Failure to unlearn the precedence effect

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Studies of the precedence effect using two binaural clicks have shown that listeners' ability to discriminate changes in the interaural time difference (ITD) of the lagging click is much poorer than that for the leading click [e.g., Zurek, J. Acoust. Soc. Am. **67**, 952–964 (1980)]. This difference is thought to reflect an auditory process that suppresses directional information from the lagging sound and attributes greater perceptual weight to directional information contained in the leading one. A report by Saberi and Perrott [J. Acoust. Soc. Am. **87**, 1732–1737 (1990)] suggested that listeners can ''unlearn'' this suppression of the lag's directional information after training with an adaptive psychophysical procedure involving 100 reversals and extremely small step sizes. Here, an attempt was made to find a similar effect using psychophysical procedures that are more common to precedence studies. Eight subjects were rigorously trained on the precedence task using either a blocked procedure or an adaptive procedure to vary ITD. Listeners showed no sign of unlearning. After 9–31 h of participating in the task, all subjects maintained high lag just-noticeable differences (jnd's) and low single source jnd's. This failure to train away the precedence effect (as manifested in discrimination suppression) suggests that directional information contained in the lagging source is not easily accessed. Several possible explanations for the discrepancies between the present study and Saberi and Perrott's finding are discussed.
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I. INTRODUCTION

People spend an abundance of time in enclosed spaces, such as homes, classrooms, and work environments. A common feature of these environments is their reverberant nature due to the hard surfaces comprising the walls, floors, and ceiling, as well as furniture and objects contained in the room. In a typical classroom, the initial reflections that reach the ears from nearby surfaces may be attenuated by as little as 5–10 dB relative to the direct sound. Hence, the listener receives a complex mixture of acoustic signals, each carrying its own localization cues. In order to avoid localization errors, the auditory system must resolve those cues belonging to the source and weight them more heavily in the localization process.

Efforts to understand how the auditory system processes sounds in complex environments have utilized simple stimulus paradigms in which a direct sound (lead) and a single simulated reflection (lag) are presented in anechoic environments (or over headphones) with short delays between their onsets. ''Summing localization'' refers to a delay smaller than 1 ms, when the lead and lag sources are perceptually fused and when both the lead and lag contribute to the perceived direction of the fused image (e.g., Zurek, 1980; for review see Blauert, 1997, pp. 204–206; Litovsky *et al.*, 1999). As the delay is increased to 1 ms and beyond, the lead dominates localization. Fifty years ago, Wallach, Newman, and Rosenzweig (1949) coined the term ''precedence effect'' to denote the localization dominance of the leading sound. The dominance of the lead in localization has also been shown using an objective task whereby listeners discriminate changes in the ITD or location of the lag. Compared with discrimination of the lead or a single source, lag discrimination is significantly more difficult for clicks at delays of 1–3 ms (Zurek, 1980; Gaskell, 1983; Freyman *et al.*, 1991; Shinn-Cunningham *et al.*, 1993; Litovsky and Macmillan, 1994; Stellmack *et al.*, 1998; Tollin and Henning, 1998; Litovsky *et al.*, 1999). This finding of lag discrimination suppression provides an objective measure of the extent to which the auditory system suppresses directional cues contained in the lag and attributes greater perceptual weight to directional information contained in the leading source (Zurek, 1980; Litovsky *et al.*, 1999).

A number of years ago, Saberi and Perrott (1990) published a report summarizing group data from three listeners that indicated that lag discrimination suppression can be ''trained away'' with extensive practice. Using brief click stimuli, they initially measured just-noticeable-difference thresholds (jnd's) in the lag condition that revealed relatively poor performance at lead–lag delays ranging from 0.75–3 ms, consistent with previous reports (e.g., Zurek, 1980; Gaskell, 1983). Listeners were subsequently ''trained'' on the precedence task at delays ranging from 1–5 ms with emphasis at 2.35 ms for 8–20 h. A curious, and perhaps

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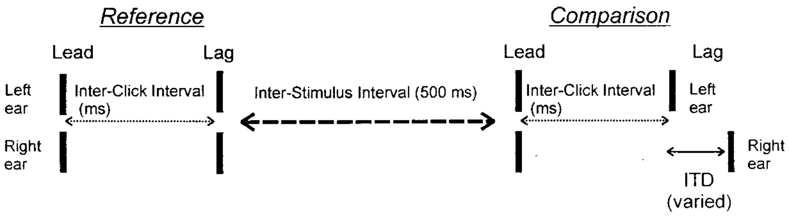

