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The effects of supervised learning on event-related potential correlates of music-syntactic processing

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ABSTRACT

Humans process music even without conscious effort according to implicit knowledge about syntactic regularities. Whether such automatic and implicit processing is modulated by veridical knowledge has remained unknown in previous neurophysiological studies. This study investigates this issue by testing whether the acquisition of veridical knowledge of a music-syntactic irregularity (acquired through supervised learning) modulates early, partly automatic, music-syntactic processes (as reflected in the early right anterior negativity, ERAN), and/or late controlled processes (as reflected in the late positive component, LPC). Excerpts of piano sonatas with syntactically regular and less regular chords were presented repeatedly (10 times) to non-musicians and amateur musicians. Participants were informed by a cue as to whether the following excerpt contained a regular or less regular chord. Results showed that the repeated exposure to several presentations of regular and less regular excerpts did not influence the ERAN elicited by less regular chords. By contrast, amplitudes of the LPC (as well as of the P3a evoked by less regular chords) decreased systematically across learning trials. These results reveal that late controlled, but not early (partly automatic), neural mechanisms of music-syntactic processing are modulated by repeated exposure to a musical piece.

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1. Introduction

It is a curious phenomenon that, even after having heard a piece of music numerous times, we still perceive music-syntactically irregular harmonies of this piece as unexpected. Dowling and Harwood (1986) suggested that, although a piece "might hold no surprises for us on the conscious level, it is full of schematic violations on the subconscious level" (p. 220). Following up on this idea, Bharucha (1987) offered the explanation that *schematic* expectancies (due to automatic, unintentional predictive processes) cannot be suppressed, and are engaged despite *veridical* expectancies due to veridical knowledge of the piece (veridical knowledge means that the individual actually knows what is about to follow, from Latin *veridicus*, i.e. "truth-telling"). Veridical expectancies are usually explicit (e.g., the memory representation of *Happy Birthday*), but

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can also be implicit (e.g., when playing a piece of music by heart, the motor sequences are often executed automatically, without the player being able to tell explicitly which notes will follow). As far as we know, only two behavioral studies directly investigated whether schematic expectancies are modulated by veridical expectancies by providing a preview of the chords, or using a musical priming paradigm (Justus and Bharucha, 2001; Tillmann and Bigand, 2010). There is a lack of neurophysiological studies informing us about how such predictive processes are modulated by, or interact with, representations of veridical knowledge about upcoming information.

Several previous learning studies in the music domain have addressed implicit learning (e.g., Dienes and Longuet-Higgins, 2004; Kuhn and Dienes, 2005; Rohrmeier et al., 2011). According to Reber (1967), implicit learning refers to processes underlying the acquisition of complex rules (governing the generation of sequential stimuli) without the subject intending to learn, and without the subject being aware of the acquired knowledge (for reviews in the music domain see Tillmann, 2005; Rohrmeier and Rebuschat, 2012). One feature of implicit learning is that it yields abstract rule-based knowledge (Rohrmeier and Rebuschat, 2012). Implicit knowledge in the form of abstract (but possibly instantiated) representations (Seger, 1994) is usually acquired through mere exposure (Rohrmeier and Rebuschat, 2012). It is mentally represented without awareness of the entirety of the complex grammar of rules, and can often not be described verbally, but can nevertheless influence behavior (Rohrmeier and Rebuschat, 2012; Paavilainen, 2013). Numerous studies suggest that implicit knowledge governs perception of music with regard to melody, harmony, timbre, and rhythm (Rohrmeier and Rebuschat, 2012). During the perception of complex rule-governed sequences (such as sentences in language, or melodies in music), implicit knowledge is a sufficient condition for the establishment of predictions about upcoming events (Rohrmeier and Koelsch, 2012). The violation of such predictions, or expectancies, is reflected in behavioral effects (for reviews see Bharucha, 1994; Tillmann, 2005; Rohrmeier et al., 2011), as well as in brain–electric responses (reviewed in Koelsch, 2012).

