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Effects of musical experience on synchrony judgment accuracy: Taking into consideration its relation to cochlear delay

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Musicians are sensitive to the synchrony of multiple tone onsets. However, even when several sounds have a simultaneous onset, their temporal relationship might not be preserved at the cochlear level because of "cochlear delays" in perception. The purpose of this study was to investigate whether cochlear delay significantly affects synchrony judgment accuracy and whether this phenomenon is dependent on musical experience. We conducted a psychoacoustic experiment to measure synchrony judgment accuracy in professional pianists, amateur pianists, amateur instrumental musicians (non-pianists), and non-musically trained people. Our experimental stimuli comprised three types of chirps, which allowed us to control for the amount of cochlear delay. We found that, regardless of the type of instrument, musicians had more accurate synchrony judgment. This may be due to the effect of careful listening, which is required as part of musical training. However, asymmetric aspects of temporal processing in the human auditory system were unaffected by musical experience.

Keywords: musical experience; cochlear delay; auditory periphery; synchrony judgment; pianists

A change in onset asynchrony of musical notes of just a few milliseconds can result in a significant difference in musical expression. Thus, it is important for musicians to be able to carefully discern the synchrony of tone onset. However, even when the components of discrete sounds physically begin at exactly the same time, their temporal relation might not be preserved at the cochlear level because of "cochlear delay" (e.g. Békésy and Wever 1960). The stiffness of the cochlear basilar membrane gradually decreases from the basal side to the apical side (e.g. de Boer 1980). As a result, the higher components of an input wave excite the basal side, while the lower components excite the apical side. The vibration in the region of the cochlear membrane associated with the lowest frequency is thus delayed by about 10 ms relative to the vibration in the region associated with the highest-frequency (Uppenkamp *et al.* 2001).

In our previous research, we measured synchrony judgment accuracy using three types of chirps that elicit different amounts of cochlear delay: a compensated delay chirp, enhanced delay chirp, and intrinsic delay chirp (Aiba *et al.* 2008). We found that judgment accuracy was higher for the enhanced delay chirp, which evoked enhanced cochlear delay, than for the compensated delay chirp, which cancelled out the cochlear delay. This finding indicated that the human auditory system may have an asymmetric aspect on temporal information processing. We also found that the judgment accuracy of professional musicians was significantly higher than that of non-musicians (Aiba *et al.* 2011). In this case, most of the musicians were pianists, who are able to simultaneously control the timing of many different tones in order to play their instrument. Therefore, we hypothesized that pianists in particular have a greater ability to judge synchrony than other types of musicians.

The purposes of this study were (1) to investigate whether the amount of cochlear delay has a significant effect on synchrony judgment accuracy and (2) to assess whether musical experience has an effect on synchrony judgment accuracy.

We conducted a psychoacoustic experiment to measure synchrony judgment accuracy in professional musicians, amateur musicians, and non-musicians. We used three different types of chirps to manipulate levels of cochlear delay.

METHOD

Participants

Eight professional pianists (25.5±4.7 years of training), eight amateur pianists (17.4±7.2 years of training), five amateur musicians (non-pianists, 6.6±4.5 years of training) and seven non-musically trained people (0.4±0.7 years of training) with normal hearing and no history of hearing problems participated in this study. All of the professional pianists had received at least one prize in a domestic or foreign competition.

Materials

We employed three types of sounds meant to induce different amounts of cochlear delay: (1) compensated delay chirp, (2) enhanced delay chirp, and (3) intrinsic delay chirp (see Figure 1). In the compensated delay chirp, the frequency was instantaneously increased to cancel out the cochlear delay. We used a frequency pattern originally calculated by Dau *et al.* (2000), wherein the frequency increases as a function of time. In the enhanced delay chirp, the temporal function was opposite to that of the compensated 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. The stimuli had tapered transients at both ends with a raised cosine wave of 0.1 kHz. We also used an intrinsic delay chirp (pulse), which had no delay imposed on any frequency component. The intrinsic delay chirp was passed through a low-pass filter with a cut-off frequency of 10.4 kHz.

Procedure

We used a two-interval, two-alternative forced choice (2I2AFC) procedure wherein participants were asked to detect synchronous pairs of stimuli. Two pairs of sounds were presented to the participant in each trial: one interval

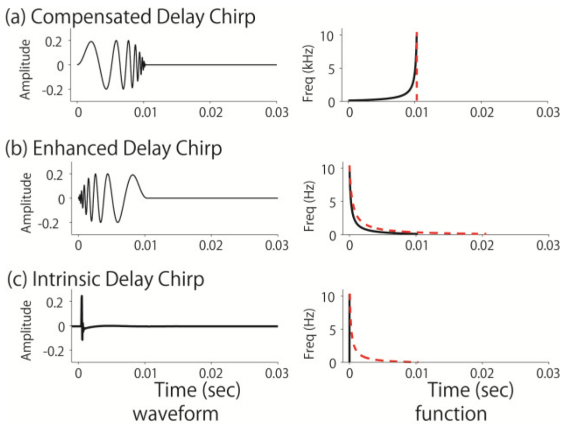

Figure 1. The panels on the left show the waveforms of each chirp, and the panels on the right show the corresponding function of cochlear delay. The solid lines on the right show the frequency pattern as a function of time for each delay condition. The broken line shows the time required for all frequencies to reach maximum amplitude at the basilar membrane. (See full color version at www.performancescience.org.)

contained a synchronous pair and the other interval contained an asynchronous pair. The asynchronous pairs had seven types of temporal asynchrony (0.2, 0.4, 1.0, 2.3, 5.1, 11.4, or 25.6 ms), spaced in a rough logarithmic pattern. The order of presentation of the synchronous and asynchronous pairs was randomized across trials. The two pairs were separated by a 500–700 ms inter-stimulus interval. The type of sound was consistent within each trial.

