meaning

Individuals tend to move to music (singing, playing an instrument, dancing, clapping, conducting, head-nodding, tapping, swaying, etc.), that is, individuals tend to show physical activity in response to, and in synchrony with, music. Merely the fact that an individual shows such activity has meaning for the individual; in addition, the way in which the individual moves expresses meaning information: These movements are "composed" by the individual (and should therefore be differentiated from the motor-effects as one aspect of the emotional effects of music, such as smiling during emotional contagion when listening to joyful music; see next section). That is, it is important to understand that there is no objectivity of music (in the sense that music would direct movements of individuals like a puppeteer); music can elicit an impetus to move (and this impetus can be intended by the composer or player), but it is the individual that decides to move (i.e., to follow something that was intended by another individual), and it is the individual that "composes" the movements while moving to music (including dance movements, clapping, vocalizations, and singing or playing along).

In a social situation, that is, when more than one individual move to (or play) music, meaning can also emerge from joint, coordinated activity: For example, an action-related effect that becomes apparent in music based on an isochronous pulse (that is, a pulse to which we can easily clap, sing, and dance) is that individuals synchronize their movements to the external musical pulse. In effect, this leads in a group of individuals to coordinated physical activity. Notably, humans are one of the few species that are capable of synchronizing their movements to an external beat (non-human primates apparently do not have this capability, although some other species appear to have this capability as well; see Patel et al. [56,62]). In addition, humans are unique in that they can understand other individuals as intentional agents, share their intentionality, and act jointly to achieve a shared goal. In this regard, communicating and understanding intentions, and as well inter-individual coordination of movements is a pre-requisite for cooperation (for a summary of social functions engaged by music see also Koelsch et al. [39]). Ian Cross [7] stated that, in a social context, musical meaning can emerge from such joint performative actions; Cross referred to this dimension as *socio-intentional* [7, p. 6]. According to Cross, this dimension of musical meaning would therefore "be oriented towards attributions and interpretations of intentions and intentionality in engagement with music", and socio-intentional meaning "would be rooted in performative actions and sound structures that afford cues about shared intentionality that direct attention in interaction rather than the sharing of attention *per se*: these may be, e.g., declarative and disclosural (making manifest), concerned with the direction of another's attention to an object or event distinct from the individuals involved in the interaction; they may even be dissimulative, concerned with the *mis*direction of another's attention" [7, p. 6]. Note that mental state attribution (such as decoding intentions of another individual) is not specific for musicogenic meaning, but is presumably engaged in response to any extra- and intra-musical information (as suggested by a study by Steinbeis and Koelsch [70]); therefore, mental state attribution is a meta-phenomenon of musical meaning, and not conceptualized here as a separate dimension of musical meaning. However, the thoughts by Cross on socio-intentional musical meaning are relevant here because they describe how social interaction modulates physical musicogenic meaning. Also note that, as soon as (isochronous) music becomes a *symbol* for calling upon to move (in synchrony), then the meaning quality is symbolic (and not emerging from one's own physical activity in response to, and in synchrony with the music).

4.2. Emotional musicogenic meaning

Another dimension of musicogenic meaning is related to emotional responses evoked by music, as well as their peripheral physiological effects (note that feeling one's own emotions is different from the recognition of emotion expressed in the music). With regard to emotional effects evoked by intra-musical phenomena that contribute to the establishment of meaning, Leonard Meyer stated that *emotional responses* due to tension-resolution patterns emerging from the fulfillment or violation of expectancies based on the structure of musical information have a quality of meaning for the listener [48]. Emotional responses to irregular (unexpected) chord functions have also been shown empirically: Steinbeis et al. [72] showed that music-syntactically irregular chords induce tension (as indicated by behavioural data) and evoke increased sweat production on the palms of the hands, as indicated by electrodermal activity (such increased sweat production is due to increased autonomic activity of the sympathetic branch of the vegetative nervous system; participants of that study were non-musicians). Koelsch et al. [38] replicated the electrodermal responses to music-syntactically irregular chords, and reported that participants (non-musicians) felt less pleasant, more aroused, and more surprised when perceiving music-syntactically irregular chords. Koelsch et al. [33] replicated the finding that individuals (both non-musicians and musicians) find the music-syntactically irregular chords less pleasant than regular chords; that study [33] also showed that irregular chords elicit activity in the (basolateral) amygdala bilaterally.

