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Refinement of metre perception – training increases hierarchical metre processing

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Abstract

Auditory metre perception refers to the ability to extract a temporally regular pulse and an underlying hierarchical structure of perceptual accents from a sequence of tones. Pulse perception is widely present in humans, and can be measured by the temporal expectancy for prospective tones, which listeners generate when presented with a metrical rhythm. We tested whether musical expertise leads to an increased perception and representation of the hierarchical structure of a metrical rhythm. Musicians and musical novices were tested in a mismatch negativity (MMN) paradigm for their sensitivity to perceptual accents on tones of the same pulse level (metre-congruent deviant) and on tones of a lower hierarchical level (metre-incongruent deviant). The difference between these two perceptual accents was more pronounced in the MMNs of the musicians than in those of the non-musicians. That is, musical expertise includes increased sensitivity to metre, specifically to its hierarchical structure. This enhanced higher-order temporal pattern perception makes musicians ideal models for investigating neural correlates of metre perception and, potentially, of related abstract pattern perception. Finally, our data show that small differences in sensitivity to higher-order patterns can be captured by means of an MMN paradigm.

Introduction

Musicians practise their instruments for several hours a day, often beginning in childhood. This results in superior performance in various auditory perception tasks. In the present study, we investigated whether musical expertise leads to superior perception of auditory pulse and metre. Pulse perception has recently gained much attention from researchers attempting to describe its cognitive characteristics and neurophysiological correlates. It refers to the perception of roughly equally spaced and relatively salient tones referred to as beats (Parncutt, 1987). If the musical piece contains two or more hierarchical pulses, the musical piece is said to have a metre. Thus, metre refers to a regular pattern of strong and weak beats, where beats of higher metrical hierarchies are relatively stronger (Cooper, 1960; Lerdahl & Jackendoff, 1981; Parncutt, 1987; Jones & Boltz, 1989). Once a pulse or metre is perceived, the listener shows an expectation for prospective tones to match the established metrical grid (Jones *et al.*, 2002).

Musical expertise is not required to perceive a pulse in a musical piece. Most untrained listeners are able tap their feet to the beat of a piece of music. Automatic motor synchronization to music is one of the obvious indicators for pulse sensitivity, and is present even in infants (Zentner & Eerola, 2010). Infants also show a distinct electrophysiological response, namely the mismatch negativity (MMN), to metrical rhythms (Honing *et al.*, 2009; Winkler *et al.*, 2009). However, some individuals are better at metre perception than others. Effects of expertise in metre perception have been shown by means of electrophysiological correlates in response to metrically unexpected stimulus manipulations (Jongsma *et al.*, 2004, 2005; Vuust *et al.*, 2005). In particular, one of these studies reported that trained and untrained individuals show a different pattern of response when asked to judge the metrical consistency of tones. That is, to musicians, a tone of any metrical level is perceived as consistent with the previously perceived metre, whereas to untrained individuals, only a tone on the same pulse level or one hierarchical level below the pulse level is perceived as consistent (Jongsma *et al.*, 2004). The authors refer to the pattern observed in musicians as ‘hierarchical’ processing. Their result leads to the question whether untrained individuals merely selected a different approach to solve the task presented to them, or whether hierarchical processing is not available to them. In the latter case, the approach of untrained subjects would be explained by a lack of sensitivity to the hierarchical structure of the presented metre. To identify whether there is a perception or a strategy difference between trained and untrained individuals, we tested the sensitivity of musicians and non-musicians to the hierarchical structure of metre in unattended processing. We chose the task-independent MMN paradigm, which has been shown to be suitable for testing auditory

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expectation (Naatanen *et al.*, 2007; Winkler, 2007). The MMN component is an auditory event-related potential elicited by infrequent auditory stimuli deviating in a physical or higher-order feature from a regular standard sound (Naatanen & Escera, 2000; Naatanen, 2003). According to the current framework, the MMN indicates the violation of a predictive regularity extracted from the preceding sequence of standard stimuli (Baldeweg, 2006; Winkler, 2007). Because it is largely independent of attention, the MMN is a useful tool with which to access sensitivity to the specific standard stimulus characteristic disturbed by the deviant. Previous studies have shown that the MMN component is particularly apt for testing metrical expectancy (Honing *et al.*, 2009; Ladinig *et al.*, 2009; Winkler *et al.*, 2009).

