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Superior pre-attentive auditory processing in musicians

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THE present study focuses on influences of long-term experience on auditory processing, providing the first evidence for pre-attentively superior auditory processing in musicians. This was revealed by the brain's automatic change-detection response, which is reflected electrically as the mismatch negativity (MMN) and generated by the operation of sensoric (echoic) memory, the earliest cognitive memory system. Major chords and single tones were presented to both professional violinists and non-musicians under ignore and attend conditions. Slightly impure chords, presented among perfect major chords elicited a distinct MMN in professional musicians, but not in non-musicians. This demonstrates that compared to non-musicians, musicians are superior in pre-attentively extracting more information out of musically relevant stimuli. Since effects of long-term experience on pre-attentive auditory processing have so far been reported for language-specific phonemes only, results indicate that sensory memory mechanisms can be modulated by training on a more general level. *NeuroReport* 10:1309–1313 © 1999 Lippincott Williams & Wilkins.

Key words: ERP; MMN; Music; Sensory memory

Introduction

Several studies demonstrated that musicians have superior processing under attend conditions [1–3], but it has remained elusive whether this ability is due to enhanced functions on higher cognitive levels involving the attentional processing of sounds, or due to superior processing at a pre-attentive level on which stimuli are automatically processed, i.e. even when stimuli are ignored.

To clarify this issue we investigated influences of experience on automatic neural mechanisms. Long-term training considerably modifies neural organization, as demonstrated by studies on intact [4,5] and lesioned animals [6] as well as on humans with peripheral sensory deficits [7–9]. However, only few studies reported corresponding plasticity of the human brain [10,11]. An influence of long-term experience on pre-attentive auditory processing has so far been demonstrated for language-specific phoneme processing only [12]; the dependence on non-speech stimuli has remained elusive. Up to now, only short-term effects of experience on the pre-attentive processing of specifically trained tonal patterns has been shown [13]. Thus providing evidence for a superior pre-attentive auditory processing in musicians would indicate that long-term experience can modulate pre-attentive neural processing of acoustic input not only with respect to phonemic processing but also on a more general level.

To determine the effect of long-term training on pre-attentive acoustic processing, the present study investigated highly trained professional musical experts and musical novices who had no musical expertise. An influence of expertise was expected to be indicated by the brain's automatic detection response to infrequent changes in a repetitory acoustic environment. This response is reflected electrically as mismatch negativity (MMN [14,15]) and generated by the operation of sensory (echoic) memory, the earliest cognitive memory system. If acoustic stimuli are discriminable, MMN is elicited even in the absence of attention. In the present study, an MMN response to slightly impure chords presented among perfect major chords was predicted to be elicited in professional musicians, but not in non-musicians, independent of whether stimuli were ignored or attended. This pattern of results would support the hypothesis of superior pre-attentive auditory processing in musicians.

Materials and Methods

Two groups (11 right-handed subjects each) participated in the experiment. The musical experts comprised violinists who studied the violin for professional purposes, seven of whom were females, aged 23–27 (mean 25.4) years, none of whom had absolute pitch. Each subject had violin lessons for ≥ 12 years (average 14.2 years). Musical novices had no musical expertise (five of whom were females) and were aged 19–26 (mean 22.3 years). Stimuli were sinusoidal tones generated by a Soundblaster SB 16 soundcard and presented binaurally via headphones at ~70 dB SPL. Presentation time was 300 ms (including 10 ms rise and fall times), just the same as the interstimulus interval (ISI). Probability for the infrequent deviant stimuli was 14%. Each deviant was followed by at least four standard stimuli. A total of 180 deviants occurred in the first and the third block, 70 in the second block, and 100 in the fourth and the fifth blocks. In all five experimental blocks brain electric responses to auditory stimuli were recorded.

First block: The frequent stimulus was a major chord with a perfect major third, consisting of three tones (tone frequencies: 396 Hz, 495 Hz and 596 Hz). The deviant stimulus was the same chord as the standard stimulus, except that the third (i.e. the middle tone of the chord) was marginally diminished in frequency, causing a slightly impure chord (tone frequencies: 396 Hz, 491.25 Hz and 596 Hz). Thus, only one of the three chord tones differed between standard and deviant chord. Though very small, this impurity is decisive for players of non-tempered instruments (like violinists), since little differences of a chord's third might alter the chord's nature (i.e. determine whether the chord is major or minor). Moreover playing thirds in double-stops is part of a violinists' daily practising program. During stimulus presentation participants were reading a self-selected book under the instruction to ignore all auditory stimuli. Subjects were not informed about the occurrence of deviant stimuli.