It is likely that the violation of expectancy (e.g., due to a structural breach), and the resolution of tension are not the only intramusical phenomena that evoke emotions, but that each of the principles of meaning emerging from structural relations (build-up of a structure, extent of structure, etc.) evoke emotional responses. For example, it is likely that the anticipation of resolution during the processing of post-breach structure evokes emotional processes, and a reasonable working hypothesis is that the dorsal striatum is involved in such emotional processes: In the study by Koelsch et al. [33] this region was activated during blocks of chord sequences with irregular chords (evoking the anticipation for resolution), and a study by Salimpoor et al. [61] showed dopaminergic activity in this region when individuals anticipate an intensely pleasurable experience during music listening such as a "chill" experience (the "chill" itself evoked dopaminergic activity in the ventral striatum, presumably the nucleus accumbens; for a detailed account on emotional effects of expectancy and anticipation see also Huron [25]). Note that intra-musical phenomena are not the only ones that have effects on the emotions of listeners (for example, music can also evoke emotions due to the contagious nature of music with indexical sign quality, such as happy music [28,32]). Moreover, the arousing, or the soothing effects evoked by music have direct effects on peripheral-physiological processes (such as changes mediated by activity of the vegetative nervous system, e.g. Grewe et al. [18,19], Lundqvist et al. [47], Orini et al. [53]). These physiological changes also have a quality of meaning, for example in the sense of *subjective feeling* (e.g. Scherer [63]). We [40] have previously emphasized that subjective feeling requires conscious awareness, and presumably involves multimodal association cortices such as parietal association cortices of Brodmann's area 7.

4.3. Self-related musicogenic meaning

Musical information can also be related to one's self. These relations comprise memory representations (see also Koopman and Davies [41]), as well as associations with regard to an individual's most personal inner experiences. For example, a listener might recognize that a traumatization (or its personal consequences) expressed in music is analogous to what s/he had experienced oneself. Thus, it is proposed here that musical meaning can also emerge from relations between music and an individual's "sense of self", that is, from the relation of music to an individual's personality (beyond the mere expression of a particular emotion, or mixture of emotions).

5. Musical semantics

Musical semantics is the theory of meaning in music, how musical meaning is conveyed, and how meaning arises from the interpretation of musical information by a listener (musical semiotics, on the other hand, is the theory of musical signs). Semantic processing (that is, processing of meaning) includes (a) storage of meaningful information, (b) activation of representations of meaningful information, (c) selection of representations of meaningful information, and (d) integration of the semantic information of these representations with the previous semantic context. As for language, it remains to be specified where in the brain these processes are located, and how they are reflected electrically in ERPs (for example, in sub-components of the N400). However, the reported N400 studies indicate that these processes can be activated by musical information with regard to extra-musical meaning information, and the reported N5 studies suggest that semantic processes also emerge from (intra-musical) harmonic integration.

5.1. Meaning emerging from large-scale relations

Musical meaning can also emerge from large scale structural relations (such as relations between phrases, parts, movements, etc.). This holds for all three classes of musical meaning (extra-musical, intra-musical, and musicogenic). For example, the second theme in the sonata form has a different meaning in the recapitulation due its (intra-musical) relation to the first theme which is different in the reprise than in the exposition. With regard to extra-musical meaning, the "Summer" of Vivaldi's "Four Seasons", for example, has a different meaning when played in isolation than when played after the "Spring". The concept of intra-musical meaning due to large scale structures resembles the concept of *formal significance* proposed by Davies [12], who stated that "to understand the musical work is to understand how it is put together" [12, p. 48]. However, as mentioned above, large-scale relations emerge not only from intra-musical, but also from extra-musical (and probably also from musicogenic) meaning.

Notably, intra-musical meaning can also emerge from the logic of musical structures; according to Davies [12], e.g., "musical ideas fit together – as complementary, or as variations, or as repetitions – so that there is a development or progress of ideas, and the work comes to a close (and does not merely stop)" (p. 368; note that Davies' statement also implies that our minds differentiate between "logical" and "not logical" when listening to music).