To our knowledge, our study is the first to investigate the effects of musical expertise on metrical hierarchy perception in an unattended processing paradigm. This study is an important step towards understanding the effects of auditory training on abstract auditory pattern perception.

Materials and methods

Participants

Twenty-eight male volunteers were paid to participate in the study. Because rhythm perception is an ability in which percussionists in particular need to excel, we chose to investigate a group of trained percussionists. Fourteen participants (mean age 25.5 ± 4.0 years) were trained percussionists with an average of 16.1 ± 5.0 years of training in addition to the basic musical education provided in school. Basic musical education includes singing in class during kindergarten (2 years), primary school (6 years), and optionally during high-school (4–6 years). Self-reported hours of practice were 2.5 ± 1.37 per day for the trained percussionists. The 14 control participants (mean age 24.2 ± 3.4 years) lacked instrumental training and had not taken any other music classes in the past 5 years. All subjects were right-handed (Annett, 1992) and had no history of neurological or psychiatric illness. All procedures were approved by the ethics committee of the University of Zurich, and were carried out in accordance with the revised version of the code of Ethics of the World Medical Association, Declaration of Helsinki (Rickham, 1964). All participants gave written informed consent prior to the experiment.

Stimuli

A metrical rhythm typically contains a hierarchically organized beat structure upon which listeners build an expectation regarding the metrical strength of subsequent tones. Specifically, a listener will expect an accentuation to be more likely on a strong metrical position. That is, a beat of a higher metrical hierarchy is expected to be more accented than a beat of a lower metrical hierarchy. To test the subjects' sensitivity to that hierarchical beat structure, we presented an intensity accent at a metrically strong (metre-congruent) and at a metrically weak (metre-incongruent) position. As a basis for the experiment, a metrical rhythm was constructed. Its pattern of beat strength is indicated in Fig. 1. The duration of the ¼ note was 600 ms, and that of the 1/8 note was 300 ms. The ¾ rhythm was produced by a snare drum, and was presented continuously with an intensity of 67 dB. The metre-incongruent deviant consisted of an omission of a 1/8 note and a dynamic increase of the subsequent ¼ note, resulting in an intensity of 79 dB. The acoustic signals of the accented ¼ note (600 ms) and the unaccented 1/8 note (300 ms) differed only in duration and intensity, not in spectrum or rise-time. The metre-congruent deviant consisted of the same intensity increase on the ¼ note at the beginning of a standard bar. The sound of a snare drum is essentially an aperiodic

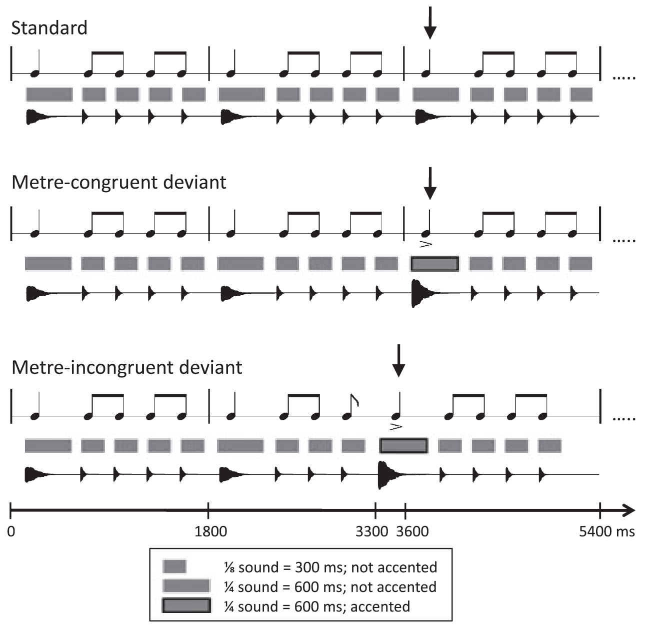

FIG. 1. Stimulus material. The top row illustrates the standard sequence, and the relative metrical strength is indicated by the length of the grey bar below the musical notation. The middle line represents the metre-congruent deviant, which occurs on a metrically strong tone. The bottom line represents the metre-incongruent deviant, which occurs on a metrically weaker tone. Both deviant tones and the standard tone used in the MMN analysis are marked with arrows.

sound burst with a rise-time of 0 ms, as indicated in Fig. 1 for the accented and the non-accented bursts. As a result of this manipulation, the metre-congruent deviant reinforces the perceived beat structure, that is, the metrical expectation, whereas the metre-incongruent deviant violates the perceived beat structure. Both deviants differ from the standard tones by the same intensity. The difference between the metre-congruent and the metre-incongruent deviants is found in the position in which they appear within the metrical grid.

