Proceedings of the 12th International Conference on Music Perception and Cognition and the 8th Triennial Conference of the European Society for the Cognitive Sciences of Music, July 23-28, 2012, Thessaloniki, Greece
Cambouropoulos E., Tsougras C., Mavromatis P., Pastiadis K. (Editors)

Difference in synchrony judgment accuracy of two pulses depending on musical experiences and its relation to the cochlear delays

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ABSTRACT

Background

Synchrony judgment is one of the most important abilities for musicians because just a few milliseconds of onset asynchrony can result in a significant difference in musical expression. However, even if all of the components physically begin exactly simultaneously, their temporal relation might not be preserved at the cochlear level because of its physical characteristics. The stiffness of the cochlear basilar membrane gradually decreases from the basal side to the apical side. Therefore, the higher components of an input wave excite the basal side, while the lower components excite the apical side. This phenomenon is referred to as “cochlear delay.” This delay largely occurs for components below 1000 Hz. The vibration in the lowest-frequency associated location is delayed by about 10 ms relative to the vibration in the high-frequency associated location (Uppenkamp, Fobel, & Patterson, 2001).

In our previous psychoacoustic study (Aiba & Tsuzaki, 2007; Aiba, Tsuzaki, Tanaka, & Unoki, 2008), an experiment was performed to measure the accuracy of synchrony judgment using stimuli that controlled the cochlear delay. In those cases, participants were not categorized by the levels of musical experience. However, most participants had the experiences to learn musical performance. The results of the experiment showed that the synchrony judgment accuracy was highest for stimuli that evoke an intrinsic cochlear delay. Furthermore, the accuracy was higher for stimuli that evoke the enhanced cochlear delay than for stimuli that cancelled out the cochlear delay, which implies that there is an asymmetric aspect of temporal processing in the human auditory system. In the present study, a psychophysical experiment was designed to investigate whether musicians similarly exhibit an asymmetric processing and whether musicians have a more accurate synchrony judgment.

Aims

The purpose of this study is to investigate whether the cochlear delay significantly affects the synchrony judgment accuracy and whether there are any differences in its effects depending on musical experiences.

Method

A psychoacoustical experiment was performed to measure the synchrony judgment accuracy for professional musicians and non-musicians. Two types of chirps and a pulse were used as experimental stimuli to control an amount of cochlear delay. These are (a) a compensated delay chirp, (b) an enhanced delay chirp, and (c) a pulse that evokes an intrinsic cochlear delay. The compensated delay chirp instantaneously increased its frequency to cancel out the cochlear delay. The increasing frequency pattern as a function of time used under the compensated delay condition was originally calculated by Dau, Wegner, Mellert, and Kollmeier (2000). The enhanced delay chirp had the reversed temporal relation of the compensatory delay chirp. In these two chirps, the frequency either increased from 0.1 to 10.4 kHz or decreased from 10.4 to 0.1 kHz. These had tapered transients at both ends with a raised cosine wave of 0.1 kHz. In addition, a pulse without delay imposed on any frequency component was used. The pulse also passed through a low-pass filter with the cut-off frequency of 10.4 kHz.

The experimental task was to detect a synchronous pair in the 2I2AFC procedure. Two pairs of sounds were presented to the participants in all the trials. In each trial, one interval contained a synchronous pair and the other interval contained an asynchronous pair. The asynchronous pairs consisted of 12 variations of a temporal gap (0.2, 0.4, 0.7, 1.0, 1.5, 2.3, 2.8, 3.4, 4.1, 5.1, 11.4, or 25.6 ms). The thresholds were estimated by fitting a sigmoid function and computing the delay value corresponding to 75% correct responses.

The participants consisted of six professional musicians (five females and one male, 25.0 ± 5.5 years of training), seven amateur musicians (four females and three males, 9.1 ± 6.2 years of training) and four non-musicians (one female and three males, 0 ± 0 years of training) with normal hearing and no history of hearing problems.

Results

The average estimated thresholds in milliseconds and the SDs for each musical experience level and sound type were as follows: professional musicians (a) 1.70 ± 0.43, (b) 1.14 ± 0.30, (c) 0.62 ± 0.15 / amateur musicians (a) 2.24 ± 0.88, (b) 1.79 ± 0.62, (c) 0.80 ± 0.41 / non-musicians (a) 2.57 ± 0.59, (b) 2.48 ± 1.16, (c) 2.08 ± 1.30. A two-way factorial fixed-effect ANOVA was performed where the musical experience levels and the sound types were treated as the main factors. The musical experience level ($F(2,48) = 8.17$, $p<.01$) and the sound type ($F(2,48) = 11.1$, $p<.01$) were significant as main factors.

The synchrony judgment accuracy was significantly higher in case of professional musicians than that of non-musicians. There was no interaction between the musical experience level and the sound type. To investigate detailed differences among the sound types depending on the musical experience levels, we performed the Tukey-Kramer HSD test on the musical experience level. As a result, for professional musicians, there

were significant differences among all three types of sounds. For amateur musicians, there was a significant difference between two types of chirps and the pulse. However, for non-musicians, there was no significant difference among all three types of sounds. This result suggests that musical experience may increase the sensitivity to the differences in a fine temporal structure of sound.

In a physiological study (Dau et al., 2000), the auditory brainstem response (ABR) was observed, when participants listened to the compensated delay chirp, the enhanced delay chirp and the pulse respectively. As a result, the ABR that evoked by the compensated delay chirp was the most salient event. It is generally assumed that the ABR is an electrophysiological event evoked by the onset of an acoustic stimulus. Dau et al., (2000) concluded that, by using the compensated delay chirp instead of the pulse as a stimulus, excitation from all cochlear locations (the basal side to the apical side) can contribute to the amplitude of the ABR, which is therefore larger than those evoked by the pulse.

In our physiological study (Aiba, Kazai, Shimotomai, Matsui, Tsuzaki, & Nagata, 2011), the ABR was also measured to observe the difference between pianists and non-pianists by using the same stimuli in this study. A time difference between the temporal gap of physical stimuli and the interval between the two ABRs (one is considered to be evoked by the first chirp and the other by the second chirp) were compared. As a result, The time difference of non-pianists was significantly longer than that of pianists. In the case of ABR of pianists, we proposed that there was less interference in the ABR evoked by secondary sounds after a subtle gap, compared to that of non-pianists. The cause is still unclear, although our results suggested and supported the idea that long-term experience with auditory signals induces the experience-dependent plasticity of the brainstem (Tzounopoulos, & Kraus, 2009). The plasticity of the brainstem could be one of the reasons that the musical experiences increase the sensitivity to the differences in fine temporal structure of sound.

Conclusions

For professional musicians, the synchrony judgment accuracy was higher than that for amateur musicians and non-musicians, and also there were significant differences among all three types of sounds. There is the possibility that the auditory system of professional musicians is more sensitive to the change of temporal relation on frequency components such as cochlear delay than that of amateur musicians and non-musicians.

Acknowledgements

This work was supported by a Grant-in-Aid for Young Scientists (B), No.22730592 and No.23730715 and Grant-in-Aid for Scientific Research (B) No.21330170, Japan Society for the Promotion of Science.

Keywords

Musical experience, Synchrony judgement, Cochlear delay, ABR (Auditory Brainstem Response)

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