FIG. 1. Stimulus configuration for a single trial is shown. Each click was a 40-μs square-wave pulse. Each trial consisted of two intervals: A reference stimulus and a comparison stimulus, which were separated by 500 ms. Each stimulus consisted of two pairs of clicks, the lead and lag. The lead pair was always diotic (zero interaural-time difference producing an image centered in the middle of the head). The lag pair was diotic in the reference stimulus as well, but dichotic in the comparison stimulus. The interclick interval (ICI) was always identical for the reference and comparison, and varied from 0.38 to 10 ms.

critical, feature of the psychophysical procedure was the implementation of unusually long adaptive tracks with very small step sizes. Following training, ITD discrimination on the lag sound improved substantially, although single-source jnd's were not reported; hence, it is difficult to surmise whether the training effect was specific to precedence or a more general improvement in ITD discrimination. Nonetheless, Saberi and Perrott (1990) concluded that listeners learned to use the directional cues available in the lag, and that the precedence effect results from a cognitive process that is subject to modification from short-term experience. The notion that precedence mechanisms are not ''hard-wired'' and can be unlearned negates most existing models of precedence which invoke active inhibition in order for the dominance of the lead to be activated (e.g., Lindermann, 1986; Zurek, 1987; Cai *et al.*, 1998).

The approach taken by Saberi and Perrott (1990) to estimate threshold used unusually long adaptive tracks that continued for 100 reversals with ITD step sizes of 2.5 μs for the last 60 reversals. This method has not been previously used in studies of the precedence effect; hence, the ''unlearning'' effect may not apply to most current research. Virtually all studies on precedence have employed alternative strategies that either average over several shorter adaptive runs (e.g., Litovsky and Macmillan, 1994; Yang and Grantham, 1997; Tollin and Henning, 1998) or that estimate psychometric functions with numerous measures at fixed ITDs (e.g., Zurek, 1980; Gaskell, 1983; Yost and Soderquist, 1984; Perrott *et al.*, 1989; Freyman *et al.*, 1991; Shinn-Cunningham *et al.*, 1993; Houtgast and Aoki, 1994; Stellmack *et al.*, 1999). The present study explored the extent to which the unlearning effect extends to these more common psychophysical methods. If unlearning precedence can be produced independent of a particular psychophysical method, existing models of the precedence effect would have to be modified in fundamental ways. Alternatively, if the unlearning effect is dependent on a specific method of tracking subject's performance, then much would remain to be understood about the particulars of this finding.

II. TRAINING WITH FIXED ITDs

A. Methods

1. Subjects

Five listeners (two male and three female) participated in this study. All listeners had normal hearing as verified by audiograms measured at standard frequencies ranging from 250 to 8000 Hz. One listener (S5) was a student with prior experience in auditory psychophysics, but not on tasks requiring ITD discrimination; the remainder of the listeners were paid subjects with little or no prior experience. Listeners were familiarized with the task for approximately 1 h prior to testing.

2. Stimuli

Square-wave pulses of 40-μs duration were presented as lead–lag binaural click pairs. Figure 1 shows the temporal sequence of stimuli on a single trial. Each trial consisted of two intervals. Interval A, containing the reference stimulus, and interval B, containing the comparison stimulus, were separated by 500 ms. Each stimulus consisted of two pairs of clicks, the lead and lag. The lead pair was diotic ($\mathrm{ITD}=0$) in both the reference and comparison. The lag pair was diotic in the reference, and contained an ITD favoring either the right or left ear in the comparison stimulus. The interclick interval (ICI), referring to the delay between onsets of the lead and lag, was always identical for the reference and comparison. The task was a two-alternative, forced-choice task, whereby the listener was asked to report whether the sound image in the comparison stimulus was perceived to the right or left of center. Feedback was provided on every trial. Tucker-Davis Technologies' AP2 array processor and PD1 Power DAC were used to generate the stimuli. The sampling rate was 200 kHz, thereby allowing interaural differences as small as 5 μs. Stimuli were amplified by a TDT HB6 headphone amplifier and presented at a level of 68 dB SPL[1] via Sennheiser HD520II headphones.

In this first experiment we aimed to provide listeners with directional cues associated with the lag that were as consistent as possible. We chose to maintain consistency by holding the lag ITD constant within a block of trials and only varying the direction of change (right vs left). Our hope was that as listeners became more familiar with the task they would be better able to utilize information regarding changes in the lag ITD.

