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Auditory Duration Discrimination in Young and Elderly Listeners with Normal Hearing

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Abstract

This study investigated the effects of age on two parameters of auditory temporal processing: auditory duration discrimination and the backward interference of auditory duration discrimination. Young and elderly listeners with normal hearing sensitivity participated. In experiment I, the just-noticeable difference (JND) in duration between a standard 1000-Hz tone of 40 msec and a comparison tone of longer duration was evaluated using a three-interval forced-choice task. In experiment II, the duration discrimination paradigm was presented with a tonal masker following the tonal stimulus at three delay times: 80 msec, 240 msec, and 720 msec. Age effects were observed on the duration discrimination task with interference but not on the initial duration discrimination task without interference. These results suggest that the time required to process the duration characteristics of acoustic stimuli is prolonged in elderly listeners.

Key Words: Age effects, backward interference, duration discrimination, temporal processing

Several prominent theories of aging stipulate that there is a generalized slowing of perceptual processing with increasing age (Birren et al, 1980; Salthouse, 1985). Evidence to support this theory derives primarily from studies using visual tasks (Kline and Schieber, 1985) and speech perception tasks (e.g., Stine et al, 1986) that either manipulate temporal aspects of the stimulus itself or vary the rate of stimulus presentation. For example, elderly subjects perform more poorly than younger subjects in visual flicker fusion studies in which subjects attempt to fuse temporally interrupted stimuli (Brozek and Keys, 1945; Coppinger, 1955). Similar evidence for age-related deficits in auditory temporal resolution derive from recent backward detection masking data reported by Cobb et al (1993). In speech perception tasks, elderly listeners exhibit excessive difficulty compared to younger listeners on tasks in which the speech rate is increased and the syntactic structure of the speech signal is reduced (Wingfield et al, 1985). Thus, elderly listeners may be limited in their ability to process temporal aspects of stimuli, especially when there is increased demand or difficulty in the perceptual task. The hypothesis related to slowed processing on suprathreshold auditory tasks has not been tested directly using simple acoustic, nonspeech stimuli.

One auditory task that may be particularly well suited to evaluating this hypothesis is duration discrimination for tones. This measure assesses a listener's ability to distinguish the just-noticeable difference (JND) in duration between a reference tone and a comparison tone. The use of tonal stimuli avoids possible confounding effects of the multiple cues that are present in speech signals. Duration discrimination is presumed to be governed by central timing mechanisms (Hirsh, 1959; Creelman, 1962) that may be altered with aging.

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Few studies have assessed duration discrimination by elderly listeners, and the results have not been conclusive. Humes and Christopherson (1991) evaluated duration discrimination by young listeners with normal hearing, young noise-masked listeners, and elderly listeners with hearing loss as part of a battery of psychoacoustic and speech perception tests. The duration discrimination task used a 100 msec, 1000-Hz reference signal and a two-alternative forced-choice paradigm (2AFC). Age effects were not observed on the duration discrimination task. In contrast, Abel et al (1990) observed age effects on a duration discrimination task using 1/3-octave noise bands centered at 500 Hz and 4000 Hz. In this study, difference limens (DLs) for standard durations of 20 and 200 msec were assessed using a four-interval forced-choice paradigm. Subject groups included young and elderly listeners with normal hearing, elderly listeners with hearing loss, and listeners with normal hearing who complained of sensitivity to noise. An effect of aging was observed at both stimulus frequencies for the shorter standard (20 msec), which was not confounded by the presence or degree of hearing loss. It should be noted, however, that the age range of the "elderly" subjects was 40–60 years in the latter study. Taken together, these studies tentatively suggest that age may affect performance on duration discrimination tasks with relatively short standards, although elderly subjects (> 65 years) have not yet been evaluated on this measure.

A second experimental paradigm that may be useful for evaluating the time course of processing signal duration is backward interference. Backward interference studies of duration identification have been reported using young adult subjects (Massaro and Idson, 1976, 1978; Kallman and Morris, 1984). These studies include the presentation of a target signal duration to be identified (e.g., "short" versus "long"), which is followed by an interference signal that is presented at various interstimulus intervals (ISIs). The ISI at which the interfering signal no longer disrupts the identification of the target signal provides an estimate of the time required to process the target durational characteristics. Young listeners with normal hearing exhibit the greatest interference effects at short ISIs but continue to exhibit some minimal interference at longer durations (up to 1005 msec) (Massaro and Idson, 1976).

