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Event-related brain potentials to sound omissions differ in musicians and non-musicians

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Abstract

The mismatch negativity (MMN) component of the auditory event-related brain potential reflects the automatic detection of sound change. MMN to occasionally omitted sounds in a tone series can be used to investigate the time course of temporal integration in the acoustic system. We used MMN to study differences in temporal integration in musicians and non-musicians. In experiment 1, occasionally omitted 'sounds' in an otherwise regular tone series evoked a reliable MMN at interstimulus intervals (SOAs) of 100, 120, 180 and 220 ms in musicians. In non-musicians, MMN was smaller/absent in the 180 and 220 ms SOAs, respectively. In experiment 2, deviance of a tone was induced by presenting tones at a shorter SOA (100 or 130 ms) compared to the standard stimulus (150 ms). Musicians showed a reliable MMN for both deviant SOAs whereas non-musicians showed an MMN only for tones presented 50 ms prior to a standard tone (SOA 100 ms). These results indicate that the temporal window of integration seems to be longer and more precise in musicians compared to musical laypersons and that long-term training is reflected in changes in neural activity.

Keywords: Mismatch-negativity; Musicians; Auditory; Event-related potentials; Temporal integration; Preattentive processing

The mismatch negativity component (MMN) of the auditory event-related potential is elicited by deviant stimuli interspersed in a sequence of otherwise physically identical sounds even if these are not attended to [8]. MMN usually peaks 100–200 ms after stimulus onset with a maximal amplitude over frontal and central scalp locations [7] and has been described for unexpected changes of a number of stimulus attributes like a decrement in stimulus duration [11], infrequent changes in frequency [1], intensity [10] or spatial location [8,16,18]. These and other results have led to the conclusion that MMN is generated by a discriminative process that detects any change in a sequence of sounds by using traces established by the previous acoustic stimulation [12].

In line with this interpretation, MMN has also been found for omissions of sounds in a temporally structured series of tones [20–22]. Most interestingly, MMN for omitted tones has only been obtained for short inter-stimulus-intervals (SOAs). Yabe et al. [20] observed an MMN for a short SOA of 100 ms but if the SOA was prolonged to 170 ms no MMN was elicited. These results suggest that the omitted tone needs to be in the same temporal window of integration as the previously presented stimulus to cause a change in the unitary auditory event percept and, thus, elicit an MMN. Using a variety of different SOAs, Yabe et al. [21] estimated the length of the temporal window of integration for normal subjects to be 150 ms.

Long-term training has been shown to modify neural organization. This has been reported for intact [14,23] and lesioned animals [13] but only few studies demonstrated corresponding plasticity for the human brain [4,5,16,17]. Recently, Münte et al., [6] found a more pronounced attention effect for musicians in a pitch detection task compared to untrained subjects which indicates changes in neural organization as a consequence of long time training.

Some investigators studied the consequences of training on preattentive auditory processing. For language specific phoneme-processing, an influence of long-term experience

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on preattentive auditory processing has been shown [9]. Koelsch, Schroeger and Tervaniemi [3] found an MMN for slightly impure chords presented among perfect major chords in professional violinists but not in non-musicians.

The present experiments investigated whether the temporal window of integration is different in trained, professional musicians and non-musicians. In experiment 1, a series of tones was presented at four different SOAs (100, 120, 180 and 220 ms; interval from sound onset to sound onset). We hypothesized that musicians have a larger window of temporal integration and, thus, expected an MMN for musicians at the longer SOAs (180 and 220 ms) but not for non-musicians (or at least a larger MMN for musicians at the longer SOAs). Experiment 2 was designed to investigate the temporal accuracy of the integration window. In an otherwise regular series of short tones (SOA 150 ms), tones were interspersed with a shorter SOA (100, 130 ms). We expected an MMN for these deviants for musicians as well as non-musicians if the tones were presented 50 ms earlier than standards but only for musicians for the tones presented 20 ms earlier.