B. Results

1. Pretraining assessment

Pretraining thresholds were obtained using a 2-down/1-up adaptive procedure (Levitt, 1971) to vary the ITD. Starting ITDs were 500 μs and each run continued until 14

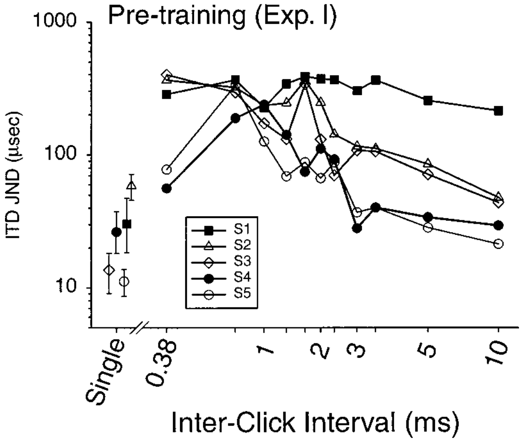

FIG. 2. Fixed training group pretraining ITD jnd's for lag discrimination. Individual lines denote data from individual listeners, with performance plotted as a function of interclick interval (lead–lag delay). Single points on the left represent individuals' performance on the no-lead (single-source) condition.

reversals were reached, with threshold for each run calculated from the geometric mean of the last ten reversals. ITDs were increased or decreased by a multiplicative factor of 2 for the initial four reversals, and by a factor of 1.4 for the last ten reversals. Measurements were made at 11 ICIs (0.38, 0.75, 1, 1.25, 1.5, 1.75, 2, 2.5, 3, 5, and 10 ms), and each listener was tested on five series of ICIs, with order of presentation randomized differently for each series. These pretraining estimates were gathered over approximately four 2-h sessions.

Pretraining data for the fixed training group are shown in Fig. 2. Solid curves show performance on the precedence lag-discrimination condition, and single points at the left show performance on the no-lead (single-source) condition for individual listeners. For three subjects (S1, S4, S5) lag discrimination is poorest at delays of 0.75 to 3 ms and performance generally improves as the delays either increase (5–10 ms) or decrease (0.38 ms). Two subjects (S2, S3) do not show the expected improvement at the shortest delay, possibly due to the difficulty of the task, which may have rendered neither lead nor lag dominant at that time interval. Finally, to ensure that subjects were not simply ''unlearning'' the precedence effect during the pretraining assessment, a two-way analysis of variance (ANOVA) (threshold repetition×ICI) was conducted for each subject. There were no significant main effects or interactions ($p > 0.05$).

2. Training with a blocked ITD procedure

Training was conducted during 6 to 11 daily sessions, which lasted 9 to 17 h. Based on these initial measurements for each listener (Fig. 2), an ICI near the poorest ITD jnd thresholds was selected as the training ICI (1.0 ms for S1, S2, S3, and S5; 1.25 ms for S2). Although 1.0 ms is considered to be at the edge of the ''summing localization'' window, the fact that performance was worse at that ICI for most listeners convinced us that for these listeners and conditions the precedence effect was well in place. On each day, one psychometric function was obtained at the training ICI by measuring discrimination performance for blocks of 50 trials with the ITD fixed within a block. ITDs were chosen semirandomly between 50 and 800 μs, and measurements were repeated three times at each ITD; hence, data are based on 150 trials per ITD. Daily thresholds seeking the ITD at which performance was 70.7% correct were obtained from psychometric functions by linear interpolation between the nearest points above and below 70.7. In addition, every day, prior to testing on the precedence conditions, three single-source baseline thresholds were obtained using the adaptive 2-down/1-up method (Levitt, 1971).

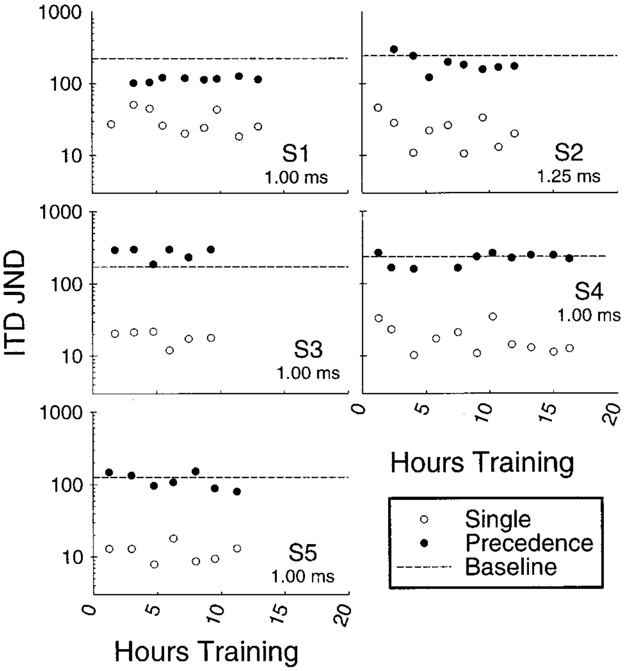

FIG. 3. Daily thresholds for the fixed training group are shown. Each panel contains data from one listener, with ITD jnd's for each day plotted as a function of number of training hours completed by the end of that day. Filled circles refer to performance on lag discrimination, and open circles refer to the no-lead (single source) condition. The value shown under the subject number refers to the interclick interval (ICI) at which the listener was trained. Horizontal dashed lines refer to thresholds obtained in the pretraining period for the ICI at which the listener was trained.