A total of 1005 complete ¾ bars were presented, including 80 metre-congruent deviants and 80 metre-incongruent deviants in an MMN paradigm (Naatanen, 2003; Naatanen *et al.*, 2004a). The stimulus material was designed in such a way that there were four to six complete standard bars between deviants, pseudorandomly distributed over the experiment. Stimuli were constructed in ADOBE AUDITION 3.0 and exported as .wav files. All stimuli were presented in one block that lasted 33 min.

Procedure

During the electroencephalography (EEG), subjects were seated comfortably in front of a screen while watching a movie without sound (*Ice Age*, 20th Century Fox, USA). Stimuli were presented through headphones (Sennheiser, HD 25-1-70 μ) with PRESENTATION software (Version 12.2; Albany, CA, USA). EEG data were recorded from 32 electrode sites with a BrainAmp amplifier system (Brain Products GmbH, Gilching, Germany), with the nose tip as a reference. EEG channels were placed according to a subset of the 10-10 system (Chatrian *et al.*, 1988). The ground electrode was positioned at AFz. An electro-oculogram was recorded from two electrodes placed on the infra-orbital ridges of the left and right eye and the outer canthi of the two eyes. EEG and electro-oculography results were sampled and digitized at 500 Hz and on-line filtered (bandpass of 0.1–100 Hz; notch filter of 50 Hz). Impedances were kept below 10 kΩ during EEG recording.

After the EEG experiment, a behavioural detection test was performed to measure a behavioural index of metre perception. For this test, an active oddball paradigm was applied, in which the same stimulus sequence was presented as in the EEG experiment. The behavioural test lasted for 13 min, and included 38 deviants of each category. Subjects were instructed to press a button with the right index finger when they perceived a metre-incongruent deviant. The number of hits and the reaction times (ms) of these responses were measured.

After the behavioural detection test, the Gordon musicality test was performed in order to assess subjects' musical aptitude. This musicality test consists of a tonal and rhythm subtest (Gordon, 1989), in which pairs of melodies are presented. Subjects are instructed to report whether these musical stimuli are the same or different. Possible differences include melodic or key differences, as well as rhythm and metre differences. The scoring differentiates between tonal and rhythm performance, and provides norms for musically trained and untrained individuals.

Behavioural data analysis

The Gordon total raw score and raw scores for the tonal and rhythm part of the test were calculated. The performance of each subject on the Gordon test was transformed into a percentage rank on the basis of the norms provided by the Gordon test. Subjects were included in further analysis if they performed within the range 10–90% on the musician norm (percussionists) and on the non-musician norm (untrained individuals). In the behavioural detection test (active oddball paradigm), correct trials were corrected for individual outliers, and hit rates (%) and the averages of reaction times were computed for each subject. To compare behavioural performance between musicians and non-musicians, independent sample *t*-tests were performed on the measures from the Gordon musicality test (percentage rank for tonal and rhythm subtest) and the behavioural detection test (hit rates and reaction times).

EEG data analysis

The EEG data were pre-processed and analysed with EEGLAB 6.01 (Delorme & Makeig, 2004) running in the MATLAB environment (Mathworks, Natick, MA, USA). Imported data were off-line filtered (1–40 Hz) and segmented into epochs from −100 to 500 ms relative to the stimulus onset. Artefact detection was performed with an amplitude threshold criterion of ± 150 μV. Then, the EEG data were screened for unique and non-stereotyped artefacts with a probability function implemented in EEGLAB (Delorme *et al.*, 2007). In this procedure, epochs containing signal values exceeding three standard deviations were removed. Independent component analysis was then applied to remove ocular artefacts (Jung *et al.*, 2000a,b). Finally, single trials were de-noized with an algorithm based on the wavelet transform (Quian Quiroga & Garcia, 2003). The wavelet coefficients used to reconstruct the single trials were selected on the basis of the grand average computed across all participants and conditions, and were the same for all electrode sites and participants.