It has been argued that humans (and perhaps other species as well) have an inborn need to understand the world (referred to as the "knowledge instinct" by Perlovsky [58]) with regard to understanding (or "making sense of") complex structures consisting of various elements, or constituents, as a synthesized, coherent entity, and that meaning emerges in part from such understanding [59]. For example, when listening to a sequence of hierarchically organized musical elements, the mind attempts to identify the intra-musical structure, and thus to establish a unified coherent sense out of "lower-level" units, this unified sense representing a "higher-level" meaning (see also Perlovsky [59, p. 11]). Such "higher-level" meaning can emerge from a musical phrase (see also intra-musical phenomena that contribute to the emergence of meaning), but also from a part, a piece, a movement, or an entire symphony (for a critical account on the perception of large-scale structures see also Cook [5]).

With regard to the integration of meaningful information into a larger semantic context, a study by Krumhansl [42] explored parallels between music and linguistic *discourse*. According to Krumhansl [42], "music and discourse both consist of units that have well-defined beginnings and ends. Topics [or musical ideas] are introduced and developed within these units, with various devices used to move the argument forward. Acoustic cues, such as pauses, pitch contour, dynamic stress, and rhythmic patterning, serve to define these units and highlight certain elements within them" [42, p. 405]. So far, however, such methods have rather investigated how listeners segment musical information, and although Krumhansl [42] stated that beginnings of new segments are associated with the presence of "new musical ideas" [42, p. 427], and that "musical ideas [are] marked by a variety of surface characteristics, such as changes in rhythmic and pitch patterns, register, and texture" (p. 427), the specification of the semantic processing of such musical ideas remains to be specified.

5.2. *Propositional semantics*

In contrast to language, major–minor tonal music does not have an explicit propositional semantics; for example, major–minor tonal music does not explicitly express relations such as true–false, or if–then. However, one should keep in mind that it remains to be specified whether similar brain mechanisms are engaged for the processing of such relations in language, and for the processing of aspects of musical information that have not been explored so far, such as the processing of chords in inversion, or the logic of musical structure. With regard to the logic of music, Davies' considerations of the logic of musical ideas and their progress was already mentioned above; in addition, musical elements (or groups of elements) also give rise to the logical distinction of "same" and "not same" [3]. For example, in a simple tonic-dominant progression, the dominant is not the same chord as the first chord. Even if such a progression is not composed to express a logical relation, we cannot exclude the possibility that our minds process such logical relations anyway.

5.3. *Psychological reality of music-semantic processing*

As already mentioned, this article does not deal with the meaning of music in terms of describing (directional) relations between signifier and signified. Instead, this article deals with the psychological reality of music-semantic processing as reflected in ERPs (and behavioural data). That is, this article does not pose the question as to *why* we perceive meaning in music, but rather as to *how* we process musical meaning. The electrophysiological data show that, while listening to music, the human mind constantly, and automatically attributes meaning to musical information, and the processing of musical meaning appears to be reflected electrically in the N400 (a classical index of semantic information processing during language perception) and the N5 (which specifically interacts with the N400). Notably, the studies investigating semantic processes with music suggest that posterior temporal (neo)cortical regions store *conceptual* features, rather than (only) lexical representations (unless musical information elicits implicitly lexical access, which, however, does not seem likely because N400 priming effects are also observed when stimuli are not task-relevant with regard to their semantics; see also above). It appears that the conceptual representations stored in posterior temporal cortex interface with a semantic network that is distributed across different brain regions, particularly frontal regions [15,46]. This is consistent with the notion that the neural generators of the N5 are located in both temporal and frontal regions, and consistent with the affective priming studies showing (sub-threshold) activations of frontal areas during the semantic processing of musical information [68].