Figure 3 shows individual ITD jnds' plotted as a function of training hours. Lag-discrimination thresholds are shown in filled circles and single-source thresholds are shown in open circles. The dashed line in each plot marks the listener's baseline performance at the training ICI (see average ITD jnd at that ICI in Fig. 2). Results suggest that lag-discrimination thresholds remained consistently above single-source thresholds across hours of training. There was no evidence of improvement in either condition as listeners gained more experience on the task.

III. TRAINING WITH ADAPTIVE CHANGES IN ITD

The methods used in the fixed training study differed from those of Saberi and Perrott (1990) in several ways. For instance, they had used an adaptive method to vary ITDs, and their training emphasized an ICI of 2.35 for all listeners. We wondered whether listeners' ability to unlearn precedence was dependent on either the adaptive changes in ITD

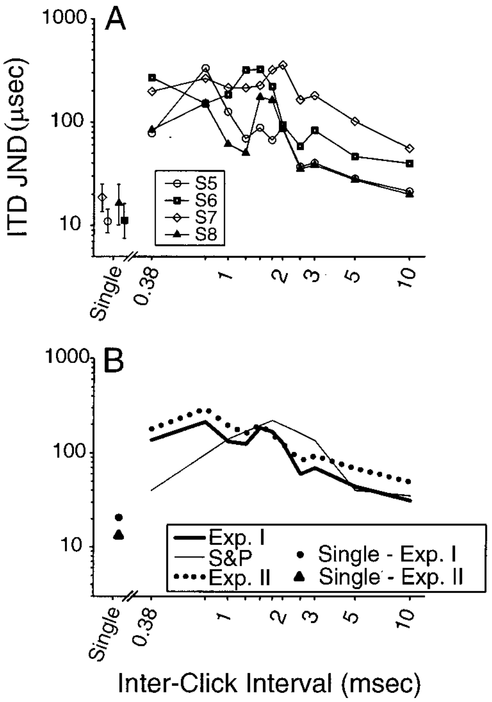

FIG. 4. (A) Adaptive training group pretraining ITD jnd's for lag discrimination. Individual lines denote data from individual listeners, with performance plotted as a function of interclick interval (lead–lag delay). Single points on the left represent individuals' performance on the no-lead (single-source) condition. (B) Group means from (A) and from Fig. 2 are shown together with the group mean from Saberi and Perrott (1990, S&P).

as a function of performance, or on the fact that we chose a training ICI near the peak of each listener's function. We decided to conduct a second experiment in which the lag ITDs varied adaptively within a run, and to fix the training ITD at 2.35 ms.

A. Method

1. Subjects

Four subjects (two male and two female) participated. One listener (S5) had participated in experiment 1 and the other listeners had no prior experience in auditory psychophysics. All listeners had normal hearing as verified by audiograms measured at standard frequencies ranging from 250 to 8000 Hz. Listeners were familiarized with the task for approximately 1 h prior to testing.

B. Results

1. Pretraining assessment

Pretraining thresholds were obtained using a method identical to that for the first experiment; hence, results are expected to be similar to those in Fig. 2. Data for the adaptive method are shown in Fig. 4. The top panel (A) shows four listeners' performance on lag-discrimination as a function of ICI, and single points at the left show individual's performance on the no-lead (single-source) condition. Lag discrimination is generally poorest at the shortest delays and performance generally improves as the delays increase. The expected finding that performance also improves at delays less than 1 ms (see Blauert, 1997) was only clearly observed for S5.

The bottom panel in Fig. 4 compares group mean data from Saberi and Perrott's (1990) pretraining condition (thin line) to group mean data from our fixed (dotted line) and adaptive (thick line) training groups. It appears that in both of our groups poor performance in the precedence condition was observed at delays as short as 0.38 ms. In contrast, Saberi and Perrott's (1990) subjects had a clearer region of poor performance with improvement not only at the longer delays but at delays less than 1 ms as well. This difference is difficult to interpret, but might be due to the difficulty of the task, which extended to short delays for our subjects. Finally, as in the first experiment, to ensure that subjects were not simply unlearning the precedence effect during the pretraining assessment, a two-way ANOVA (threshold repetition$\times$ICI) was conducted for each subject. There were no significant main effects or interactions ($p > 0.05$).

