Sound processing in amateur musicians and nonmusicians: event-related potential and behavioral indices

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To increase our understanding of auditory neurocognition in musicians, we compared nonmusicians with amateur band musicians in their neural and behavioral sound encoding accuracy. Mismatch negativity and P3a components of the auditory event-related potentials were recorded to changes in basic acoustic features (frequency, duration, location, intensity, gap) and abstract features (melodic contour and interval size). Mismatch negativity was larger in musicians than in nonmusicians for location changes whereas no statistically significant group difference was observed in response to other feature changes or in abstract-feature mismatch negativity. P3a was observed only in musicians in response to location changes. This suggests that when compared with nonmusicians, even amateur musicians have neural sound processing advantages with acoustic information most essential to their musical genre. *NeuroReport* 17:1225–1228 © 2006 Lippincott Williams & Wilkins.

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Introduction

Musical expertise can be observed in both functional and anatomical brain indices. Structural differences exist in modality-specific cortical areas [1] as well as in corpus callosum [2] and pyramidal tracts [3]. Functional, either quantitative or qualitative, facilitation in sound processing is evidenced in various cortical auditory event-related responses for several sound features [4–7] (for a review, see [8]).

Previous studies, however, have only used musicians who were high-level experts in classical music. A consequence of this is that, in addition to excellent skills in music performance, they also have expertise in reading musical scores as well as in music history and theory. Those skills are not, however, required by all musicians, for example, those in pop or rock genres. Additionally, as music is not only performed by professional musicians, amateur musicians' auditory processing skills should also be investigated before drawing firm conclusions about the brain plasticity as evidenced in musicians.

To this end, we recruited amateur musicians who regularly but without long-term formal training played in rock and indie music bands. Their neural auditory processing was probed by recording the mismatch negativity (MMN) and P3a components of the auditory event-related potentials (ERPs) [9], which are known to sensitively index also musical expertise [6–8,10]. Additionally, behavioral auditory processing was probed by two complementary musicality tests [11,12].

Materials and methods

Event-related potential study

Subjects

Two groups of 13 healthy, normal hearing, male subjects participated in this experiment. Only male subjects were recruited as they were more commonly active in playing rock, indie, and jazz bands. The musicians were aged between 21 and 43 years (mean 32.5 years; one ambidextrous, 12 right-handed). They had started playing between the ages of 6 and 21 years (mean 14.7 years), and were currently playing 3.5–21 h a week (mean 5.1 h). Six of them received formal training in music outside school (3 months–8 years; mean 5.2 years; one continues in training) but only one obtained a professional degree in music performance. The nonmusicians were aged between 19 and 44 years (mean 33.3 years; one ambidextrous, 12 right-handed). Three of them received formal training in music outside school (10 months–5 years; mean 2.6 years; none of them continues playing).

Stimulation and procedure
Multi-feature paradigm (adopted from [13]) has a 500-Hz 100 ms harmonically rich 3-partial sound as its standard. Deviants existed in five sound features: frequency ($\pm 10\%$), duration (65 ms), sound location (90° to the left or right from the standard tone in the middle), intensity (± 10 dB louder or softer), and gap (a silence of 7 ms). The sounds were presented in a pseudorandom sequence so that the standard (50%) and one of the deviant tones (each 10%) occurred in alternating order with a stimulus onset asynchrony of 500 ms.

Abstract-feature paradigm (adopted from [10]) has an inverted U-shaped 5-tone melody as its standard (86%). In abstract terms, the contour follows the rule ABCED. Two different deviants exist: for the Contour deviant, the melodic contour was changed by replacing the penultimate one by the first tone (ABCAD) and for the Interval deviant, the last tone was replaced by the first tone (ABCEA). The melodies consisted of 50-ms sinusoidal tones separated by 50-ms silences and were presented with 1200-ms stimulus onset asynchrony at 12 randomly varying frequency levels.

The experiment was approved by the Psychology Research Ethics Committee of the University of Portsmouth according to the Declaration of Helsinki and informed consent was given by all participants. During the recordings, the stimulation was delivered via headphones while the participants watched a self-selected silent movie with subtitles.