Second block: The same stimuli as in the first block were presented, but participants were informed about the existence and nature of the impure chord, asked to detect the deviant stimuli, and indicate their detection by pressing a response button. This behavioural task was employed to find out to what extent stimuli were consciously discriminable.

Third block: Stimulation was the same as that employed during the first and second blocks. As in the first block, subjects were instructed to ignore stimuli and to read a book. This block should replicate results of the first block and, additionally, allowed us to determine whether an attend block helps non-musicians transferring the practise of discrimination to an ignore block.

Fourth block: In the fourth block, single tones were presented under ignore conditions. Standard and deviant stimuli of the fourth block were of the same frequencies as the middle tones of the standard and deviant chords in the previous blocks (i.e. 495 Hz and 491.25 Hz). This was done to determine subjects' pre-attentive auditory processing when standard and deviant tones were not embedded in chords, i.e. when stimuli contained less musical information than in blocks 1–3.

Fifth block: The fifth block was a control block, in which single tones with a larger frequency difference (10%) between standard and deviant stimuli were presented (596 Hz as standard and 660 Hz as deviant). This condition was employed to compare the pre-attentive brain functions between experts and novices when they encounter a relatively salient frequency difference.

Measurements: EEG measurements were performed in an acoustically and electrically shielded room. Seven Ag-AgCl electrodes were applied: Fz, Cz and Pz (10-20 system), both mastoids (ML and MR, respectively), one electrode placed at 1/3 of the arc connecting Fz to LM (Fc3), and a homologous electrode over the right hemisphere (Fc4). As reference served nose tip, sampling rate was 200 Hz (bandpass 0.5–40 Hz). The baseline for the waveforms was defined as the mean amplitude between −100 ms and 0 ms relative to stimulus onset. For artefact reduction epochs were rejected off-line from the raw EEG whenever the s.d. in a 200 ms interval exceeded 40 μV in the vertical EOG (and in the horizontal EOG in the second block), or 90 μV in the horizontal EOG in all other blocks, or 20 μV at Fz, Pz or Cz in a 500 ms interval in any block. All standard stimuli directly following a deviant were excluded from averaging. To evaluate the MMN, difference waves were computed by subtracting the event-related potentials (ERPs) to the standard stimulus from the ERPs to the deviant stimuli. Since the MMN is known to be largest at frontal electrode sites [14,15], the mean average was computed for all frontal electrodes (Fz, Fc3, Fc4) for statistical evaluation.

Results and Discussion

First block: Figure 1 shows the ERP waveforms of the first experimental block. In musicians, deviant opposed to standard stimuli elicited a distinct negative deflection in the ERP with a peak latency of ~300 ms. It was largest at frontal electrodes, decreasing over central to parietal electrodes and inverting polarity at mastoidal sites (Fig. 1A). This

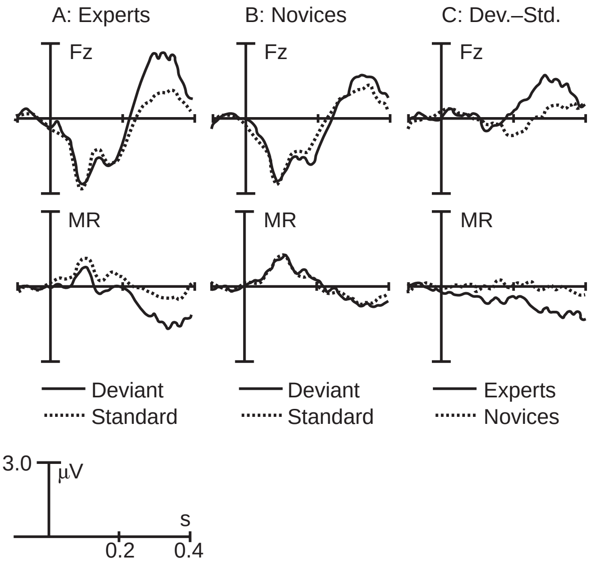

FIG. 1. ERP waveforms of the first experimental block (ignore condition), from fronto-central (Fz) and right-mastoid (MR) electrodes, averaged separately across experts (**A**) and novices (**B**). (**C**) Difference waves of the ERPs (standard subtracted from deviant).