2. Training with an adaptive method

Training was conducted during 7 to 15 daily sessions, which corresponded to 13 to 23 h. As in the fixed training group, number of hours refers to actual time spent listening to stimuli, not including intermittent breaks taken within a session. Training was conducted at an ICI of 2.35 ms for all listeners. Note that for three listeners (S5, S6, and S8) this ICI was greater than their pretraining peak jnd (see Fig. 4), and for one listener (S7) 2.35 was near the peak jnd. One listener (S8) showed excellent performance at 2.35 ms, before training, and after 11 h of training was subsequently tested at an ICI of 1.75 ms, near the peak jnd. Every day, prior to testing on the precedence conditions, one single-source baseline threshold was obtained using the adaptive 2-down/1-up method. Subsequently, testing was conducted for the precedence lag-discrimination condition. ITD jnd thresholds were measured adaptively using a PEST algorithm (Taylor and Creelman, 1967; Hawley, 1994). For both single and precedence runs the starting ITDs were 500 μs. On average, 35 thresholds were measured per day (one single source and the remainder precedence). Stimuli were identical to those used in the first experiment.

Figure 5 shows daily performance for individual listeners. Each plot shows the mean and standard deviation bars for the lag-discrimination thresholds (filled circles), and single-source thresholds (open circles), as a function of training time. The horizontal dashed line in each plot marks the listener's baseline performance at the training ICI [see the average ITD jnd at that ICI in Fig. 4(A)]. Three listeners (S5, S6, and S7) exhibited a consistent elevated threshold on the precedence condition compared with the single condition. For these listeners, precedence thresholds remained stable at the dashed line, suggesting that with increased training they were not learning to extract information regarding the ITD of the lag at smaller ITDs. At the same ICI of 2.35 ms, one listener (S8) exhibited better performance on the precedence condition compared with the pretraining baseline performance; however, lag-discrimination thresholds remained

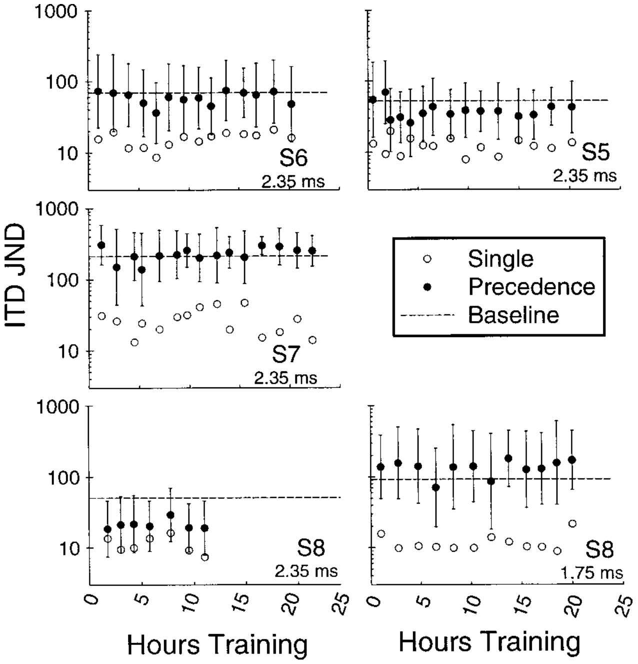

FIG. 5. Daily thresholds for the adaptive training group are shown. Each panel contains data from one listener, with daily average and standard deviation for ITD jnd's. Filled circles refer to performance on lag discrimination, and open circles refer to the no-lead (single-source) condition. The value shown under the subject number refers to the interclick interval (ICI) at which the listener was trained; this value was initially 2.35 for all listeners. S8 was also tested at an ICI of 1.75 (bottom right panel). Horizontal dashed lines refer to thresholds obtained in the pretraining period for the ICI at which the listener was trained.

consistently higher than the single-source thresholds after 11 h of training. This listener was subsequently trained at an ICI of 1.75 ms, near the pretraining peak jnd. Data for the 1.75-ms ICI are also shown in Fig. 5 (bottom right). Again, after 20 additional training hours, lag-discrimination thresholds remained consistently near baseline performance, and greater than single-source thresholds.

