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**Short-term learning effect in different psychoacoustic measures**

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Running Head: Perceptual learning of temporal processing

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Background: Learning effect has been studied in the literature, but the learning done in short-term training was not studied. Also, to date, the learning effect of different psychoacoustic measures was not compared. In the current study, we compared the perceptual learning effect caused by performing four different ATP tasks, in a short-term training design including two training sessions.

Methods: 74 young normal hearing participants each performed one of the following tasks: spectral temporal order judgment (TOJ), dichotic TOJ, gap detection, or duration discrimination. Each task was performed in two consecutive sessions.

Results: A learning effect was observed only for the spectral TOJ task. The change from the first to the second session was larger in spectral TOJ (81%) than in dichotic TOJ (2%), gap detection (7%) and duration discrimination (5%).

Conclusions: The difference in perceptual learning between spectral TOJ and other ATP tasks suggests that the performance of this task involves other cue(s) in addition to the temporal one.

Keywords: Perceptual learning, training, auditory temporal processing, TOJ
Auditory temporal processing (ATP) refers to the individual's time resolution when processing rapid stimuli [e.g., 1,2]. Different psychoacoustic measures have been used to assess ATP abilities. Among them are gap detection [e.g., 2,3], duration discrimination [e.g., 4, 5], spectral temporal order judgment (TOJ) [e.g., 1,26,7], and dichotic TOJ [e.g., 1,2,6,7]. These tasks have been studied among healthy young participants, and in comparison to different populations such as aphasic patients [8-11]; dyslexic readers [12-16]; aging adults [1,6,7,17-19]; children with autistic spectrum disorders (ASD) [20]; children and young adults with attention deficit/hyperactivity disorder (ADHD) [21-22]; and sleep deprived young adults [23-24].

When using different paradigms to measure the same mechanism, it may legitimately be asked as to whether these paradigms are equivalent? Do they reflect the same perceptual mechanism? When considering gap detection, duration discrimination, spectral and dichotic TOJ, all of them indeed are considered to measure ATP. However, there are some differences between them. For example, both TOJ tasks require judgment of the stimuli order, while gap detection and duration discrimination require discrimination of differences between the stimuli (difference in stimuli length or gap length). Gap detection and TOJ tasks require perception among short intervals, while duration discrimination is based on discriminating *stimulus duration*. Moreover, while gap detection, duration discrimination and spectral TOJ can be performed monaurally, dichotic TOJ requires diotic presentation, therefore necessarily involves central processing. Finally, while the stimuli in gap detection, duration discrimination, and dichotic TOJ involve only single frequency, in spectral
TOJ the participant is required to perceive the relative pitch of the sounds. In order to compare the perceptual mechanisms underlying these tasks empirically, the thresholds obtained from different tasks should be compared. However, this can be difficult to achieve, as different tasks use different ranges of values. In the current study we aimed to answer this question in a different manner, by comparing the perceptual learning effect of different tasks that measure auditory temporal processing.

Perceptual learning refers to the process whereby performing the same task repeatedly results in improved performance [25-27]. This topic comprises a large variety of studies, ranging from studies testing the human capacity to learn [e.g., 27], to maintain learning gains over time [e.g., 28,29], to generalize across different tasks [e.g., 30] or senses [e.g., 31], and to improve the ability of those who have difficulties in the area being trained [e.g., 32].

The literature points to two factors that affect perceptual learning: (1) the number of repetitions involved in the training [28,33], and (2) the duration of the training, in terms of being performed in a single session, or over more than one day [25,28,29,33]. Most recent studies involved six or more training sessions, leaving the effect of short-term perceptual learning largely unknown.

The aim of the current study was twofold: (1) to measure the learning effect for short-term training, including only two sessions, performed consecutively; and (2) to compare the perceptual learning effect for different tasks measuring auditory temporal processing.
Method

Participants
A total of 74 participants, age 20-27, each performed one of the following tasks: spectral TOJ (N=19, 63% females), dichotic TOJ (N=20, 42% females), gap detection (N=15, 60% females), or duration discrimination (N=20, 65% females). All participants were native Hebrew speakers. Participants were screened for hearing level at 0.5, 1, 2, and 4 kHz, with thresholds of 25 dB HL at all frequencies.

Tasks and stimuli
Each task included practice session in which the participants were familiarized with the stimuli and the task. The practice session was followed by the experiment that was repeated twice. During the practice session, participants received feedback for each response, but no feedback was provided during the experimental sessions. Practice sessions usually resulted in above 85% accuracy rate.

Spectral TOJ. In each trial, pairs of pure tones were presented binaurally, one at 1kHz and the other at 1.8kHz, with a duration of 15 msec, and rise/fall time of 1 msec, at 40 dB SL. The participants were required to press the appropriate keys on a computer keyboard corresponding to the order of the tones (i.e., the temporal order of the tones, high-low, or low-high), which varied randomly. Tones were separated by an inter-stimulus interval (ISI, the time between the offset of the first stimulus presented to the "lead" ear and the onset of the second stimulus presented to the "lag" ear), which varied in a two-down-one-up adaptive procedure. The initial ISI of 250 msec was changed according to the participants' responses in the following step sizes: steps of 25 msec for ISIs of 250 to 100; steps of 10 msec for ISIs of 100 to 50 msec; steps of 5 msec for ISIs of 50 to 15 msec; and steps of 2.5 msec for ISIs of less than 15
msec. The experiment continued for ten reversals, and the TOJ threshold was calculated as the average of the last eight reversals. The practice session included 30 pairs of stimuli that were presented with an ISI of 250 msec. (see also [1]).