response is regarded here as the MMN, an ERP component known to reflect pre-attentive auditory change detection processes in the brain. Notably, when asked after the first block, only six violinists reported that they had recognised the occurrence of the impure chord while the other five violinists did not. However, MMN did not differ between these two subgroups. All musical novices reported that they did not recognize any impure chord. Correspondingly, their brain responses to standard and deviant stimuli did not differ from each other (Fig. 1B). This indicates that cognitive processing of auditory information did not differ between pure and slightly impure chords in novices. Repeated measurement analyses of variance (ANOVA) for frontal electrodes with factors group (novices *vs* experts) × stimulus type (standard *vs* deviant) in the time window from 275 to 325 ms revealed an effect of stimulus type ($p < 0.0001$) and an interaction between the two factors ($p < 0.005$). Subsequent two-tailed *t*-tests revealed an effect of stimulus type for experts ($p < 0.0001$), but not for novices. Notably, the MMN in musicians cannot just be due to the performance of a dual task in musicians (they could have allocated attention to both the reading and the listening to the chords), since a conscious detection and evaluation of the deviant stimuli would have elicited both N2b and P3 [14,15], but neither of these components is visible in the ERPs.

Second block: Novices detected on average 13% and musicians 83% of the deviants. While all musicians were able to detect at least 67% of the deviants, six non-musicians detected < 1% of the impure chords. Thus behavioural results demonstrate the superior ability of attentive auditory discrimination in musicians. Additionally, ERPs indicate superior pre-attentive discrimination for musicians: as in the first block, they showed a distinct MMN (with a peak latency of about 300 ms), reflecting the automatic detection of impure chords (Fig. 2A). The MMN was followed by an additional negative (N2b) and a subsequent positive deflection (P3b). This N2b–P3 complex (around 350–700 ms) reflects higher cognitive processes concerned with the conscious detection and evaluation of deviants [14,15]. Novices tended to show a small MMN, but no polarity inversal and no subsequent N2b or P3 (Fig. 2B). ANOVAs for frontal electrodes (two factors: group × stimulus type) for the 275–325 ms time window, revealed an effect of stimulus type ($p < 0.0001$) and an interaction between the two factors ($p < 0.005$). Two-tailed *t*-tests for frontal electrodes (275–325 ms) revealed an effect of stimulus type for both experts ($p < 0.001$) and novices ($p < 0.05$).

Third block: Musicians showed a MMN which did not differ from their MMN of the first block (ANOVAs for the group of musicians employing two factors (stimulus type × block) revealed no interaction between the two factors). As in the first block, no N2b or P3 was elicited, indicating that musicians actually ignored the stimulation. Novices showed no MMN, despite the intervening detection task of the second block (Fig. 3A). ANOVAs for

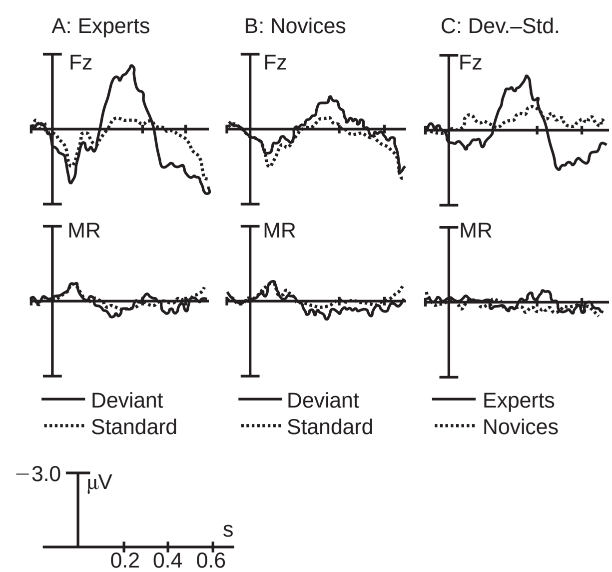

FIG. 2. ERP waveforms of the second experimental block (attend condition, stimulation as in block 1), separately for experts (**A**) and novices (**B**). (**C**) Difference waves of the ERPs (standard subtracted from deviant).