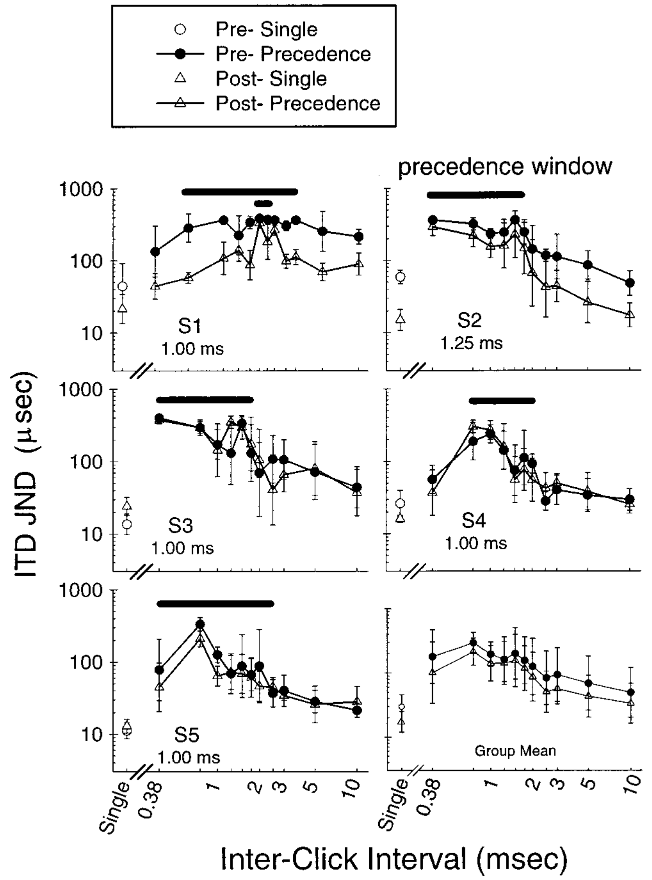

FIG. 6. Comparing pre- and post-training performance for the fixed training. Each panel contains data from one listener, with ITD jnd's plotted as a function of the interclick interval (ICI). Pre-training data are shown by circles and post-training data are shown by triangles. Single points on the left represent data from the single-source (no lead) condition. Horizontal bars across the top of each plot mark the ''precedence window,'' defined as the range of delays at which performance was significantly higher than on the single-source condition.

IV. COMPARISON OF PRE- AND POST-TRAINING FOR EXPERIMENTS 1 AND 2

Following the training period, each listener was once again tested on the baseline ICI series, with five adaptive measures at each ICI. Figure 6 shows pre- and post-training thresholds as a function of ICI for each listener in the fixed training group (experiment 1) with group means at the bottom right. In each plot, pretraining performance is shown in circles, and post-training in triangles. Data from the single-source condition are also shown in each plot as a single data point on the left. Figure 7 shows pre- and post-training thresholds for the adaptive training group (experiment 2). Finally, group means are plotted in Fig. 8 for the fixed training group (A), adaptive training group (B), and for Saberi and Perrott's listeners (panel C).

To analyze the single-source results, for each listener a one-way ANOVA was conducted using the five repeated estimates obtained before and after training. There was a significant main effect for two listeners, although pointing towards opposite conclusions. For S2 pretraining thresholds were higher than post-training thresholds ($p<0.001$), while for S3 pretraining thresholds were lower than post-training thresholds ($p<0.05$).

To analyze the lag-discrimination thresholds, a two-way ANOVA was conducted for each listener, comparing pre- and post-training performance across ICIs, including the single-source condition as one of the ICI values. All listeners showed a main effect of ICI ($p<0.0001$), suggesting a dependence of precedence performance on the delay between lead and lag. Statistical tests also showed one listener to have a main effect of pre-post condition (S2, $p<0.0001$). Finally, one listener (S1) had a significant interaction between ICI and pre-post condition (S1, $p<0.009$), revealing an effect of training only at ICIs that were outside the region of 0.75 to 3 ms ($p<0.05$). For this listener, small amounts of improvement were seen either at ICIs of 0.0, 0.2, 0.38, or at ICIs beyond the classic precedence window (5 and 10 ms). However, this listener showed no improvement within the traditional precedence window of 1 to 3 ms for clicks (e.g., Zurek, 1980; Gaskell, 1983; Saberi and Perrott, 1990; Tollin and Henning, 1998).

The next analysis was aimed at identifying a ''prece-

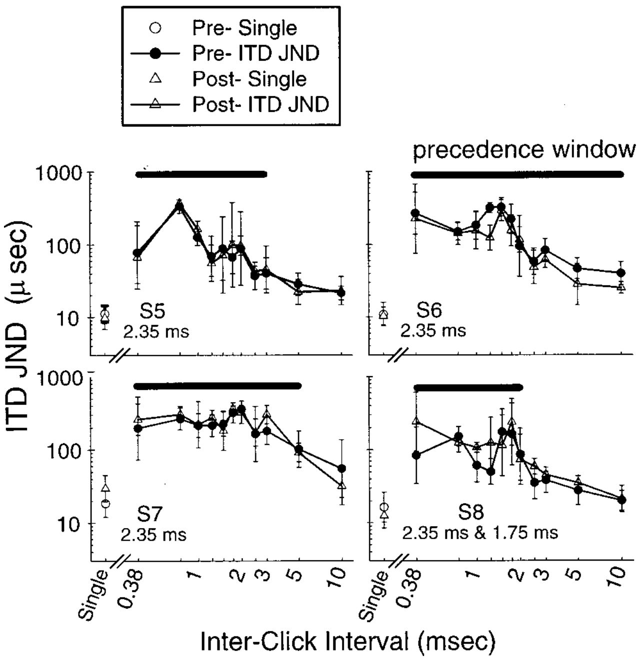

FIG. 7. Same as Fig. 6 for the adaptive training group.