MMN amplitudes and latencies were measured in the difference waveforms, which were computed by subtracting the potentials evoked by standards from the potentials evoked by deviants, resulting in two difference waves (metre-congruent and metre-incongruent) for each group (trained percussionists and non-trained controls). MMN analysis was carried out for the frontal (Fz) electrode, which has been used in previous MMN studies (Naatanen *et al.*, 2004b; Naatanen *et al.*, 2007). MMN validation by means of polarity inversion was assessed at the left mastoid channel (TP9). For MMN quantification, individual MMN amplitudes and latencies were measured from the most negative peak occurring 120–250 ms after deviant onset, which is a commonly used latency band for MMN peak analysis (Winkler *et al.*, 2002; Lappe *et al.*, 2008).

Results

Behavioural results

The two groups performed equally well on the Gordon rhythm test ($t_{26} = -0.929$, $P_{\text{one-tailed}} = 0.182$) and the Gordon melody test ($t_{26} = -1.299$, $P_{\text{one-tailed}} = 0.115$). After correction for outliers, 25 subjects were included in the subsequent analysis. In the behavioural detection test (active oddball paradigm), the two groups performed equally well on the identification of the metre-incongruent deviants ($t_{23} = -0.64$, $P = 0.528$). Musicians displayed a mean hit rate of 83 ± 19%, and non-musicians displayed a mean hit rate of 87 ± 14%. Interestingly, non-musicians identified the metre-incongruent deviants significantly faster than musicians ($t_{23} = -2.81$, $P_{\text{two-tailed}} < 0.05$; corrected). The mean reaction times were 537 ± 62 ms for non-musicians and 596 ± 35 ms for percussionists.

EEG results

The EEG results are illustrated in Figs 2 and 3. Figure 2 shows the auditory event-related potentials elicited by the standard and the two different types of deviants. In the difference waves, distinct MMNs can be identified for the metre-congruent deviants (musicians, 176 ms; non-musicians, 174 ms) and the metre-incongruent deviants (musicians, 182 ms; non-musicians, 186 ms). A parametric mixed-effect ANOVA with within-subject factor 'beat' (metre-MMN–accent-MMN) and between-subject factor 'group' (percussionists–non-trained controls) revealed a main effect of beat ($F_{1,23} = 30.56$, $P < 0.001$, partial $\eta^2 = 0.57$) with mean MMN amplitudes of −3.31 μV for the metre-congruent deviants and −4.52 μV for the metre-incongruent deviants (mean latencies computed across both groups). Thus, the non-congruent deviant was significantly more negative than the congruent deviant in both groups of subjects. Furthermore, we observed a significant interaction between group and beat ($F_{1,23} = 4.41$, $P < 0.05$, partial $\eta^2 = 0.1608$). The observed interaction effect is shown in Fig. 3. Percussionists displayed a higher sensitivity to the metre-incongruent deviants than non-trained controls, as reflected by the enhanced MMN amplitude. However, percussionists showed a lower sensitivity to the metre-congruent deviants than the control group. *Post hoc* analysis revealed an effect of beat for controls ($t_{13} = 2.899$, $P < 0.05$) and for musicians ($t_{10} = 4.528$, $P < 0.05$). That is, both groups showed significantly smaller amplitudes for metre-congruent deviants than for metre-incongruent deviants. Analysis of latency revealed a main effect of beat ($F_{1,23} = 4.612$, $P < 0.05$, partial $\eta^2 = 0.1670$), with mean MMN latencies of 166.6 ms for the metre-congruent deviants and 180.5 ms for the metre-incongruent deviants (mean latencies computed across both groups). A one-sample *t*-test on mastoid electrodes revealed significant differences for TP9 ($t_{24} = -9.862$, $P < 0.001$) and TP10 ($t_{24} = -9.920$, $P < 0.001$), showing a clear MMN polarity inversion at the two mastoids.

In addition to the MMN, some subjects showed a positivity in the difference waves at an early (70–130 ms) and late (210–290 ms) time window for both the metre-congruent deviants (musicians, 100 and 260 ms; non-musicians, 90 and 260 ms) and the metre-incongruent deviants (musicians, 96 and 264 ms; non-musicians, 94 and 280 ms)