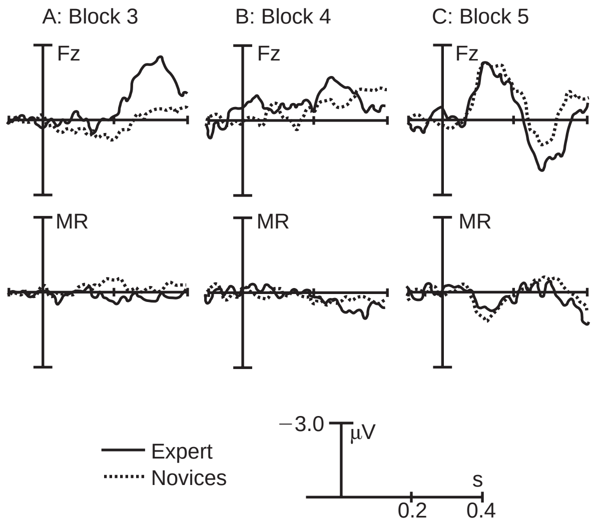

FIG. 3. Difference waves (standard subtracted from deviant stimuli), separately for experts and novices, of experimental block 3 (**A**), 4 (**B**) and 5 (**C**). In the third block (ignore condition, stimulation as in block 1) ERP effects are virtually the same as in the first block. In the fourth and fifth experimental block, single tones were presented under ignore conditions, MMNs did not differ between experts and novices, in either the fourth block or in the fifth block.

frontal electrodes (group × stimulus type), 275–325 ms, revealed an effect of stimulus type ($p < 0.0005$) and an interaction between the two factors ($p < 0.005$). Two-tailed *t*-tests for frontal electrodes (275–325 ms) revealed effects for experts ($p < 0.0005$), while novices had no significant effect.

Behavioural results of the second block indicate, that compared with novices, musical experts had superior auditory processing under attend conditions: they detected more impure chords. This was also reflected in the ERPs, where musicians showed an N2b–P3 complex as well as the MMN. Novices were not able to differentiate pure and slightly mistuned chords even when they attended the stimuli. ERP data of the first and third block show that musicians had superior auditory processing as well under ignore conditions, i.e. even when they did not attend the stimuli. These results demonstrate that highly trained musicians automatically detect differences in auditory information which are undetectable for non-musicians. This provides evidence for the hypotheses that influence of long-term expertise on the operation of the sensory memory system underlying the MMN is not confined to speech stimuli [12,16] but exists on a more general level. Contrary to language-specific phoneme processing, these mechanisms seem to be not dependent on auditory information stored as specific permanent memory trace in long-term memory: whereas phonemes build a set of elements stored in long-term memory, an assumption of separate permanent auditory memory traces for all intervals and pitches is regarded here as not plausible. While language-specific processing is due to this long-term stored representations of phonemes, the processes of acquiring information from musically relevant information may rather be due to elaborated neural mechanisms of sensory memory operation. Moreover, contrary to language-specific phoneme processing, in this study no lateralization to the left could be revealed for the processing of chords.

It is noteworthy that the MMN in musicians was not enhanced by the intervening detection task. This implies that the attentive discrimination of a short-term duration did not further enhance the neural pre-attentively activated memory processes in musicians. Instead, these automatic processes rather relied on previous long-term learning which had modified the neural mechanisms.

Fourth block: ERP data of the fourth block show that deviant stimuli elicited a MMN in both experts and novices (Fig. 3B). ANOVAs (frontal electrodes) with factors group × stimulus type, for 250–300 ms revealed effects of stimulus type ($p < 0.0001$), but no interaction between the two factors. This indicates that for novices the frequency difference between the two tones was easier to detect when presented as single tones than when presented within a chord. Notably, this was not the case for musicians, who tended to show a reduced MMN compared to their MMNs of the previous blocks (a marginal interaction ($p < 0.07$) was revealed in a two-way ANOVA between factors stimulus type × block (two levels: the summarized MMNs of blocks 1–3 at 290 ± 10 ms *vs* MMN of block 4 for 260 ± 10 ms). Since it is known that the amplitude of MMN is enhanced when elicited by multidimensional deviants [15,17–19] this could only be due to the fact that musicians extracted more information from the auditory information inherent in the chords. Not only the frequency difference of the middle tone of the deviant chords, but also e.g. beats of the impure chord and relations to the lower and upper tones were evaluated. Thus deviant chords were multidimensional deviants for musicians, but not for non-musicians. This provides evidence for the hypotheses that musicians automatically evaluate more information inherent in specific auditory input than do non-musicians. It is suggested that this is done by expertise-dependent mechanisms of generation of sensory memory traces, wherein these traces contain more information of an auditory event than when encoded by a non-expert.