Fifteen professional musicians (age: 18–30 years, ten women, all enrolled as students in the Hannover Academy of Music) and 15 non-musicians (age: 18–30 years, ten women) participated in the study. None of the non-musicians had any formal training in music or experience with a musical instrument. In contrast, all of the musicians had extensive musical training since childhood (7 years on average) and practice their instruments daily (between 3 and 8 h according to self-report). Subjects received monetary compensation for their participation. The study protocol was approved by the ethics committee of Hannover Medical School.

Computer generated, 50 ms long sine-wave tone pips (5 ms rise and fall times, 1000 Hz) served as stimulus material. These were presented at about 70 dB(SPL) via a speaker standing in front of the subjects (controlled by a microcomputer).

In experiment 1, four blocks of stimuli were presented that differed only in the duration of the SOA (100, 120, 180 or 220 ms). In each block, 10 800 tones were presented. Occasionally (~3% of all cases), the tone was omitted. Between two omissions 25–48 tones were presented (with equal probability). In experiment 2, 10 800 standard tones (SOA: 150 ms), 150 deviants with SOA 100 ms (i.e. 50 ms earlier than standards, henceforth: deviant SOA-condition) and 150 deviant tones with SOA 130 ms (20 ms earlier than standards) were presented in one block of stimuli. In both experiments, subjects were reading a self-selected book during stimulus presentation to ensure automatic auditory processing.

EEG was recorded from all 19 standard locations of the 10–20 system [2] and ten additional sites with tin electrodes mounted in an elastic cap. The reference electrode was placed on the cheek. The EEG was rereferenced off-line to the left mastoid electrode. An additional electrode was placed on the nosetip for further rereferencing purposes. Eye-movements were recorded with electrodes affixed at the right external canthus (vs. left external canthus after rereferencing, hEOG) and at the right and left orbital ridges (vEOG). These biosignals were amplified with a bandpass from 0.01 to 70 Hz (notch-filter at 50 Hz) and digitized at 250 Hz. All trials with EOG-activity exceeding 200 μV were discarded from further analysis.

EEG was averaged separately for all SOA-conditions from 50 ms pre- to 400 ms poststimulus presentation relative to a baseline encompassing 50 ms prior to stimulus (or omission) onset. MMN was measured as the difference wave of the evoked potential for deviant stimuli and the respective standard tone. Mean MMN-amplitude between 130 and 170 ms at electrode FZ was used for statistical analyses. Separate F-tests for each SOA were used to determine whether MMN-amplitude differed for professional musicians and non-musicians.

For all four SOA-conditions in experiment 1, a clear MMN was present in professional musicians (SOA 100 ms: $F(1,14) = 14.99$, $P < 0.0017$, 120 ms: $F(1,14) = 17.66$, $P < 0.0009$, 180 ms: $F(1,14) = 10.09$, $P < 0.0067$, 220 ms: $F(1,14) = 8.97$, $P < 0.0096$; see Fig. 1; Fig. 2 depicts the scalp distribution of the MMN for musicians and non-musicians). When rereferenced to the nosetip-electrode, MMN was reversed in polarity at the left mastoid electrode indicating that the component in question really is an MMN [21].

In contrast, for non-musicians only the short SOAs showed a reliable MMN (marginally significant for SOA 100 ms, $F(1,14) = 2.59$, $P < 0.1299$, 120 ms: $F(1,14) = 8.87$, $P < 0.01$, 180 and 220 ms: $F < 1$). For SOAs of 100, 180 and 220 ms a group-difference was obtained indicating that MMN was reliably enhanced in musicians compared to musical laypersons (100 ms: $F(1,28) = 6.88$, $P < 0.014$, 120 ms: $F < 1$, 180 ms: $F(1,28) = 4.24$, $P < 0.0488$, and marginally reliable difference for SOA 220 ms, $F(1,28) = 3.43$,

