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New fast mismatch negativity paradigm for determining the neural prerequisites for musical ability

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ABSTRACT

Studies have consistently shown that the mismatch negativity (MMN) for different auditory features correlates with musical skills, and that this effect is more pronounced for stimuli integrated in complex musical contexts. Hence, the MMN can potentially be used for determining the development of auditory skills and musical expertise. MMN paradigms, however, are typically very long in duration, and far from sounding musical. Therefore, we developed a novel multi-feature MMN paradigm with 6 different deviant types integrated in a complex musical context of no more than 20 min in duration. We found significant MMNs for all 6 deviant types. Hence, this short objective measure can putatively be used as an index for auditory and musical development.

1. Introduction

Learning and performing music requires a variety of auditory skills, placing demands on the underlying neural substrates as well as on the brain's plastic potential. Recent studies of human brain function indicate that musicians are more sensitive to basic auditory features than non-musicians (Brattico et al., 2001; Koelsch et al., 1999; Pantev et al., 1998) and, further, that behavioral measures of auditory performance correlate with event-related potentials (ERPs) as recorded by electroencephalography (EEG) (Lang et al., 1990; Pakarinen et al., 2007; Schneider et al., 2002). Studies indicate that the stimuli need to consist of realistic, complex musical material in order to disclose fine-grained processing differences between participants (Brattico et al., 2001; Koelsch et al., 1999; Seppänen et al., 2007). Therefore, there is a need for paradigms integrating different auditory features into musically relevant contexts (Vuust et al., 2011) in order to

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study the development of auditory skills and musical expertise.

The mismatch negativity (MMN) (Näätänen et al., 1978) is a component of the auditory ERP recorded with EEG related to change in different sound features such as pitch, timbre, location of sound source, intensity and rhythm (Näätänen et al., 2001, 2007; Näätänen and Winkler, 1999). It peaks approximately 100–200 msec after change onset, with the amplitude and latency of the MMN depending on deviation magnitude such that larger deviations yield larger and faster MMNs (Näätänen et al., 1987).

Recording the MMN to musically relevant sound features in a musical context may be a possible objective way of measuring auditory skills for the following reasons: first, the MMN is automatically elicited, even in the absence of subjects' attention towards the stimuli, typically in paradigms where they are reading a book or watching a silent video while being exposed to sound patterns (Alho, 1992; Fujioka et al., 2004). Second, the amplitude and latency of the MMN is associated with auditory behavioral measures (Lang et al., 1990; Sams et al., 1985; Tiitinen et al., 1994). Such a correlation was recently extended by Seppänen et al. (2007) to include more musically related tests incorporating ear-training aspects. Third, the MMN is sensitive to discrimination learning (Näätänen et al., 1993) and musical expertise (Brattico et al., 2009; Nikjeh et al., 2009; Russeler et al., 2001; Vuust et al., 2005). In particular, specific auditory skills required for performing different musical tasks such as conducting an orchestra (Munte et al., 2001; Nager et al., 2003), playing certain instruments (Koelsch et al., 1999), or musical genres (Seppänen et al., 2007), lead to special sensitivity to different sound features reflected in the amplitude and latency of the MMN (for a review, see Tervaniemi, 2009).

Some disadvantages of the traditional MMN paradigms used are that they are time-consuming (often exceeding an hour) and they do not sound musical. However, Näätänen et al. recently introduced a novel paradigm (Näätänen et al., 2004) in which several types of acoustic changes are presented in the same sound sequence. This allows for several MMNs to be independently elicited for different auditory attributes, making the duration of the experiment significantly reduced to less than 15 min. Importantly, no difference was observed between the MMNs recorded using the new paradigm and the ones obtained in the traditional oddball paradigm.

Here we present a new, fast, musical multi-feature MMN paradigm, in which 6 types of acoustic changes relevant for musical processing in different musical genres are presented in the same sound sequence. Specifically, 5 of the 6 musical features are aspects of musical sound that previously have elicited larger MMNs according to musical expertise: pitch mistuning, intensity, timbre, sound-source location, and rhythm (Brattico et al., 2009; Pantev et al., 2003; Tervaniemi et al., 2006; Vuust et al., 2009). Since we wanted a paradigm that could be used to compare non-musicians to musicians, as well as musicians from different musical genres with each other, we included a pitch slide typical for improvisational music instead of classical music (see also Tervaniemi et al., 2006; Vuust et al., 2005).

In comparison with the recently developed multi-feature paradigm (Näätänen et al., 2004; Pakarinen et al., 2007), the present paradigm has a greater similarity to real music. It is based on a musical figure, well-known in many genres of Western tonal music: the Alberti bass, an accompaniment originally encountered in classical music such as Mozart's sonatas or Beethoven's rondos, and later adopted with variations in other contemporary musical genres (Fuller, 2010). Here we show that the musical multi-feature paradigm enables one to record MMNs corresponding to the respective MMNs obtained in the traditional one-deviant paradigms.

2. Methods

2.1. *Subjects*

Eleven subjects (mean age 26, range 22–27 years; 4 females) gave informed consent and participated in the experiment. The subjects had no formal music training apart from music lessons at primary and secondary school, and were never taught to play an instrument, with the exception of one subject who had played the piano for less than a year when he was 8 years old. All participants had normal hearing and reported no cognitive deficits or neurological diseases. The experiment protocols were done in accordance with the Declaration of Helsinki, and approved by the Ethical committee of the Department of Psychology, University of Helsinki. Subjects were paid for their voluntary participation.

2.2. *Stimuli and procedure*

Auditory stimuli were similar to the 'Optimal' paradigm presented in Näätänen et al. (2004), yet were more complex and musically enriched. In the Optimal paradigm, a 'standard' simple tone is presented once after each 'deviant' tone. In this way, it is possible to record ERP responses for many auditory feature deviations in a considerably shorter time, and with an equally good signal-to-noise ratio as the traditional oddball paradigms. Similarly, in the present study, standards and deviants were alternated, but each of them consisted of musical 4-tone patterns rather than single tones (Fig. 1).

The standard pattern consisted of either major or minor mode tones arranged in an 'Alberti bass' configuration, an accompaniment commonly used in the Western musical culture in both classical and improvisational music genres. To make the stimuli more musically interesting, we changed the key every 6th measure, allowing for 6 different types of deviants to appear exactly once in each key, in a randomized order. The order of the 24 possible keys (12 major and 12 minor) was pseudo-randomized, so that each key appeared once for every 24 transpositions. The keys were kept in the middle register of the piano with the bass note between F3 and E4. Sound stimuli were generated using the Wizoo Acoustic Piano sample sounds from the software sampler Halion in Cubase (Steinberg Media Technologies GmbH). Deviant patterns were similar to standards, except that the third tone of the pattern was modified with Adobe Audition (Adobe Systems Incorporated) as illustrated in Fig. 1. The pitch deviant was created by mistuning the third tone by 24 cents, tuned downwards in the major mode, upwards in the minor mode. The rhythm deviant was created by anticipating the