The empirical data, as well as the theoretical framework for the investigation of musical meaning presented here, illustrate the importance to distinguish between the different dimensions of musical meaning. Such differentiation can help to avoid confusion when dealing with different theories on musical meaning. For example, Hanslick's argument that absolute music is not about expression of emotion has created confusion, because he implicitly wrote about intra-musical meaning, whereas expression of emotion due to (extra-musical) indexical sign quality represents a different dimension of musical meaning (for details about Hanslick's argument see, e.g., Davies [12], Cumming [8]). Another example is that Scruton [64] aims at making statements about intra-musical meaning, although the perception of successive pitches with increasing and decreasing fundamental frequency as upward- and downward-movement is due to extra-musical sign quality.[4]

This has important theoretical implications: For example, meaning emerging from extra-musical sign qualities does not necessarily require a *metaphorical transference of ideas* (as claimed by Scruton [64,65]), but mainly mere semantic priming (for a critical account on Scruton's use of the term "methaphor" see Cumming [8]): the interpretation, e.g., of symbolic extra-musical sign quality does not require more *metaphorical transference of ideas* than a word. The use of the term *metaphorical meaning* (or metaphorical transference of ideas), however, appears to be appropriate with regard to intra-musical structural properties, such as "breach" and "conflict", because intra-musical structural properties might prime representations of such concepts, although the music does not *sound*, e.g., like a breach in a programmatic fashion (that is, there are no cracking noises and the like). Nevertheless, "breach" and "conflict" are extra-musical concepts, and their meaning should be differentiated from intra-musical meaning (and so should their musicogenic effects, such as perceived "tension").

In this regard, it is also important to consider that the understanding and the interpretation of musical information, as well as of meaning communicated by other individuals in general, is usually multi-dimensional – meaning emerges from sign qualities, from the structural context, and from idiosyncratic responses – independently of whether or not another individual (e.g., a composer or musician) intended to convey exactly this meaning. In fact, it is also a psychological reality that the understanding of meaning is idiosyncratic in the sense that the same utterance, musical phrase, and the like, is interpreted differently by different individuals (due to different personal associations, different cultural backgrounds, different grasps of the structure, etc.), or even interpreted differently by the same individual in different contexts (depending on the attentional or emotional state, the social context, etc.).

5.4. Conclusion

This article presents a neurobiological theory of musical meaning. I suggest that two different classes of musical meaning are mediated by different cognitive processes, and reflected in different event-related brain potentials (the N400 reflecting processing of extra-musical meaning and the N5 reflecting processing of intra-musical meaning). The data presented in this article show that music can communicate meaning, notably not only meaning related to emotion, or affect, but iconic, indexical, and symbolic meaning (with regard to extra-musical meaning), as well as intra-musical meaning. The data also show that musical meaning is at least partly processed with the same mechanisms as meaning in language. Therefore, the notion that language and music are strictly separate domains with regard to the processing of meaning is not tenable anymore.

The fact that (a) musical information can prime representations of meaningful (extra-musical) concepts, (b) that intra-musical meaning can emerge from structural relations, and (c) that musical meaning can emerge from musical discourse, implies that musical meaning is not only a matter of semiotics (i.e., not only a matter of the sign qualities of music), but a matter of semantics that includes storage, activation, and selection of representations of meaningful concepts, as well as integration of the semantic information of these representations with the previous semantic context. Notably, the N5 as an index of the processing of meaning emerging from structural relations has so far only been reported for music; therefore, music – and not only language – is important to understand how meaning emerges from the interpretation of information in the human brain.

[4] The association of high/low pitches with the concepts "high"/"low" is presumably a mixture of (a) iconic sign quality, mainly due to the position of the larynx being higher (if the individual is standing or sitting) during the production of tones with higher pitches compared to lower pitches, and (b) possibly symbolic sign quality, because the association of high/low pitches with the concepts "high"/"low" might not be universal: Lawrence Zbikowski [75] noted that Greek music theorists of antiquity used the terms "sharpness" and "heaviness", that in Bali and Java the terms "small" and "large" are used, and that the Suyá of the Amazon basin use the terms "young" and "old" to refer to high and low pitches [75, p. 5]. This does not rule out, however, that those peoples would also agree that high/low pitches are "high"/"low", and that in Western listeners high and low pitch information also primes representations of concepts such as "sharp/heavy", "small/large", or "young/old".

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