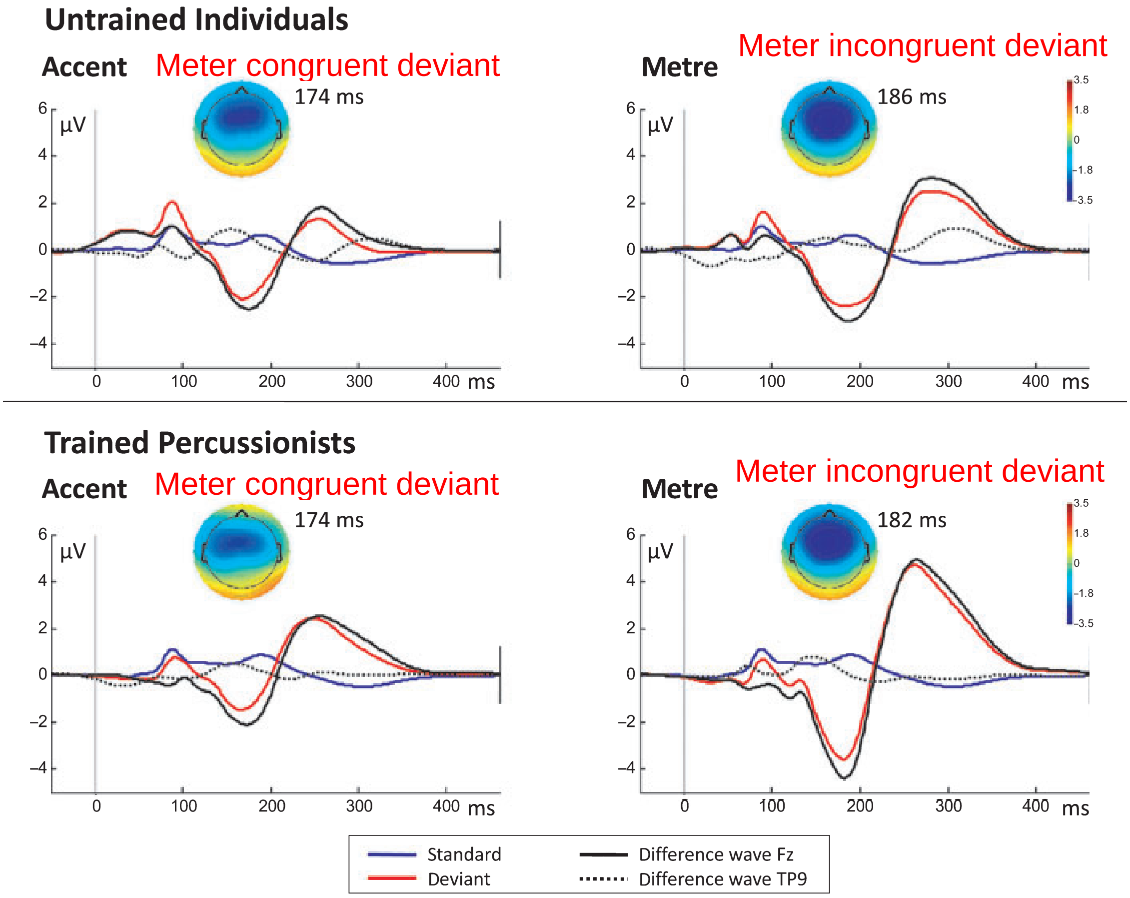

FIG. 2. Grand averages of the MMNs recorded in musically untrained individuals (above) and trained percussionists (below). Averages of the evoked responses to standards (blue line) and deviants (red line) are shown for a frontal electrode site (channel Fz). In addition, difference waves are given for a frontal channel (Fz; black solid line) and a mastoid channel (TP9; black dotted line). Topographies at the MMN peak maximum are illustrated for each group of participants and for each type of deviant. Difference waves were computed by subtracting the responses evoked by standards from responses evoked by deviants.

on the Fz channel. A parametric mixed-effect ANOVA with the factors beat and group revealed a significant main effect of beat ($F_{1,23}$ = 10.567, $P < 0.05$, partial η^2 = 0.3148) for the late positivity.

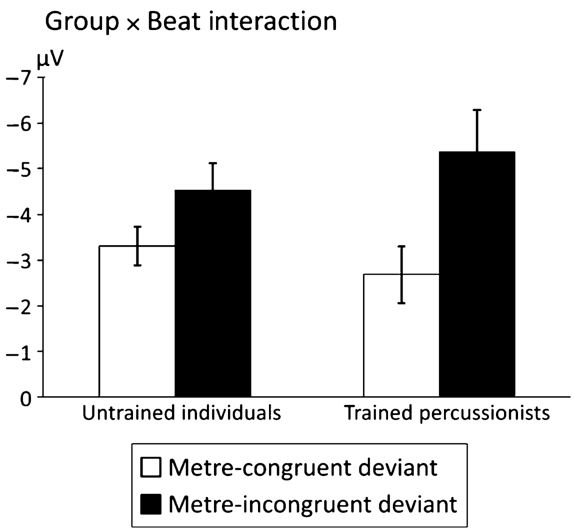

FIG. 3. Peak of the MMN to metre-congruent and metre-incongruent deviants for both groups of subjects. Means and standard deviations are plotted. There is a significant interaction between groups (untrained individuals and trained percussionists) and deviants (metre-congruent and metre-incongruent).