Data recording and analysis
Electroencephalogram (EEG) was continuously recorded by using 30 electrodes attached to an electrode cap. The reference electrode was attached to the tip of the nose. Electrooculogram recordings were obtained using electrodes applied at the left and right outer canthi (horizontal) and above and below the left eye (vertical). EEG was filtered and digitized on-line with a band-pass of 0.05–50 Hz and a sampling rate of 250 Hz by using SynAmps amplifiers (NeuroScan Inc., El Paso, Texas, USA).

The continuous EEG records were filtered off-line with a band-pass of 0.5 to 30 Hz and divided into epochs of 500 ms duration including a 100-ms prestimulus baseline (Multi-feature paradigm) and 600 ms duration including a 100-ms predeviance baseline (Abstract-feature paradigm). Epochs with a signal change larger than 100 μV on any recording channel were excluded from the analysis.

The ERP effects were quantified from individual difference waves using a 40-ms time window centered on the peak of the respective component in the grand-average difference waves (MMN at Fz, P3a at Cz). The significance of the MMN and P3a components was first determined by comparing the amplitude values to zero by two-tailed *t*-test (MMN at Fz, P3a at Cz). If significant in both groups, data from nine electrodes (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4) were then entered into repeated-measures analysis of variance with Group (musicians, nonmusicians) as a between-subject factor, and Laterality (left, middle, right electrodes) and Frontality (anterior–central–posterior electrodes) as within-subject factors separately for each deviant in both paradigms.

Musicality tests
After the ERP recordings, the volunteers participated in musicality tests of two kinds. The tests were chosen to probe two complementary elements in musicality: sensory-level discrimination and cognitive structuring of ongoing sound material. By pitch and duration parts of the Seashore test [11], the participants' accuracy in discriminating small frequency and duration differences between sounds presented in pairs was determined. Additionally, the participants' ability to track rhythmic passages was tested. Their ability to structure musical sequences into meaningful subunits was determined by using the musicality test developed by Karma [12]. The scores were compared by independent samples *t*-test (two-tailed values are reported).

Results

Event-related potential experiment
Multi-feature paradigm
The musicians' and nonmusicians' feature-change discrimination accuracy differed as reflected by the MMN amplitude evoked by Intensity and Location changes. The intensity-MMN was significant only in the musician group ($P<0.001$; $P>0.1$ in nonmusicians) (for amplitude values, see Table 1). The location-MMN was significant in both musician and nonmusician groups ($P<0.001$ and $P<0.003$, respectively). This location-MMN was frontally maximal [$F(2,48)=29.9$, $P<0.001$] and right lateralized [$F(2,48)=8.0$, $P<0.001$]. It was also significantly larger in musicians than nonmusicians ($P<0.05$). No significant interactions were observed. The MMN was followed by a significant P3a in musicians, while in nonmusicians it approached, but did not reach, significance (musicians $P<0.05$; nonmusicians $P<0.06$) (Fig. 1).

Additionally, topographical differences in the duration-MMN were found. This MMN was significant in both musicians and nonmusicians ($P<0.004$ and $P<0.008$, respectively). It was frontally maximal [$F(2,48)=33.4$, $P<0.001$] and right lateralized ($P<0.008$). No group difference exists in the MMN amplitude but a significant interaction between Frontality, Lateralization, and Group was observed [$F(4,120)=2.7$, $P<0.05$]. This resulted from musicians having MMN with more frontal and right-lateralized distribution when compared with nonmusicians.

No group differences were found with other feature changes: Frequency-MMN was significant in both musicians and nonmusicians ($P<0.001$ and $P<0.002$, respectively). The frequency-MMN was frontally maximal [$F(2,48)=38.1$,

Table 1 Mean ERP amplitudes (MMN at Fz, P3a at Cz; SEM in parenthesis) and statistical significances in the group comparisons

	Musicians (μV)	Nonmusicians (μV)	*P*-value in group comparison
Multi-feature paradigm			
Intensity-MMN	−1.29 (0.3)***	−0.42 (0.3)	—
Location-MMN	−3.68 (0.3)***	−2.06 (0.5)**	0.027*
Location-P3a	1.22 (0.5)*	1.17 (0.6)	—
Duration-MMN	−1.43 (0.4)**	−1.34 (0.4)**	0.94
Frequency-MMN	−2.20 (0.2)***	−1.94 (0.5)**	0.96
Gap-MMN	−2.98 (0.5)***	−1.92 (0.3)***	0.13
Abstract-feature paradigm			
Contour-MMN	−0.87 (0.3)*	−0.51 (0.2)*	0.77
Interval-MMN	−1.16 (0.3)**	−0.80 (0.2)**	0.90