dence window'' for each listener, defined as a temporal region for which lag discrimination is significantly worse than single-source discrimination. Subsequent to the general ANOVAs, *post hoc* Scheffe's grouping tests were conducted for each listener to reveal the ICIs that fell into the precedence window. At the top of each plot in Fig. 6, thick horizontal bars indicate the precedence window for each listener. For listeners with no effect of pre-post training, thresholds were combined within a given ICI. Listener S1, for whom there was an interaction effect between ICI and training, the precedence window was smaller in the post-training sessions (1.5 and 1.75 ms) compared with a more extensive precedence window in the pretraining sessions (0.75 to 10 ms). For this listener, pretraining precedence thresholds were significantly higher than single-source thresholds at most ICIs, whereas post-training thresholds were only higher than single source at two ICIs. For S2 there was no difference in the precedence window for pre- and post-training. Three listeners (S1, S4, and S5) showed a ''peaked'' function, with a significant decrease in thresholds at both short and long ICIs. For the other listeners (S2, S3, S6, S7, and S8) the precedence window extended to the very short ICIs, within the range of summing localization (e.g., Blauert, 1997).

In summary, comparison of pre- and post-training shows that, with a few minor exceptions, training did not result in improvement on the precedence task, at the training ICI or at any other ICIs. Overall, after training on the precedence task for 13 to 31.5 h performance remained constant. In addition, the precedence window, defining a range of ICIs at which precedence was most robust, varied among listeners. The precedence windows measured here are in agreement with previous studies showing strong precedence at delays of 1–3 ms (e.g., Zurek, 1980; Gaskell, 1983; Shinn-Cunningham *et al.*, 1993; Tollin and Henning, 1998; Stellmack *et al.*, 1998).

V. DISCUSSION

This study was aimed at finding an effect of unlearning precedence similar to one reported by Saberi and Perrott (1990). We began with a commonly used method of fixing the interaural parameters of the lagging source. After failing to reduce our listeners' lag-ITD thresholds following 9 to 17 h of training, we switched to another common paradigm whereby the ITD of the lag is varied adaptively. After 13 to 23 h of training we still saw no improvement in performance, and thus concluded that the precedence effect is not easily unlearned and must therefore have some hardwired mechanisms that are rapid, automatic, and not cognitively mediated.

The discrepancy in findings must seriously be considered, however, since Saberi and Perrott's unlearning effect was robust enough to be carried over to tone pips of various frequencies and high-pass-filtered clicks. We considered the possibility that Saberi and Perrott did not actually demonstrate a release from precedence, but rather a more general learning effect that simply reflected listeners' improvement on the interaural discrimination task. If their listeners had shown improvement on all ITD thresholds, including those with a single click, then an argument could be made that the training effect was not specific to ITD discrimination on the lagging click. However, because they did not report single-click thresholds, it is not possible to assess this hypothesis directly. It is reasonable to assume, though, that there would have been little if any training effect for single-click ITD thresholds in their study because their listeners were moderately-to-very experienced with lateralization tasks. This supposition is supported by the results of their first study in which lead-click ITD thresholds were about 20 μs. Therefore, we regard it as highly unlikely that Saberi and

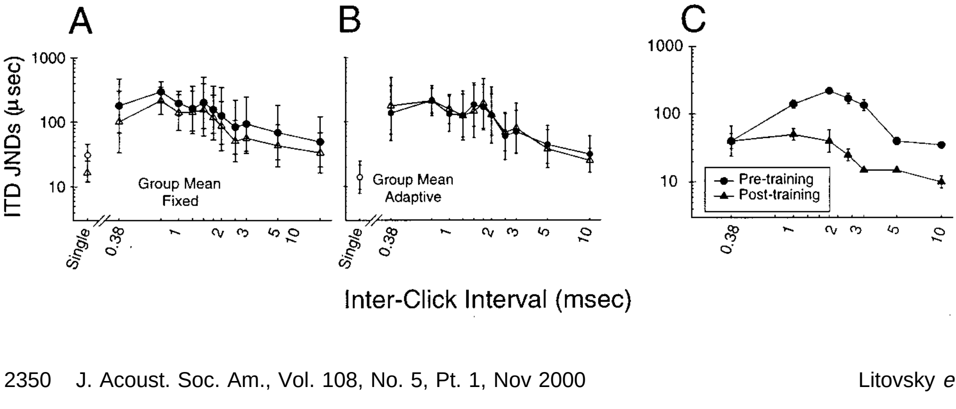

FIG. 8. Group means for the fixed training method (A) and adaptive training method (B); ITD jnd thresholds are plotted as a function of ICI for pre-training (○) and post-training (△) sessions. (C) Data from Saberi and Perrott (1990) are replotted also showing ITD jnd's as a function of ICI.