Discussion

The present study tested metre perception in musically trained and untrained individuals. In particular, we examined whether musical expertise leads to changes in the perception of metrical hierarchy. This was done by means of a MMN paradigm, in which a metrical rhythm was presented as the standard stimulus. Two deviants were constructed, one consisting of an intensity accent at a metrically weak (i.e. unexpected) position and one consisting of an accent at a metrically strong (i.e. expected) position of the standard rhythm. The amplitudes of the MMN components elicited by the two deviants differed from each other by a greater amount in musicians than in non-musicians (Fig. 3). That is, musicians display a higher sensitivity than non-musicians to the metrical context in which a deviant is presented. We conclude that musical expertise includes an increased sensitivity to the hierarchical structure of metre.

Effect of musical expertise on the MMN

It has been well documented that one does not need to be a musical expert to perceive a pulse in music. The appreciation of Bach's 'Well-Tempered Clavier' or an interpretation of Paul Desmond's 'Take Five' would be unthinkable without perceiving a pulse. A pulse helps to convey the essence of these musical pieces. Most listeners will spontaneously tap to the pulse of a musical piece, and can thus perceive that metrical characteristic. Temporal 'expectancy' is used as a concept for metrical pulse perception. This measure quantifies the strength with which the onset of a tone is expected in the context of a musical piece (Jones & Boltz, 1989; Desain, 1992; Jones & McAuley, 2005). Temporal expectancy is present in musicians and in non-musicians alike, as determined by several electrophysiological studies (van Zuijen *et al.*, 2005; Honing *et al.*, 2009), and can even be observed in infants and young children (Hannon & Trehub, 2005a; Honing *et al.*, 2009; Winkler *et al.*, 2009). Furthermore, even populations without any musical expertise are able to encode, remember, and reproduce rhythms containing a pulse better than rhythms containing no pulse (Povel & Essens, 1985; Jones *et al.*, 2006; Grube & Griffiths, 2009).

Although no special training is required to perceive metre, influences of exposure to and training for metre perception have been reported, at least in the course of child development. Young children focus their attention on lower levels of metrical hierarchies than do older children, as shown by synchronized-tapping experiments (Drake *et al.*, 2000). These developmental changes in temporal attention are influenced by musical training and exposure to music. For instance, musically trained children focus their attention on higher hierarchical levels than untrained children of the same age (Drake *et al.*, 2000). Furthermore, children at the age of 12 months already show experience-related changes in their sensitivity to specific metrical categories (Hannon & Trehub, 2005b). Taken together, these results suggest that exposure to music and musical training lead to different levels of expertise in metre perception in children.

Our results provide evidence that the influence of training persists into adulthood. In particular, we show that training is reflected in the stronger hierarchical representation of metres. Musicians commonly take part in an extensive training regime, including several hours of practice per day, from childhood on and over the course of many years. As a result, the musician's brain shows experience-related functional and structural changes [for reviews, see Munte *et al.* (2002) and Jancke (2009)]. Previous studies have shown that musical skill is associated with enhanced auditory representations for tones of the musical scale, increased sensitivity to the timbre of an instrument, and increased sensitivity to melodic contour and pitch interval (Pantev *et al.*, 1998, 2001; Fujioka *et al.*, 2004). It is also associated with enhancement of the somatosensory (Elbert *et al.*, 1995) and motor (Amunts *et al.*, 1997; Bangert & Schlaug, 2006) representations of the fingering digits or hands, respectively. Our results add to these previous findings by showing functional differences between musicians and non-musicians on the level of timing perception. In particular, our results show enhanced sensitivity to metrical hierarchies in musicians as compared with non-musicians (Fig. 3), suggesting that musical training affects the perception of metrical structure. The effect of musical expertise is statistically apparent in an interaction between beat (metre-congruent vs. metre-incongruent) and group (musicians vs. non-musicians). In other words, the difference between the two accents is perceived as larger by musicians than by non-musicians. Thus, musicians display increased sensitivity to a metre-incongruent deviant than non-musicians when the musicians' sensitivity to the same accent at a metre-congruent position is taken into account. This difference in the strength of hierarchical representation could lead to behavioural differences reported in earlier studies. For example, a strong representation of metrical hierarchies allows more flexible synchronization with any level of hierarchy (Drake *et al.*, 2000). Our study was specifically motivated by a finding of Jongsma and colleagues (Jongsma *et al.*, 2004). These authors reported that musicians employ hierarchical processing in the behavioural rating of temporal expectation, whereas non-musicians do not. Our results expand upon these findings by suggesting that a lack of hierarchical representation of metre forces non-musicians to choose a different approach to perform that metrical task. In our data, increased metrical hierarchy processing was reflected in an MMN, which is largely independent of attention. A MMN component can be measured even when subjects focus their attention on a completely unrelated task, such as watching a movie. Taken together, our findings provide evidence for an effect of expertise on the hierarchical representation of metre, even in a processing condition without a musical processing task.