Backward interference using a duration discrimination task has not been evaluated previously in young and elderly subjects. Newman and Spitzer (1983), however, evaluated the effects of aging on backward interference for a pitch identification task. Elderly subjects with normal hearing showed poorer performance on a backward interference task involving pitch recognition than younger subjects with normal hearing at all ISIs, and performance reached a plateau at a longer ISI for elderly subjects compared to younger subjects. These results suggest that the elderly subjects required more processing time than the younger subjects to recognize frequency characteristics of a sound. Similar findings were reported by Raz et al (1990). As noted earlier, the effects of age on the time required to process the duration of tones has not yet been evaluated.

This study aimed to evaluate basic auditory duration discrimination abilities of elderly subjects with and without backward interference. The first experiment assessed duration discrimination for brief stimuli in young and elderly subjects, in order to determine if there is an aging effect in the ability to discriminate differences in duration of brief tones presented in isolation. The second experiment employed the same discrimination task used in a backward interference paradigm to investigate processing time differences between young and elderly subjects in the discrimination of duration. If central processing rate is slower in elderly listeners, then backward interference effects should extend over a longer time interval than that observed for younger listeners. Both experiments evaluated performance in young and elderly subjects with normal hearing.

METHOD

Subjects

Ten elderly subjects (65–80 years) and 10 young subjects (18–35 years) were recruited as volunteers. Preliminary testing included evaluation of pure-tone thresholds and performance on the Short Portable Mental Status Questionnaire (Pfeiffer, 1975). The latter measure was included to ensure selection of subjects without any obvious intellectual impairment. Subjects were high school graduates, in overall good health, who had no history of significant otologic disorders. All subjects exhibited hearing within normal limits (pure-tone thresholds $\leq$ 20 dB HL, re: ANSI, 1989, from 250–4000 Hz), as shown in Figure 1. Although there are small differences in auditory sensitivity between the two subject groups, these differences are not expected to influence performance on suprathreshold auditory temporal processing tasks (Abel et al, 1990). Performance on the mental status questionnaire indicated that all subjects exhibited intact intellectual functioning.

Stimuli

The stimuli for experiment I were 1000-Hz pure-tone bursts with a reference steady-state duration of 40 msec and cosinusoidal rise-fall envelopes of 5 msec. The test frequency of 1000 Hz was chosen prior to the experiment as a frequency where thresholds for young and older subjects were expected to be similar and as a frequency used commonly in psychoacoustic experiments. A monaural presentation was used, with stimuli fixed at a suprathreshold level of 70 dB SPL. The same target stimuli were used in experiment II, together with a 250 msec, 1000-Hz interfering tone with the same rise-fall envelopes. Stimuli were digitally created and stored.

Instrumentation

A computer (Crescent PC) controlled the stimulus presentation, event timing, and data collection. The stimuli were digital-to-analog converted by a 12-bit converter with a 20-kHz sampling rate and low-pass filtered at 7000 Hz (Frequency Devices 901F). Tone bursts were amplified (Colbourn S82-24), attenuated (Hewlett Packard 350D), and delivered to the subject via a single Etymotic insert earphone. Simultaneously, the computer presented typed visual cues on the subject's monitor to mark the three observation intervals. A three-button box was used for the subject's responses. A splitter sent the same visual presentation seen by the subject to a monitor in the control room. A loudspeaker located in the control room allowed for continuous monitoring of each run's progress by the examiner. The subject sat alone in a sound-treated booth.

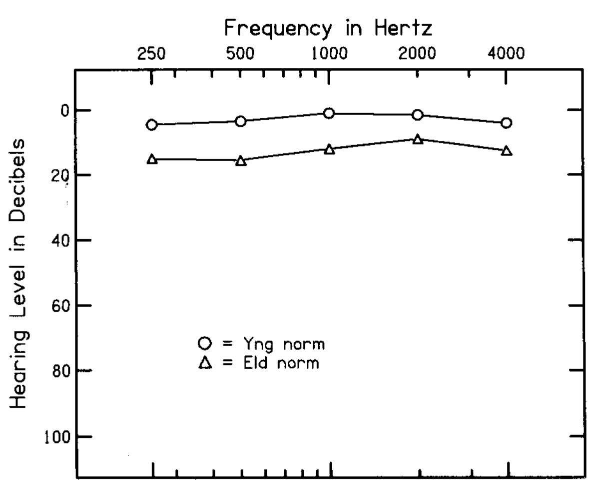

Figure 1 Mean audiograms of the young and elderly subject groups.