With regard to violations of expectancies established on the basis of implicit knowledge, numerous neurophysiological studies have indicated that processing of music-syntactic expectancy violations is reflected electrically in an early anterior negativity that often has right-hemispheric weighting (the *early right-anterior negativity*, or ERAN; Koelsch et al., 2000; Leino et al., 2007; Carrión and Bly, 2008; Miranda and Ullman, 2007; Müller et al., 2010; Garza Villarreal et al., 2011; Kim et al., 2011; Kalda and Minati, 2012; Brattico et al., 2013; Koelsch et al., 2013; Sammler et al., 2013; for a review see Koelsch, 2012). ERAN effects have been shown in non-musicians, that is, in individuals who have implicit knowledge of music-syntactic regularities (although the ERAN has slightly larger amplitude in musicians than in non-musicians, e.g. Koelsch et al., 2002a). Thus, in non-musicians, the ERAN is solely based on the application of implicit knowledge stored in long-term memory. Such application of implicit knowledge appears to be automatic, or at least partially automatic (e.g. Bharucha, 1994), that is, it can be observed even in the absence of voluntarily directed attention: Although the ERAN amplitude can be modulated by attentional factors, the ERAN is evoked even when individuals perform attention-demanding reading tasks during the perception of music (Koelsch et al., 2002b; Loui et al., 2005) or when their attention is directed to a concurrent auditory stream of linguistic information (Maidhof and Koelsch, 2011). Therefore, the present study used the ERAN as an electrophysiological marker of (partially) automatic syntactic processing based on implicit knowledge (amateur musicians also have explicit knowledge, in addition to implicit knowledge, which might contribute to a larger ERAN amplitude in musicians compared to non-musicians).

The (implicit) long-term representations of syntactic regularities are remarkably stable: In a study by Koelsch and Jentschke (2008), two types of short (3.6 s) chord sequences, of which the final chord was syntactically either regular or irregular, were presented to participants for approximately two hours (participants were watching a silent movie with subtitles). It was found that the amplitude of the ERAN declined over the course of the experiment, but was still present at the end of the experiment (Koelsch and Jentschke, 2008). In that study, participants were not informed about the harmonically irregular chords, and thus presumably did not consciously intend to acquire knowledge about the statistical regularities of the irregular chords occurring in that study. The fact that the ERAN declined over the course of the experiment indicates that several hundreds of presentations are needed to modulate the long-term memory representations of statistical regularities that usually guide music-syntactic processing. However, the observed ERAN effect was still significant at the end of the experiment, indicating that cognitive representations of basic music-syntactic regularities cannot easily be modified (for a behavioral study leading to the same conclusion see Bharucha and Stoeckig, 1986). This finding is consistent with results of a study by Carrión and Bly (2008) which reported that the amplitude of the ERAN elicited by irregular chords did not increase when participants underwent an implicit learning session in which they were presented with eighty-four training sequences that ended on syntactically correct chords. Notably, in contrast to the ERAN, the P300 (or P3b) amplitude increased in that study (Carrión and Bly, 2008) as an effect of training. This result is in line with studies showing that the conscious, deliberate detection of music-syntactic irregularities by non-musicians (based on implicit knowledge) evokes P300 potentials (Koelsch et al., 2000; Regnault et al., 2001).

However, the P300 is elicited by the detection of expectancy violations based on veridical knowledge as well: early electrophysiological studies with music showed that the detection of wrong tones occurring in familiar melodies elicits a P300 (Besson and Macar, 1987; Verleger, 1990; Paller et al., 1992; Besson and Faïta, 1995). In some of the mentioned studies (Besson and Faïta, 1995; Regnault et al., 2001; Besson et al., 1994), the P300 evoked by unexpected musical events was referred to as late positive component (LPC). The label LPC was used due to the prolonged morphology of this P300-like component, and due to the fact that task-relevant music-syntactic irregularities can evoke an LPC, even when musical information is unfamiliar. Thus, the LPC resembles the P600 elicited in language experiments, and is taken to reflect

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