**Dichotic TOJ.** In each trial, two 1-kHz, 40 dB SL, 15 msec pure tones were presented, with 1 msec rise/fall time. One tone was presented to each ear, separated by temporal intervals. The participants were required to press the appropriate keys on a computer keyboard corresponding to the order of stimulation between ears (i.e., the temporal order of the tones, right-left, or left-right), which varied randomly. Tones were separated by an ISI, which varied in a two-down-one-up adaptive procedure. The initial ISI of 250 msec was changed according to the participants' responses in the following step sizes: steps of 25 msec for ISIs of 250 to 100; steps of 10 msec for ISIs of 100 to 50 msec; steps of 5 msec for ISIs of 50 to 15 msec; and steps of 2.5 msec for ISIs of less than 15 msec. The experiment continued for ten reversals, and the TOJ threshold was calculated as the average of the last eight reversals. The practice session included 30 pairs of stimuli that were presented with an ISI of 250 msec. (see also [1]).

**Gap detection.** On each trial participants were presented with a pair of two 50ms duration, 1 kHz pure tones, presented binaurally and separated by an ISI of 100ms. Each pair contained a target tone with a gap of silence that ranged between 0.5 to 36ms, and a reference tone with a gap of 0ms. This procedure of using a gap in both the reference and target tones was adapted in order to prevent judgments based on possible perceived changes in the overall envelope of a tone with a gap versus a tone with no gap (see Schneider et al., 1994). Participants judged which of the two tones contained the gap. The duration of the gap changed adaptively in a 2-down-1-up staircase procedure. The initial value was 40 msec and was changed in steps of 2.5
msec according to the participants' responses. The experiment continued for ten reversals, and the TOJ threshold was calculated as the average of the last eight reversals. The practice session included 30 pairs of stimuli that were presented with a gap of 40 msec. (see also [2]).

*Duration discrimination.* On each trial participants were presented with a pair of two 50ms duration, 1 kHz pure tones, presented binaurally and separated by an ISI of 100ms inter-stimulus interval (ISI). Each pair consisted of a reference tone with duration of 100 msec, and a target tone with varying duration. The target tone’s duration changed adaptively in a 2-down-1-up staircase procedure. The initial duration delta was 80 msec, and was changes according to the participants' responses in steps of 5 msec to duration delta of 50 msec and then in steps of 2.5 msec. The experiment was terminated after 10 reversals, and the threshold was calculated as the average of the last eight reversals. The practice session included 30 pairs of stimuli that were presented with a delta duration of 80 msec.

**Apparatus**

The tasks were programmed using Matlab™ software version 6.5 and were presented using a PC. The auditory stimuli were presented through TDH-49 headphones. Screening for hearing level was performed by using a Maico Hearing Instruments Ltd. MA32 audiometer.

**Procedure**

Prior to the experiment, participants signed an informed consent and were informed that the study was designed to test their perceptual abilities in regard to each task, in two consecutive sessions. Participants' hearing levels were then measured, and they
were instructed in the assigned task. The study was approved by the Ariel University Institutional Review Board.
Results

Figure 1 presents thresholds for all four psychoacoustic tasks in the two sessions. Since each task presented a different range of threshold values, the data were first analyzed for each task separately. Four paired t-test analyses were carried out for each task, comparing the two sessions. A significant difference was found between spectral TOJ thresholds in the first (44.583 msec) and the second sessions (8.542 msec, $t_{(18)}=3.021, p<0.01$), but not for any of the other tasks ($t_{(19)}=-0.444, p>0.05$ for dichotic TOJ; $t_{(14)}=1.170, p>0.05$ for gap detection; and $t_{(19)}=1.946, p>0.05$ for duration discrimination). In order to compare learning effect for all the tasks together, threshold data for every session was transformed into Z scores. Repeated-measures ANOVA with session as within-subjects variable and task as between-subjects variable revealed significant effect for session ($F_{(1,70)}=9.815, p<0.01$) and task ($F_{(3,70)}=16.294, p<0.001$), and a session by task interaction ($F_{(3,70)}=20.617, p<0.001$). Post-hoc analysis showed that mean Z score for thresholds in the first session was larger than in the second session ($p<0.05$). It also showed that mean Z score for thresholds in all tasks were different ($p<0.05$ to 0.001). Paired-sample t-tests for thresholds Z scores in each task revealed significant difference between first and second session for the spectral TOJ task ($p<0.001$), but not for any of the others ($p>0.05$).