Procedure

An adaptive three-interval forced-choice (3IFC) paradigm was used to measure duration discrimination thresholds of pure tones. In the #IFC procedure, two standards (T) and a comparison tone (T + ΔT) were presented on each listening trial. This procedure allowed the separation of response bias from sensitivity changes with a determination of the stimulus levels required to achieve threshold (the JND), as outlined in the theory of signal detectability (Green and Swets, 1974). Utilization of three intervals enabled the subject to discriminate the presentation interval that sounded different from the other two intervals, rather than labelling an interval as "long" or "short." Presumably, this procedure minimized cognitive demands on the subject. The comparison tonal duration was varied adaptively to achieve the difference duration at which the probability of obtaining either an UP or DOWN sequence was 70.7 percent (Levitt, 1971). The resulting threshold represented the JND for duration.

Practice runs of duration discrimination were given, with a minimum of five threshold estimates obtained. Practice runs ended when the means of successive threshold estimates did not vary by more than 10 percent. The final three-point average was used as an estimate of JND.

Experiment I used a standard tone duration of 40 msec. This fixed standard occurred in two of the three stimulus intervals, with a comparison tone presented randomly in a third interval. The initial duration of the comparison tone was 80 msec, and the duration was decreased adaptively in 5-msec steps during the first three reversals. Thereafter, the duration was decreased in 1-msec steps. The DL estimate was taken as the mean of the stimulus values associated with the final six tracking reversals. The ISI was fixed at 1500 msec, in order to match the memory load of the longest trial of experiment II. Subjects were instructed to press the button corresponding to the interval in which the tone burst was different, and longer, than in the other two intervals. Feedback on the correct interval followed each subject's response.

Experiment II, the 3IFC backward interference experiment, utilized the same stimuli as were used in experiment I. The interference signals were 1000-Hz pure tones of 250-msec duration presented at 70 dB SPL. Trials were blocked in three delay times: 80, 240, and 720 msec. The presentation order of each block was randomized for each subject. Each interval of target and masker was separated by 500 msec. Again, this was a threshold-based measurement of 70.7 percent correct performance in duration discrimination. As the duration discrimination task was well practiced by this time, additional practice was not given in the backward interference condition. Feedback followed each subject's response.

Subjects were tested in three to four sessions, each lasting 2 hours. The initial session consisted of an audiometric evaluation, a brief familiarization run of 10 trials, and practice runs for the duration discrimination task. During the second session, practice was completed, if necessary, and a three-point average was derived as the threshold for duration discrimination. During sessions two and three, thresholds were obtained under the backward interference condition. Breaks were provided every half hour during testing.

RESULTS

The mean duration discrimination performance of the two subject groups for experiment I is shown in Figure 2. A t test was conducted to determine whether there were significant age effects reflected in the performance of these two groups. The results of the t test showed no significant differences between group means in the discrimination of the duration of tone bursts ($t = -.65$, $p > .05$).

Mean JNDs for both age groups at each delay time from experiment II are plotted in Figure 3. Raw data from the backward interference task were subjected to an analysis of variance (ANOVA) using a split-plot factorial design (Shavelson, 1988). Independent variables were age (between-groups variable) and delay time (within-groups variable). The dependent variable was the threshold obtained for 70.7 percent correct performance on duration discrimination.

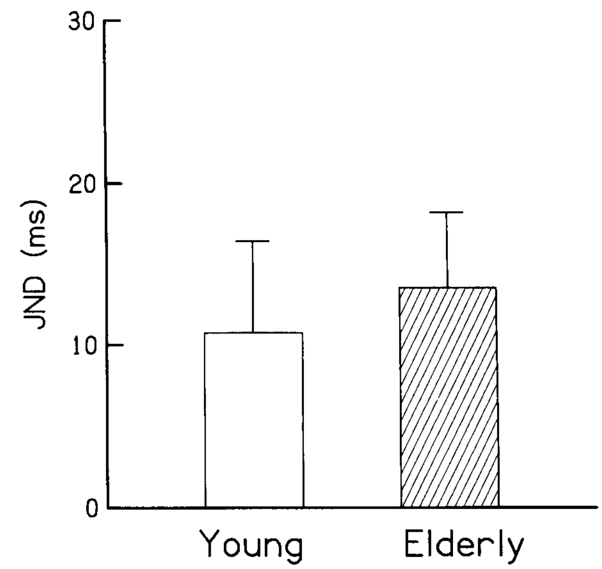

Figure 2 Mean just-noticeable differences (JNDs) and standard deviations of the two subject groups on the duration DL task.