MMN and attention debate

It has been debated whether and in what way the MMN is influenced by attentional processes. There is increasing evidence that the MMN is elicited in individuals with minimal consciousness and presumably minimal attentional resources (Kotchoubey *et al.*, 2005; Fischer *et al.*, 2010). However, in healthy individuals, the amplitude of the MMN may still be affected by fluctuations in attention (Sussman, 2007; Haroush *et al.*, 2010). In our study, such attentional shifts could be larger and more strongly correlated with the specific stimulus manipulation in musicians than in non-musicians. Thus, the finding of a larger sensitivity to metrical hierarchies in musicians could be attributable to an increase in an involuntary attentional shift towards the critical metrical stimulus manipulation. Accordingly, previous studies have reported effects of musical training on top-down processes (Baumann *et al.*, 2008) and increased selective attention abilities in musicians as compared with non-musicians (Nager *et al.*, 2003). Nevertheless, a number of previous studies have shown larger MMNs in musicians than in non-musicians, suggesting superior abilities in the pre-attentive processing of sounds in musicians as a function of intensive musical training (Koelsch *et al.*, 1999; Russeler *et al.*, 2001; Brattico *et al.*, 2002). Because the expertise-related influence of temporary top-down attentional processes cannot be completely ruled out in the present study, firm conclusions about the experience-related changes in the unattended processing of metrical structure cannot be made.

Effect of musical expertise on behavioural metre perception

The behavioural results from our study did not show a superior hit rate for musicians than for non-musicians in the metre deviant detection task. In fact, non-musicians responded even faster than musicians. Similarly, we did not observe a group difference in the Gordon rhythm test. One might wonder why the behavioural detection test (active oddball paradigm) was not able to identify a superior hit rate for metre identification in musicians over non-musicians, whereas the MMNs of the two groups showed differences in response to the two deviants. First, we need to point out that both groups performed at the ceiling level in the metre deviant detection task. Thus, the presented metre manipulation was easy to detect, even for musical novices. We assume, therefore, that only a more specific test, such as the one constructed by Jongsma *et al.* (2004), would be able to identify the effects of expertise on behavioural metre perception. More importantly, however, it should be noted that the behavioural results of the active oddball paradigm cannot be directly related to the MMN results in our study. The MMN appeared with latencies of 182 ms in musicians and 186 ms in untrained individuals after the deviant tone, and is thus elicited solely by the metre-incongruent deviant. The metre-incongruent manipulation, however, is additionally reinforced 300 ms after that deviant tone. At that point in time, the listener expects to hear the ¼ note of the standard stimulus. However, as a consequence of the metre-incongruent deviant, that tone does not appear. This late stimulus characteristic is essentially a rhythm change. The differentiation between rhythm and metre perception has been discussed elsewhere (Lerdahl & Jackendoff, 1981, 1983; Geiser *et al.*, 2009). The relatively long reaction times of more than 500 ms in both groups of subjects suggest that in the behavioral task both musicians and non-musicians rely on that additional observation. Surprisingly, musical novices identified metre-incongruent deviants significantly faster than musically trained individuals. We can only speculate that musicians might have been more careful when processing this second stimulus characteristic.