Perrott's training result was a general learning effect.

Why is it that we failed to find the effect of unlearning the precedence effect? Is it possible that their highly trained subjects may have had been better able to listen for the appropriate cues for discriminating ITD of the lagging click? Evidence against this hypothesis comes from the fact that all three of Saberi and Perrott's listeners, even the one with the least experience, showed the training effect while our listeners, even the one with the most experience, did not. Further, almost all of the published data on lag-ITD discrimination suppression (e.g., Zurek, 1980; Shinn-Cunningham *et al.*, 1993; Saberi, 1996; Tollin and Henning, 1998; Litovsky and Shinn-Cunningham, 2000) have employed highly trained listeners but have not reported unlearning of the kind shown by Saberi and Perrott.

Our failure to find the effect may in fact be due to methodological and procedural details. First, in Saberi and Perrott's (1990) study, listeners were trained each day using a single long adaptive track with linear step sizes beginning with 10 μs, and ending with 2.5 μs. In our study, subjects were trained either with fixed ITDs or with repeated adaptive tracks using PEST rules. In either case, subjects in their study spent more time listening to trials near thresholds, which might have facilitated improved discrimination and lowering of thresholds. Second, while they used a 300-ms interstimulus interval, we used a 500-ms interval. The shorter interval used by Saberi and Perrott may have contributed to an ''apparent motion'' percept that could conceivably increase sensitivity to directional changes in the comparison stimulus compared with the reference stimulus. Third, in the training phase we focused on the delay at which each listener's threshold had been highest in the pretraining phase, with the aim of presenting listeners with consistent relatively unchanging interaural cues, which we thought would maximize any effect of training. In contrast, Saberi and Perrott varied the delay within the 1–5-ms window of interest, which might have actually been a better paradigm for inducing a general learning effect. Finally, the level in the present study was higher, leaving the possibility that we had weaker precedence (Shinn-Cunningham *et al.*, 1993; Litovsky and Yin, 1998). That might explain our failure to find a training effect if it were not for the fact that thresholds were lower (i.e., weaker precedence) in the Saberi and Perrott study. However, nothing is known about the effect of sound level on training, and hence the impact of a level difference on the discrepancy in results cannot be established.

Although these methodological differences exist between the present study and that of Saberi and Perrott, it is difficult at this point to conceive of learning mechanisms that would be sensitive to such seemingly inconsequential details.

VI. SUMMARY

For a number of years the phenomenon of lag-discrimination suppression has been a widely documented, objectively measurable, manifestation of the precedence effect (Zurek, 1980; Gaskell, 1983; Freyman *et al.*, 1991; Shinn-Cunningham *et al.*, 1993; Litovsky and Macmillan, 1994; Stellmack *et al.*, 1998; Tollin and Henning, 1998; Litovsky and Shinn-Cunningham, 2000; see Litovsky *et al.*, 1999 for a recent review). Some authors have argued that an active inhibitory mechanism is necessary to account for this and related precedence phenomena, and that a likely candidate for initial stages of this process lies in the brainstem (Lindemann, 1986; Zurek, 1987; Yin, 1994; Cai *et al.*, 1998; Litovsky and Yin, 1998). However, with one exception (Fitzpatrick *et al.*, 1995), most of the physiological data supporting these claims have been collected in anesthetized animals. At the same time, it is clear that higher-order mechanisms must be involved in many of the precedence phenomena that have been shown to be susceptible to changes in listeners' ongoing auditory experience and environmental awareness (e.g., Hafter *et al.*, 1988; Clifton *et al.*, 1994; Clifton and Freynamn, 1997; Blauert, 1997). Whether the loss of ITD discrimination ability shortly after a preceding sound is malleable in the same way is an important piece of knowledge for a basic understanding of auditory processing. However, before we can develop sound theoretical models, we need to establish the basic experimental findings and understand the source of differences in findings.

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[1] For these brief stimuli, defining the actual level in dB SPL depends on the time window chosen for the measurement. Over a 1000-ms time window, which is equivalent to the ''slow'' setting on a sound-level meter, the level was 68 dB SPL. Using a shorter time window of 35 ms, which is equivalent to the ''impulse'' setting on a sound-level meter, the measured level was 79 dB SPL.

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