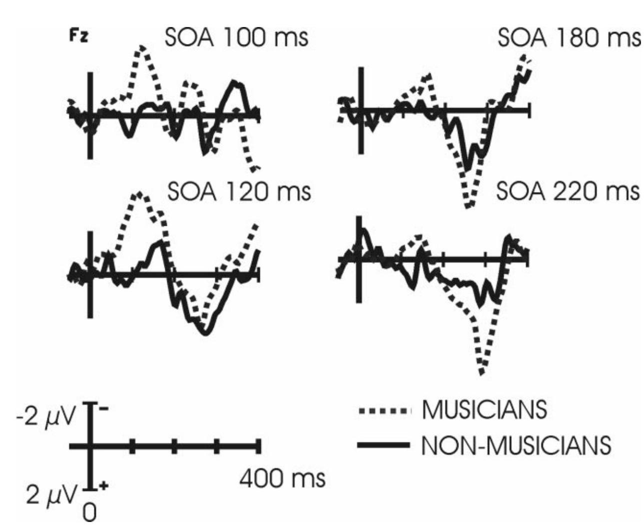

Fig. 1. MMN (standard tone-omission) from experiment 1 at the frontal electrode FZ for professional musicians and non-musicians for the four different SOA conditions.

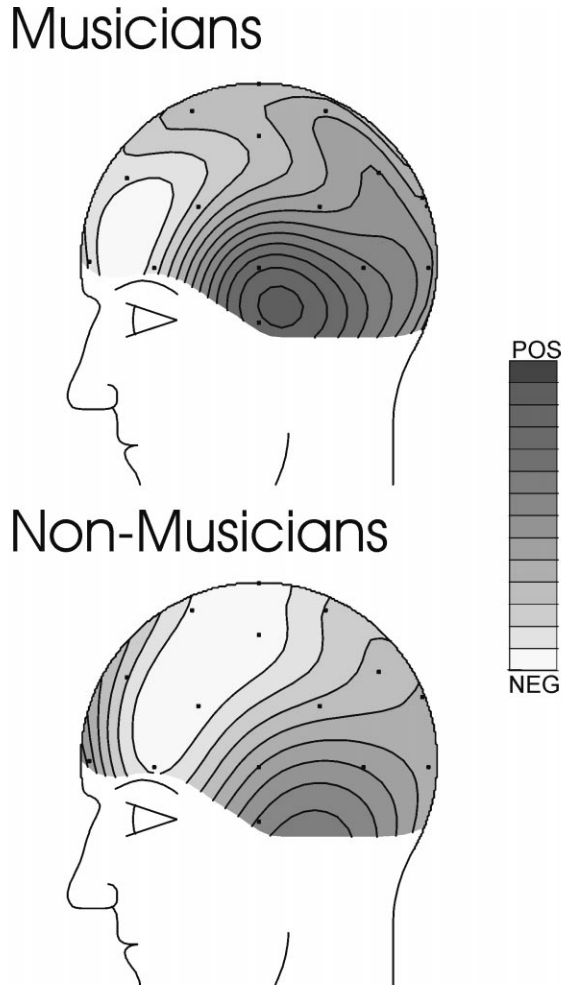

Fig. 2. Scalp topography for the MMN (omission-standard) for musicians (top) and non-musicians (bottom) for the SOA = 120 ms condition of experiment 1. All 29 recorded scalp electrodes were used for computation of the brain map. Scaling is relative to the maximal amplitude in each group; dark shaded areas indicate positivity, light shaded areas negativity.

$P < 0.0744$). Thus, professional musicians seem to have a larger temporal window of integration and a trend for a larger MMN-amplitude at very short SOAs (100 ms).

Fig. 2 depicts the scalp distribution of the MMN for musicians and non-musicians. To test whether the neural generators of the MMN are different for musicians and non-musicians, we standardized MMN-amplitude for each group prior to computing an ANOVA. This is necessary because of non-linearity of signal conduction in the brain tissue and in the skull ANOVA models may confuse differences in the amplitude of an EEG signal (due to differences in source strength) with genuine topographic differences [19]. The ANOVA revealed that the sources for the MMN in musicians and non-musicians are not different (GROUP by ELECTRODE interaction: $F(1, 28) = 0.31$).

