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Auditory Temporal Order Perception in Younger and Older Adults

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This investigation examined the abilities of younger and older listeners to discriminate and identify temporal order of sounds presented in tonal sequences. It was hypothesized that older listeners would exhibit greater difficulty than younger listeners on both temporal processing tasks, particularly for complex stimulus patterns. It was also anticipated that tone order discrimination would be easier than tone order identification for all listeners. Listeners were younger and older adults with either normal hearing or mild-to-moderate sensorineural hearing losses. Stimuli were temporally contiguous three-tone sequences within a 1/3 octave frequency range centered at 4000 Hz. For the discrimination task, listeners discerned differences between standard and comparison stimulus sequences that varied in tonal temporal order. For the identification task, listeners identified tone order of a single sequence using labels of relative pitch. Older listeners performed more poorly than younger listeners on the discrimination task for the more complex pitch patterns and on the identification task for faster stimulus presentation rates. The results also showed that order discrimination is easier than order identification for all listeners. The effects of hearing loss on the ordering tasks were minimal.

KEY WORDS: auditory temporal processing, temporal order discrimination, temporal order identification, age-related processes

This study examines age-related changes in auditory sequential processing in younger and older adults with and without sensorineural hearing loss. Although hearing loss among the elderly population is well documented (Gates, Cooper, Kannel, & Miller 1990; Pearson, Morrell, Gordon-Salant, Brant, & Fozard, 1995), other consequences of aging on perceptual processing of supra-threshold sounds are less well understood. Several recent reports implicate various aspects of temporal processing as being diminished in a number of older listeners. Some of the evidence comes from studies that used temporally altered speech stimuli to compare the recognition performance of young and elderly listeners (Bergman et al., 1976; Gordon-Salant & Fitzgibbons, 1993). Other results come from psychoacoustic experiments with simple stimuli that report age-related differences in temporal gap detection (Moore, Peters, & Glasberg, 1992; Schneider, Pichora-Fuller, Kowalchuk, & Lamb, 1994; Snell, 1997) and duration discrimination (Abel, Krever, & Alberti, 1990; Fitzgibbons & Gordon-Salant, 1994). Some of these results also indicate that age-related deficits in temporal processing may become exaggerated for listening conditions that feature a high degree of stimulus complexity or experimental uncertainty (Fitzgibbons & Gordon-Salant,

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1995). Generally, the psychoacoustic temporal measures show little correlation with audibility factors associated with age-related hearing loss.

The present investigation extends the study of aging and temporal processing to listening tasks that focus on the perception of auditory sequences. The principal experiments use tone sequences and compare the abilities of younger and older listeners to discriminate and identify the temporal order of components within the auditory patterns. The rationale for the experiments is twofold. First, sensitivity to temporal sequencing is a basic aspect of auditory processing that is essential for perceiving a variety of complex time-varying signals, such as speech or music. Second, most of the prevalent theorizing about slowed perceptual processing among the elderly population ascribes the primary difficulties to central and cognitive stages of information processing (Cerella, 1991; Hawkins & Pressen, 1986; Salthouse, 1985). Accurate perception and recall of the temporal order of sounds presented in sequence undoubtedly involves the contribution of various central processing mechanisms that may undergo changes with aging.

There is some evidence that elderly listeners do exhibit significant difficulty with temporal order perception. Trainor and Trehub (1989) compared the performance of younger and older adults on a series of temporal order recognition and discrimination tasks. Listeners were required to distinguish between two contrasting component orders within four-tone sequences of alternating higher and lower frequencies in the region below 1000 Hz. The experiments examined several variables, including stimulus presentation mode (single or recycled patterns), presentation rate, component frequency spacings, and listener practice. The study was designed to examine the disruptive effects of perceptual organization, or auditory stream segregation (Bregman & Campbell, 1971), on temporal ordering performance. It was reasoned that older listeners, with hypothesized slower processing abilities (Salthouse, 1985), might experience perceptual streaming phenomena at lower stimulus rates than would be evident for the younger listeners. Results indicated that the temporal ordering judgments of the older listeners were significantly poorer than those of the younger listeners in each experiment. However, the magnitude of the age-related performance differences appeared to be largely independent of the task (discrimination vs. identification), amount of practice, or the stimulus presentation rate.

Humes and Christopherson (1991) also reported findings indicating that temporal sequencing tasks may be particularly difficult for older listeners. Their study examined various auditory processing abilities in younger and older groups of listeners using the Test of Basic Auditory Capabilities (TBAC), a battery of forced-choice discrimination tasks (Johnson, Watson, & Jensen, 1987). Two of the tests required temporal order judgments, one using four-tone sequences, and the other four-syllable sequences consisting of different consonant-vowel tokens. Each task required listeners to distinguish between standard and comparison sequences that differed by the temporal ordering of the two middle components; presentation rate of sequences was varied within a block of listening trials. Performance of the older listeners on both ordering tasks was significantly poorer than that of the younger listeners, with no apparent influence of audibility factors related to hearing loss.