***$P<0.001$, **$P<0.01$, *$P<0.05$.

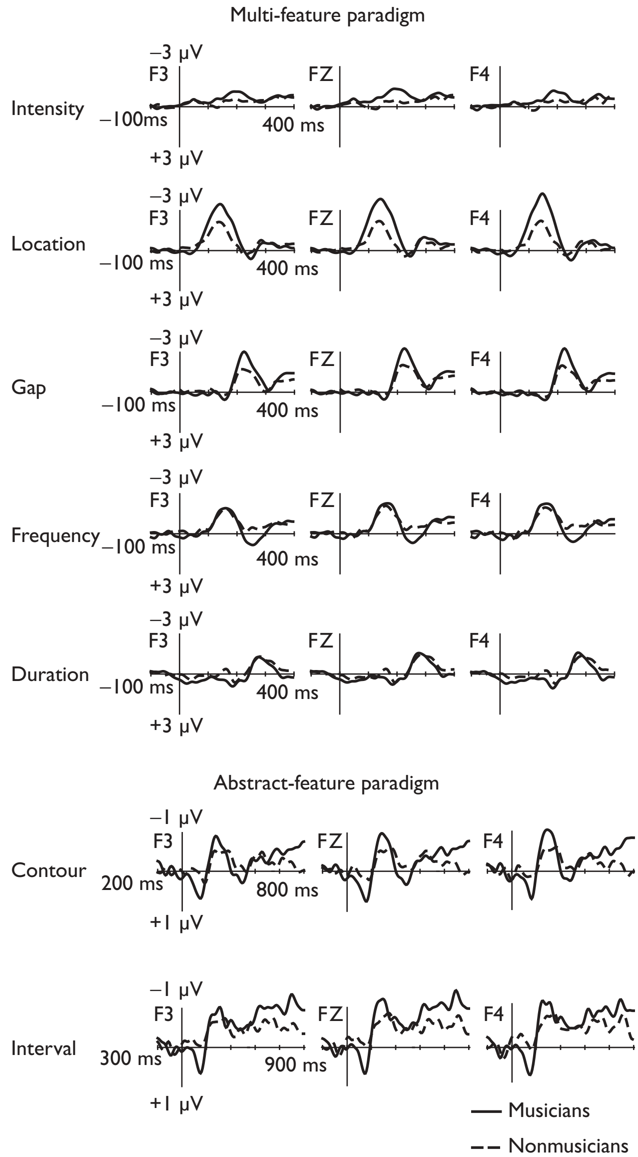

Fig. 1 Subtraction waves (deviant minus standard) in Multi-feature paradigm for five different deviants as indicated on the left (top panel) and in Abstract-feature paradigm for Contour deviant and Interval deviant (bottom panel). The data are displayed at three frontal electrodes (F3, Fz, and F4) for musicians (continuous line) and nonmusicians (dashed line).

$P<0.001$] and right-lateralized [$F(2,48)=11.1$, $P<0.001$]. In addition, an interaction between MMN frontality and lateralization was observed [$F(4,96)=2.9$; $P<0.05$]. No group differences exist in the MMN amplitude. The gap-MMN was also significant in both musicians and nonmusicians ($P<0.001$ in both groups). The gap-MMN was maximal frontally [$F(2,48)=43.7$, $P<0.001$) and right-lateralized [$F(2,48)=6.0$, $P<0.005$]. No group difference or any significant interactions in the MMN amplitude were observed.

Abstract-feature paradigm

No group differences were observed with abstract-feature changes. Both Contour-MMN and Interval-MMNs were significant in both musicians and nonmusicians (Contour: $P<0.05$ in both groups, Interval: $P<0.002$ and $P<0.006$, respectively). Both Contour-MMN and Interval-MMNs were frontally maximal [$F(2,48)=6.8$, $P<0.003$; $F(2,48)=12.1$, $P<0.001$]. There was, however, no group difference in the MMN amplitude or any significant interactions.