Professional musicians showed a reliable MMN for both deviant SOA-conditions of experiment 2, whereas for non-musicians, a reliable MMN was only found for the 100 ms SOA condition (i.e. tones were presented 50 ms earlier than the standard tone; see Fig. 3).

Statistically, this is reflected in a reliable group-difference of MMN-amplitude for SOA 130 ms ($F(1, 28) = 10.84$, $P < 0.0027$) and a non-reliable MMN-difference for 100 ms SOA. Thus, the temporal integration window for musicians seems to be more precise compared to that of non-musicians.

In two experiments we compared temporal integration in preattentive auditory processing for professional musicians and musical laypersons. More specifically, we investigated differences in the length (experiment 1) and precision (experiment 2) of the window of temporal integration. In experiment 1, tone omissions were interspersed in an otherwise regular series of tones. An MMN indicating detection of these omissions was found for all four tested SOA-conditions in musicians, but only for short SOAs (100, 120 ms) for non-musicians. This finding indicates that musicians have a prolonged window of temporal integration. In experiment 2, an MMN was evoked for tones presented 20 or 50 ms earlier than a standard tone in the group of professional musicians whereas in the group of musical laypersons, an MMN was only evoked for tones presented 50 ms earlier. We conclude that musicians have a more precise window of temporal integration.

Previous studies showed training-induced neural plasticity in the auditory system in a spatial detection task for professional conductors compared to non-musicians [5] and in a pitch detection task [6]. Both tasks required active auditory processing which rests on attentional resources. The same holds true for recently performed imaging experiments [13]. Investigations in other modalities also employed tasks that require attentional resources [15,17]. In contrast, here we could show neural plasticity for non-attentional, automatic,

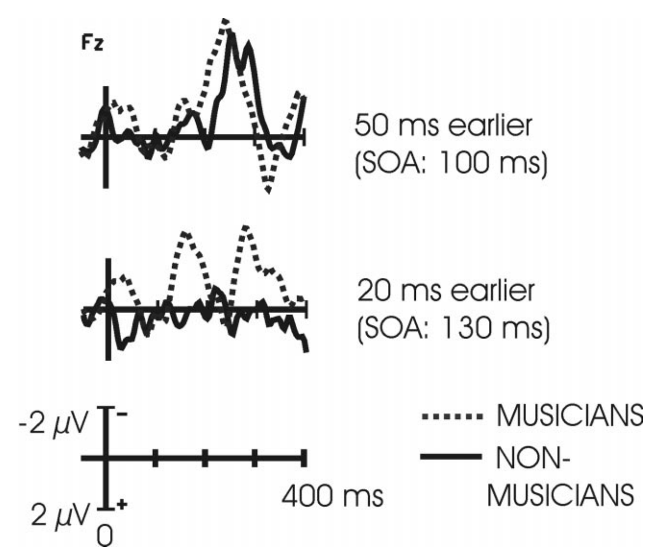

Fig. 3. MMN (standard tone-deviant SOA condition) from experiment 2 at the frontal electrode FZ for professional musicians and non-musicians for the deviant SOA of 100 ms (top) and 130 ms (bottom), respectively.

preattentive processing. The superiority in preattentive auditory processing of musicians seems to be mainly due to more effective information processing as a result of long-term training that leads to the recruitment of more neurons in automatic auditory perception. This idea is supported by the finding that the neural generators of the MMN do not differ between musicians and non-musicians. Furthermore, our study shows that memory specific neural mechanisms are superior in musicians as the MMN-differences were obtained for omissions of tones. In a previous study [3], MMN-differences between musical laypersons and professionals could also be explained merely by assuming more accurate tuning of frequency-specific neurons in musicians.

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