In order to quantify the amount of learning achieved in each task, we calculated the percentage of change in performance from the first to the second session, as followed:

$$\frac{(Th_2- Th_1)}{Th_1}$$

whereas $Th_1$ is the threshold obtained in the first session, and $Th_2$ is the threshold obtained in the second session. Figure 2 presents the percentage of change from the
first to second sessions in all four psychoacoustic tasks. One-way ANOVA showed a significant main effect for task ($F_{(3,73)}=6.44, p<0.01$). Post-hoc analyses revealed that the mean percentage of change was significantly higher for spectral TOJ than for the other tasks ($p<0.01$ to 0.001). No differences were found between the other tasks.
Discussion

In the current study, we compared perceptual learning in short-term training for four auditory temporal tasks: spectral TOJ, dichotic TOJ, gap detection, and duration discrimination. In this short training paradigm, a learning effect was observed for spectral TOJ, and not for any of the other three tasks. Moreover, the magnitude of the learning effect for the spectral TOJ task, presented as the mean percentage of change in the performance threshold between the first and second sessions, was substantial (54%), and much higher than that of the other tasks (4-11%).

Other studies that tested perceptual learning for auditory psychoacoustic tasks showed that the performance in these tasks can be improved by training [e.g., 34-36]. However, most of them focused on learning processes comprising multiple training sessions (6 to 14), some of which were performed over several days. In one study, performance of short-term learning procedure was presented. In their study, Hauptmann and Karni [25] tested the performance in visual letter enumeration task when presenting in two consecutive sessions. This double presentation repeated itself number of times with one or two days apart. The first pair resembles the design of the current study and show significant improvement in reaction time from the first to the second presentation, but no effect on accuracy. In the current study we tested the same effect of short-term learning effect, but on auditory perception. Since reaction time was already found to be affected by double presentation, and accuracy not, we focused on perceptual thresholds in order to test whether it is also sensitive enough to short-term training. We indeed found that ATP threshold is sensitive to short-term training, but it is task-dependent.

Studies testing perceptual learning in auditory psychoacoustic tasks found learning effect for gap detection, frequency and pitch discrimination, and for the
ability to detect a tone in backward masking [e.g., 37-43]. Larger learning effect was found for adults than for adolescents [42], but similar learning effect was found for young and aging adults [37], and for musicians and non-musicians [40]. Some studies have reported on generalization of learning to different ear [38] and task [41], but not all of them [43]. Most of these studies on perceptual learning in psychoacoustic measures have tested long-term learning, going on for several days. Only a few tested short-term learning, but nonetheless reported on training effect [40, 43,44]. Moreover, Cohen et al. [43] suggested that shorter training sessions facilitate more latent learning.

The fact that the spectral TOJ task exhibited a substantial learning effect, whereas no learning effect was evident for the other tasks, raises two issues. The first is the nature of the perceptual learning. It is not surprising that learning effects are generally not evident in such short-term training procedures. It is hard to believe that any sensory or central learning will occur in only two consecutive task sessions. Familiarization with the task might improve performance, but since these were simple tasks, each preceded by a familiarization phase, we did not expect the additional familiarization afforded by the first session to affect performance. However, performance in the spectral task improved significantly between sessions, raising the question as to what specifically participants learn while performing it. Previously, when comparing spectral TOJ to spatial TOJ, it was suggested that while performing the spectral TOJ task, participants learn to use the frequency difference between the tones as a cue for determining the order of the tones [1]. This cue enables the listener to create a global pattern for each sequence (high-low vs. low-high), and to report the order of the tones by differentiating between patterns rather than by attending to each of the tones in the sequence. This form of sequence perception was previously
suggested by Warren [e.g., 45], and it obtains further support in the present study, wherein spectral TOJ is compared to three other temporal processing tasks.

The second issue is the difference between the tasks. The four tasks that were included in the study all measure auditory temporal processing abilities. Nevertheless, as was also mentioned earlier, they differ in term of the judgment done by the participant (order judgment vs. differences discrimination); the perceptual process involved in the tasks (based on short intervals or discriminating stimulus duration); the presentation of the stimuli (monaural vs dioty); or the nature of the stimuli (with or without frequency differences). The results seem to support the latter description of the tasks when spectral TOJ was different from the other tasks in the effect of short-term perceptual learning. This difference raises the possibility that spectral TOJ differs perceptually from the other auditory temporal tasks in the study. Taken together with the previous suggestion of the usage of an additional cue in performing the spectral TOJ task, the results of the current study might suggest that spectral TOJ does not in fact measure temporal processing, at least not to the extent that dichotic TOJ, gap detection and duration discrimination do. Spectral TOJ might instead measure the participants' ability to make use of the spectral cue provided by the frequency differences. On the other hand, in spite of the differences between the other tasks, a similar (non) short-term learning effect was found, suggesting similar perceptual mechanisms in these tasks. These conclusions should be considered when using different tasks to measure the same ability. More specifically, spectral TOJ should be regarded cautiously when testing ATP.
References


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The authors declare no conflict of interests.
Figure 1. Threshold in two consecutive sessions for spectral TOJ, dichotic TOJ, gap detection and duration discrimination.
Figure 2. Percentage of threshold decrease in from 1st to 2nd session for spectral TOJ, dichotic TOJ, gap detection and duration discrimination.