Transfer effects

Previous studies have suggested that musical training improves other cognitive and perceptual processing abilities (Aleman *et al.*, 2000; Ho *et al.*, 2003; Schellenberg, 2004). In particular, learning to play a musical instrument in childhood may stimulate cognitive development and may lead to the enhancement of skills in a variety of extra-musical domains (Ho *et al.*, 2003; Bangert & Heath, 2004; Schellenberg, 2004; Thompson *et al.*, 2004). We hypothesize that such a transfer effect could be mediated by the ability to perceive metrical hierarchies. For example, it has been shown very recently that musicians display superior processing of temporal structure in speech perception (Marie *et al.*, 2010). It is also well known that timing is a crucial element for correct language acquisition and perception (Ramus & Mehler, 1999; Ramus *et al.*, 2000; Schmidt-Kassow & Kotz, 2009). This is yet singular evidence. Ongoing research will test the hypothesis of a transfer of auditory metre perception capabilities to other perceptive domains.

Musical pulse perception is suggested to be ubiquitous in humans, beginning from birth. Our electrophysiological data showed that pulse perception is present in the listeners independently of their level of musical training. However, musical training refines metre perception by increasing the listeners' representation of the hierarchical structure of metre. To our knowledge, this study is one of the first to report an auditory plasticity effect in higher-order temporal pattern perception. In the future, our experimental paradigm could serve as a model for investigating more general mechanisms of abstract pattern perception.

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Abbreviations

EEG, electroencephalography; MMN, mismatch negativity.

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CORRIGENDUM
Refinement of metre perception – training increases hierarchical metre processing

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In the published manuscript of Geiser *et al.* (2010) an error occurred in Fig. 2. The condition names presented in Fig. 2 were incorrect. The correct Fig. 2 is indicated below. The authors apologize for the error and any inconvenience caused.

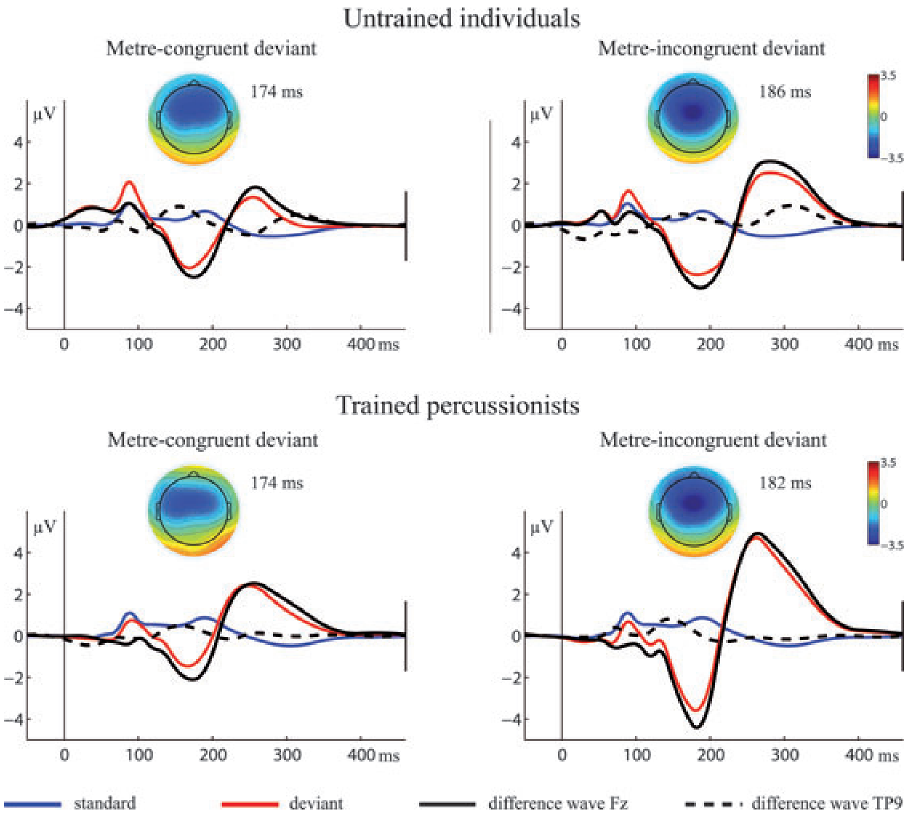

FIG. 2. Grand averages of the MMNs recorded in musically untrained individuals (above) and trained percussionists (below). Averages of the evoked responses to standards (blue line) and deviants (red line) are shown for a frontal electrode site (channel Fz). In addition, difference waves are given for a frontal channel (Fz; black solid line) and a mastoid channel (TP9; black dotted line). Topographies at the MMN peak maximum are illustrated for each group of participants and for each type of deviant. Difference waves were computed by subtracting the responses evoked by standards from responses evoked by deviants.

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