Perceptual learning and its generalization in the discrimination of interaural time differences

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1. Introduction

Several researchers have examined the discrimination threshold of interaural time differences (ITDs),^{1,2)} but influences of practice on discrimination has attracted little attention. In this study, we examined the effects of practice on ITD discrimination thresholds, since learning effect, if there is any, would reveal novel aspects of auditory space perception. In addition, generalization of the learning effect to untrained ITD regions was also investigated. The answers to these questions should expose details of the processing stages involved in the perceptual learning.

2. Methods

ITD discrimination threshold was measured using a transformed up-down method³⁾ (2-down 1-up). In each trial, standard and comparison stimuli were presented successively. The order of presentation was randomized in each trial. Subjects were instructed to identify which of the two observation periods contained a signal perceived to be further right in space. Frequency and the level of the tones in each observation interval was fixed at 500 Hz and 57 dB SPL. The duration of the tones was 300 ms and a silent interval (500 ms) was inserted between the two intervals. Tones were generated digitally and sent to D/A converter (STAX: DAC Talent) through a sound card (Digital Audio Labs: Digital I/O Card) on a PC. Subjects received binaural signals through headphones (SENNHEISER: HDA-200). The number of trials in each block (about 9 min) was fixed at 88 to control the amount of practice in the whole training period. In each block, two staircases starting from either high (120 μ s) or low (9 μ s) initial values (*i.e.*, the differences in ITDs between the standard and comparison stimuli at the beginning of a block) were run in a randomized order. Thus we had two threshold estimates in each block. Step size was always in fixed ratio (0.14 log unit).

The experiment consisted of screening (1 day), pretest (1-2 days), training phase (9 days), and posttest (1 day) periods. Feedback to each response was presented

visually during the learning phase, but not during the test periods. Four adult subjects with normal hearing were recruited. They have never been engaged in psychoacoustic experiments. All of them were tested in pretest and posttest periods with three standard ITD values of -300, 0 and 300 μ s (Positive values mean that the right channel signal leads). In these test periods, three to five blocks of measurements were done in each condition. In the learning phase, 8 blocks were conducted for each subject with either -300 μ s (two subjects) or 300 μ s (two subjects) standard stimuli.

Each reversal point was recorded and the mean value was calculated as the threshold. The first three reversals were discarded, and the threshold was excluded from analysis when the number of remaining reversals was less than five.

3. Results

To investigate the learning effect, an index of learning effect was calculated for each subject by dividing the mean threshold in each training day by the mean threshold during the pretest. Figure 1 shows mean index value over 4 subjects as a function of training day. The mean index decreased from 0.8 to 0.4 during the learning phase. This clearly indicates an improvement of ITD discrimination thresholds with practice.

To investigate the generalization of learning, a similar index was calculated for 3 posttest stimuli by dividing posttest ITD by pretest ITD. Among these, one (T) was used for pretest and training, but the other two, UnT (0) and UnT (cont.), were introduced only in posttest period. White bars in Fig. 2 show the mean values of generalization index across 4 subjects for the three posttest stimuli. At trained ITD the mean value of the index was 0.4, and this means that the ITD discrimination thresholds improved with practice. For the other two conditions, however, the index was between 0.9 and 1.2 indicating there was no generalization of the learning for the two untrained stimuli. The mean thresholds in the condition T were 81.5 (39.6) μ s in pretest, and 37.2 (24.4) μ s in posttest (the numbers in the parentheses are the standard deviations over sub-

Fig. 1 Performance during training phase. Ordinate represents mean value of the index of learning effect across subjects. Days 0 and 10 show the performance in pre- and post-test respectively. Error bars represent standard errors. See text for details.

jects). Black bars show the same learning index from a test conducted 74 days after the posttest. Procedure in the test was same for posttest. These results indicate the same tendency as for posttest period. That is, low values of index for trained condition and high values for untrained conditions. In summary, results show a clear learning effect for ITD discrimination, and the effect lasts at least for 74 days. They also suggest that there is almost no generalization for other ITD values.

4. Discussion

Practice decreased ITD discrimination thresholds and the learning effect did not generalize to untrained ITD regions.

The learning effect obtained in the present study could result from such factors as familiarization to the experimental setting, or changes of motivation of subjects. It is difficult, however, for these factors to explain the learning effect, since there was no generalization of the learning effect to untrained regions.

ITD-selectivity of the learning effect observed in this study is consistent with the idea that sounds are processed by the neural substrata which are ITD selective and only a small number of them are involved in the long-lasting improvement of the discrimination threshold. In the mammalian auditory system, physiological studies have reported that interaural time difference is processed through a group of ITD-selective neurons and the output of these neurons are integrated with

Fig. 2 Generalization of the learning effect. Ordinate represents mean value of the index of learning effect across subjects. In abscissa, T indicates the trained condition, UnT (0) indicates the condition where the ITD of the standard stimulus was 0 μ s. UnT (Cont.) indicates the condition where the sign of the ITD of the standard stimulus was the reverse of the trained ITD. The white bars represent the indexes in posttest, the black bars in the test conducted 74 days after posttest. Error bars represent standard errors. See text for details.

information of interaural level difference, then making spatially tuned units.⁴⁾ ITD-selectivity of the learning effect is consistent with these findings.

The next question is whether the processing stage involved in perceptual learning revealed in this study is located before or after the integration of ITD and interaural level difference. This will be investigated for the better understanding of the mechanism of the perceptual learning.

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