Fifth block: The MMN elicited by the deviants of the fifth block did not differ between musicians and non-musicians (Fig. 3C), thus ERP differences of the previous blocks between experts and novices could not be due to any generalized sensitization of pre-attentive mechanisms in musicians: ANOVAs (frontal electrodes) with factors group $\times$ stimulus type over 125–175 ms, revealed effects of stimulus type ($p < 0.0001$), but no interaction between the two factors.

Conclusion

The present study indicates a long-term training effect on automatic neural mechanisms of information-acquirement on sensory memory level, providing the first evidence for superior pre-attentive auditory processing in musicians. Stimuli were non-speech stimuli, thus this study demonstrates that an enhanced pre-attentive sensitivity is not confined to language-specific phoneme processing. When chords were ignored, musical experts had compared to novices improved sensory memory processing of musically relevant information. During conscious sound discrimination, pre-attentive mechanisms determined the accuracy of performance [20,21]. Thus the superior discrimination performance of musicians is not only due to processing at higher cognitive levels but also to pre-attentive memory-based processing. Contrary to phoneme processing, this superior automatic discrimination is most probably not due to long-term stored representations (i.e. permanent sensory memory traces), but due to an elaborated mechanism of information acquirement underlying the generation of MMN. Nevertheless, since attentive auditory discrimination performance has in this study shown up to be improved by long-term musical training, the present data demonstrate that long-term experience is able to modify even pre-attentive neural memory mechanisms, rather on a more general level than just in respect to pre-attentive phonemic processing. Moreover, results and paradigm of the present study also open a new field for studying pre-attentive aspects of categorical perception in musicians and non-musicians [1–3].

NOTE: Examples of the stimulation are available under http://www.cns.mpg.de

References

1. Burns EM and Ward WD. *J Acoust Soc Am* **63**, 456–468 (1978).
2. Locke S and Kellar L. *Cortex* **9**, 355–368 (1973).
3. Siegel JA and Siegel W. *Percept Psychophys.* **21 (2)**, 143–152 (1977).
4. Recanzone GH, Schreiner CE and Merzenich MM. *J Neurosci* **13**, 87–103 (1993).
5. Zohary E, Celebrini S, Britten KH and Newsome WT. *Science* **263**, 1289–1292 (1994).
6. Irvine DRF. *Austr J Psychol* **44**, 131–138 (1992).
7. Kujala T, Alho K, Huotilainen M *et al. Psychophysiology* **34**, 213–216 (1997).
8. Cohen LG, Celnik P, Pascualleone A *et al. Nature* **389**, 180–183 (1997).
9. Sterr A, Müller MM, Elbert T *et al. Nature* **391**, 134–135 (1998)
10. Pantev C, Oostenveld R, Engelien A *et al. Nature* **392**, 811–814 (1998).
11. Elbert T, Pantev C, Wienbruch C *et al. Science* **270**, 305–307 (1995).
12. Näätänen R, Lehtokoski A, Lennes M *et al. Nature* **385**, 432–434 (1997).
13. Näätänen R, Schröger E, Karakas S *et al. NeuroReport* **4**, 503–506 (1993).
14. Näätänen R. *Attention and Brain Function*. Hillsdale, NJ: Erlbaum, 1992.
15. Schröger E. *Behav Res Methods Instr Comp* **30**, 131–145 (1998).
16. Chour M, Ceponiene R, Lehtokoski A *et al. Nature Neurosci* **1**, 351–353 (1998).
17. Ritter W, Deacon D, Gomes H *et al. Ear Hear* **16**, 52–67 (1995).
18. Schröger E. *Psychophysiology* **32**, 55–65 (1995).
19. Levänen S, Hari R, McEvoy L and Sams M. *Exp Brain Res* **97**, 177–183 (1993).
20. Tiitinen H, May P, Reinikainen and Näätänen R. *Nature* **372**, 90–92 (1994).
21. Winkler I, Tervaniemi M and Näätänen R. *J Acoust Soc Am* **102**, 1072–1082 (1997).

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