A significant interaction between age and delay time was found ($F = 3.65$, $p < .05$). A test of simple main effects found that young and elderly subjects performed essentially the same at 240 and 720 msec, but that the young subjects performed significantly better in the 80-msec delay condition ($F = 6.04$, $p < .05$). Elderly subjects showed improved performance at 240 and 720 msec compared to the 80 msec condition ($F = 12.92$, $p < .01$), but young subjects had no significant differences in performance across delay conditions. Neither group achieved the

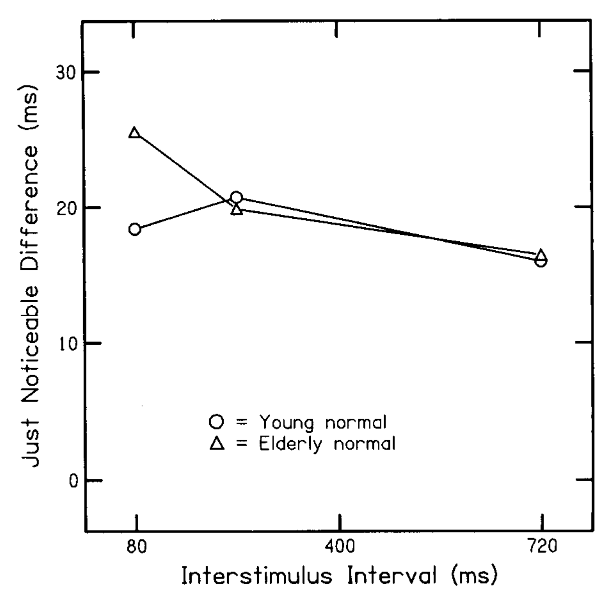

Figure 3 Mean JNDs of the two subject groups for the three delay conditions in the duration discrimination backward interference task.

duration discrimination performance observed without interference (results for experiment I), even at the longest delay time.

DISCUSSION

The duration discrimination results for the young listeners with normal hearing in experiment I showed discrimination thresholds of approximately 10 msec, which are comparable to those found by other investigators (Small and Campbell, 1962; Abel, 1971). Moreover, the results of experiment I indicate that elderly listeners are as capable as younger listeners in the discrimination of brief tone durations. These results are in agreement with the results of Humes and Christopherson (1991), although they used hearing-impaired subjects and longer standard tone durations. Thus, in simple psychoacoustic measures of duration discrimination without interference or increased stimulus complexity, elderly listeners with normal hearing perform comparably to younger listeners.

The results of experiment II show that when brief tones are followed closely by an interfering stimulus, duration discrimination abilities in older subjects are poorer than those of younger subjects. By 240 msec, however, the abilities of younger and older subjects are not significantly different. These findings differ from the results of backward interference studies for frequency identification. Newman and Spitzer (1983), using a percent correct performance measure, found peak performance for elderly subjects at a delay time of 360 msec, while peak performance for younger subjects occurred at 248 msec. Raz et al (1990) found that the elderly subjects showed decreased performance when compared with the young subjects at all delay times from 10 msec to 320 msec. Both age groups improved with increased delay time, but the younger group showed faster improvement than the elderly group. The elderly subjects also showed decreased performance when the interfering tone differed from the target in frequency as compared to a similar target and interfering tone.

The present study showed that elderly subjects did not perform differently from young subjects on duration discrimination at the longer delay times shown to elicit age effects for frequency identification. Raz et al (1990) suggested that age differences in mnemonic abilities may account for the interference shown at longer delay times for frequency identification. The results of the present study, however, suggest that elderly listeners do not have a deficit in the ability to hold durational characteristics in memory. It is also possible that the 2IFC paradigm used by Raz et al (1990) caused subjects to use a labelling strategy (high versus low), which would use higher, or at least different, cognitive processing than the same/different task utilized in this study for duration discrimination.

The differential age effects of backward interference for auditory duration discrimination are comparable to those observed for visual processing tasks. For example, Walsh (1976) observed that older subjects showed a prolonged susceptibility to the disruptive effects of a patterned line-segment mask. Older subjects required an average ISI of 151 msec to be released from the visual mask, compared to an ISI of 122 msec for masking release for the younger subjects. The fact that the time course of perceptual processing as measured by the backward interference paradigm demonstrates comparable age effects across sensory modalities confirms that this measure assesses some aspect of central processing mechanisms.

In summary, elderly listeners are as capable as young listeners in the discrimination of duration for brief tones, but when brief tones are followed closely by interfering stimuli, the performance of elderly listeners decreases when compared to that of younger listeners. These results imply that the ability of the elderly auditory system to process duration information is decreased when interfering stimuli are in close temporal proximity to the signal. The findings add support to the notion that there is a slowed processing of the durational characteristics of acoustic signals in older listeners and that these age effects are revealed on tasks that increase the complexity of the stimulus paradigm. The practical implication of these findings is that elderly listeners may be at a disadvantage when discriminating durational changes in complex, rapidly fluctuating acoustic waveforms that comprise everyday conversational speech.

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