There were three sound-type conditions: (1) compensated delay, (2) enhanced delay, and (3) intrinsic delay. The total number of stimulus-type combinations was 72 (three sound-type conditions, twelve variations of temporal asynchrony, and two patterns of synchronous pair order). The participants repeated each combination 10 times, which brought the total number of trials to 720. All factors (sound type, temporal asynchrony, and presentation order) were randomized and executed as within-participant factors.

The participants were informed that each trial would have two intervals containing two sounds, and that the two sounds would be synchronous in one interval but asynchronous in the other interval. They were asked to choose the interval containing the synchronous pair. Participants had as many training trials as they felt they needed, and received feedback after each judgment. They were able to take breaks at any time.

Thresholds were estimated from the seven points on the psychometric function by fitting a sigmoid function on the data for each participant and computing the temporal asynchrony value corresponding to 75% correct responses.

RESULTS

The average estimated thresholds for each level of musical experience and each sound type are shown in Figure 2. A two-way factorial fixed-effect ANOVA was performed with music experience and sound type as the main factors. Music experience ($F_{3,80}=7.14$, $p<0.01$) and sound type ($F_{2,80}=21.7$, $p<0.01$) were both significant as main factors.

The accuracy of synchrony judgment was highest among the group of professional pianists. We found no interaction between level of music experience and sound type. We used the Tukey-Kramer HSD test to investigate detailed differences in sound type and music experience, respectively. We found a significant difference between professional pianists and amateur pianists and non-musically trained individuals in terms of judgment accuracy. Additionally, we found no significant differences in judgment accuracy between amateur musicians (non-pianists) and amateur pianists. There were significant differences in judgment accuracy among all three sound types.

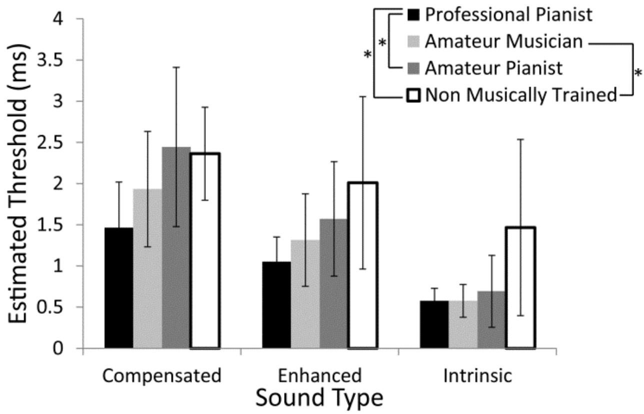

Figure 1. The average estimated thresholds and SDs in ms for each level of music experience and sound type. The arms at the side of the graph legend indicate the participant groups that showed significant differences (*p<0.05).

DISCUSSION

We found the judgment accuracy of professional pianists and non-musically trained individuals to be the highest and the lowest of the participant groups, respectively. However, we found no significant differences between amateur musicians (non-pianists) and amateur pianists in terms of judgment accuracy. Our results indicate that, regardless of the type of instrument a musician plays, careful attention regarding the synchrony of tone onset is important for musical performance. It is possible that, as musicians work to improve their instrumental performance, the accuracy of their synchrony judgment increases.

With regard to sound type, the synchrony judgment accuracy of individuals with all types of music experience decreased in the following order: compensated delay, enhanced delay, and intrinsic delay condition. This suggests that asymmetric aspects of temporal processing in the human auditory system do not change with music experience. In all types of music experience, the auditory system appeared less sensitive to this delay following the intrinsic, natural direction; that is, cochlear delays. There is the possibility that the improvement of synchrony judgment accuracy of musicians occurred in the upper levels of cochlear range.

In our future research, we plan to compare the onset judgment of professional pianists, who work more with sounds that have a sudden attack, with that of violinists, who work with sounds that often have a gradual onset.

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References

Aiba E., Kazai K., Shimotomai T. *et al.* (2011). Accuracy of synchrony judgment and its relation to the auditory brainstem response: the difference between pianists and non-pianists. *Journal of Advanced Computational Intelligence and Intelligent Informatics*, *15*, pp. 962-971.

Aiba E., Tsuzaki M., Tanaka S., and Unoki M. (2008). Judgment of perceptual synchrony between two pulses and verification of its relation to cochlear delay by an auditory model. *Japanese Psychological Research*, *50*, pp. 204-213.

Békésy G. V. and Wever E. G. (1960). *Experiments in Hearing*. New York: McGraw-Hill Book Co Inc.

de Boer E. (1980). Auditory physics. Physical principles in hearing theory. I. *Physics Reports*, *62*, pp. 87-174.

Dau T., Wegner O., Mellert V., and Kollmeier B. (2000). Auditory brainstem responses with optimized chirp signals compensating basilar-membrane dispersion. *Journal of the Acoustical Society of America*, *107*, pp. 1530-1540.

Uppenkamp S., Fobel S., and Patterson R. D. (2001). The effects of temporal asymmetry on the detection and perception of short chirps. *Hearing Research*, *158*, pp. 71-83.