Musicality testing

According to the Seashore musicality test, the musicians were more accurate than nonmusicians in detecting slight frequency differences between paired sounds [musicians 44/50, nonmusicians 38/50; $t(24)=3.5$, $P<0.002$]. The groups did not, however, differ in their accuracy in detecting temporal changes, as evidenced by their scores in the sound duration [musicians 42/50, nonmusicians 44/50; $t(24)=1.3$, $P>0.2$] and rhythm tests [musicians 28/30, nonmusicians 27/30; $t(24)=1.2$, $P>0.2$]. According to the Karma musicality test, the musicians were more advanced in grouping sound sequences of 12–15 sounds into three or four subsequences, for instance on the basis of sound frequency or intensity [musicians 34/40, nonmusicians 30/40; $t(24)=2.3$, $P<0.05$].

Discussion

The present ERP data, collected while the participants were not listening to the sounds but were concentrating on watching a silent video, indicate that sound discrimination is facilitated in amateur musicians when compared with nonmusicians. This finding, observed at the sensory-level discrimination of intensity and location changes, indicates that despite the lack of formal training in music skills or theory, amateur musicians have more advanced cortical mechanisms to encode and categorize sound information than nonmusicians. Remarkably, however, this facilitation observed in musicians in sound-change discrimination was not generalized to more complex transposed-melody material (at least not during a performance of a task not related to the sounds). In other words, the neural facilitation in amateur musicians might not be advanced enough to encode also temporally and spectrally more complicated sound information in a manner different from that observable in nonmusicians. This present lack of group difference could also be attributed to the presence of MMN in nonmusicians, which constitutes a novel finding.

Importantly, the musicians were more accurate than the nonmusicians in the present behavioural pitch discrimination task (as in the Seashore musicality test, [11]) even if no group difference was observed in the corresponding pitch-change-specific ERP indices. The present observation about the discrepancy between preattentive ERP indices and subsequent attentional tests is not the first to provide us with controversial results in musicians (for previous evidence, see [14,15]). It may be that in some circumstances, musicians can utilize the automatically formed neural sound representations more accurately than nonmusicians if specifically asked to do so.

For practical reasons, the musicality test battery used in the present study did not include all parts of the original battery as developed by the Seashore [11]. This is unfortunate as it remains unclear how the participants would have performed in a paired loudness test. Moreover, owing to traditional lack of interest in spatial processing in musical contexts, a standardized musicality battery (such as the Seashore test) does not include a section on that acoustic parameter at all. In some special groups of musicians, however, such as conductors, even spatial hearing is part of their musical expertise. In fact, both MMN and P3a components to location deviants were enhanced in conductors when compared with other musicians [16]. Correspondingly in musicians specialized in the rock genre, the spatial sound features also carry particular musical information: for instance, several digital sound manipulations are commonly used to imitate spatial effects. In addition, during performance, they need to monitor and synchronize their playing in an acoustically demanding environment, via loudspeakers different from those directed towards the audience. Yet, they are able to create auditory scenes that are properly timed as perceived by the audience. From this viewpoint, the present finding of amateur band musicians having a more sensitive encoding of location changes reveals that spatial encoding is an elementary part of their expertise.

Finally, in a musicality test probing the participants' ability to structure ongoing sound material into meaningful 'chunks', musical Gestalts [12,17], the amateur musicians were superior to nonmusicians. This suggests that these musicians have an advantage over the nonmusicians when temporal grouping of ongoing auditory material under attentional control is requested for. On the other hand, the lack of group difference in the automatic neural level of processing when transposed melodies with contour or interval deviances were employed suggests that, as these musicians do not operate with melodic abstract sound entities in their music, information of that kind is not processed in an advanced manner by them.

Taken together, the present data provide evidence for the superiority of musicians in encoding the sound parameters of highest importance in their musical performance. Remarkably, the superiority could be observed even at the automatic level of sound-change processing in amateur musicians. Previously, corresponding neuroplastic effects were reported in studies on musicians [16] and in cross-linguistic contexts in native speakers with respect to the crucial elements of their language (e.g. formant structure [18] and duration cues [19]). Thus, the human auditory system has the capacity to selectively model with the highest accuracy the features of the surrounding sound environments that are of the highest relevance.

Conclusions

Amateur band musicians, who have a limited amount of systematic training in music skills, encode location information more accurately than nonmusicians do. This advantage is, however, not generalized to more complex frequency-varying sound information. This suggests that, when compared with nonmusicians, even amateur musicians have a neural advantage in sound processing with the acoustic information most essential to their musical genre.

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