These few available results indicate the likelihood of an age-related difficulty with sequence perception, although the magnitude and source of the processing deficit are difficult to assess. Thus, for the older listener, it remains unclear whether diminished temporal ordering ability reflects slowed auditory processing or a more general dysfunction in sequential pattern recognition and recall. One purpose of the present investigation is to derive estimates of the minimum stimulus durations that are required by listeners to discriminate tone-order differences within sequences. Observation of significant age-related differences in the measured duration thresholds would give some indication of the extent to which processing speed differs across age groups. Also, it is of interest to know if measured duration thresholds are stable or vary with changes in stimulus attributes. This question was addressed by designing discrimination conditions that featured varying degrees of stimulus complexity and predictability. It was hypothesized that increases in stimulus complexity would have a relatively greater impact on the order discrimination performance of older listeners than on that of younger listeners. This outcome is suggested by previous results showing strong influences of stimulus complexity on duration discrimination performance of older listeners (Fitzgibbons & Gordon-Salant, 1995).

The stimulus sequences used in the order discrimination experiments were also used in a temporal order identification task. One purpose of these measurements was to compare the stimulus durations required for order identification with those required for accurate order discrimination. Additionally, differences in the relative difficulty of the discrimination and identification tasks may have different consequences for ordering judgments of younger and older listeners. Another purpose of the order identification task is to explore possible explanations for age-related performance differences. For example, if the older listeners exhibited a general cognitive difficulty with sequential pattern recognition and recall, then performance deficits for these listeners should be evident across a broad range of stimulus sequence presentation rates. Alternatively, if the age effects are primarily a consequence of slowed auditory processing, then performance differences among the younger and older listeners should be restricted to conditions in which stimulus presentation rates exceed some limiting value. Finally, each experiment is designed to examine the independent and interactive influences of age and sensorineural hearing loss on sequential processing. Toward this goal, performance was compared for four groups of listeners who were matched according to age and degree of hearing loss. Also, the spectral composition of all stimulus sequences was restricted to a narrow region centered at 4000 Hz that coincided with a region of maximal sensitivity loss in the listeners with hearing impairment.

Method

Participants

Listeners in the experiments included 40 adults assigned to four groups with 10 participants each, defined according to age and hearing status. These individuals participated in a larger project that included speech experiments, the results of which are reported elsewhere (Gordon-Salant & Fitzgibbons, 1997). The first group included elderly listeners (65–76 years) with normal hearing (pure tone thresholds ≤ 15 dB HL, re: ANSI, 1989, 250–4000 Hz) (Group label = ENH). The second group consisted of young listeners (20–40 years) with normal hearing (pure tone thresholds ≤ 15 dB HL, re: ANSI, 1989, 250–4000 Hz) (Group label = YNH). The third group included elderly listeners (65–76 years) with mild-to-moderate, sloping sensorineural hearing losses (Group label = EHL). These individuals had a negative history for otologic disease, noise exposure, familial hearing loss, and ototoxicity. The presumed etiology of hearing loss for these listeners was presbycusis. Participants in the fourth group were young adults (18–44 years) with sensorineural hearing loss (Group label = YHL). Each listener in this group was matched audiologically on an individual basis to a listener in the EHL group. The etiology of the hearing losses of the younger listeners was either heredity or unknown. Audiometric data for the four subject groups are displayed in Table 1. Immittance measures for all participants showed tympanograms with normal peak pressure (–50 to +50 daPa), normal acoustic admittance at the plane of the tympanic membrane (0.3–1.4 mmho), normal equivalent volume (0.6–1.5 cm^3), and normal tympanometric widths (50–110 daPa) (American Speech-Language-Hearing Association, 1990); acoustic reflexes were elicited at levels of 100 dB HL or lower in each ear. These immittance results are consistent with the presence of normal middle-ear function. Additionally, each participant exhibited good general health and passed the Short Portable Mental Status Questionnaire (Pfeiffer, 1975), a screening procedure for cognitive function.

Stimuli

All stimuli for the experiments were sequences of three pure tones generated using inverse Fast Fourier Transform (FFT) procedures with a digital signal processing board (Tucker-Davis Technologies AP2) and a 16-bit digital-to-analog (D/A) converter (Tucker-Davis Technologies DD1, 20 kHz sampling rate) that was followed by low-pass filtering (Frequency Devices 901F; 6000 Hz cutoff, 90 dB/oct). The tone frequencies for all sequences spanned a 1/3 octave range and were arbitrarily designated as low (L), 3548 Hz; medium (M), 4000 Hz; and high (H), 4467 Hz. The tones within sequences were equal in duration and were presented contiguously in time with each component having a 1-ms cosine-squared rise/fall envelope. Tonal duration was varied adaptively as an independent variable in the experiments, and changes of duration were implemented equally and simultaneously on all tonal components within sequences.

Table 1. Mean pure tone thresholds (and standard deviations) in dB HL (re ANSI, 1989) of the four groups (YNH = young listeners with normal hearing, ENH = elderly listeners with normal hearing, YHL = young listeners with hearing loss, EHL = elderly listeners with hearing loss).

Frequency (Hz)	Participant Group			
	YNH	ENH	YHL	EHL
250	3.9 (3.3)	11.0 (4.6)	21.0 (17.6)	20.0 (12.0)
500	2.2 (2.6)	8.5 (6.3)	20.5 (17.9)	21.0 (12.9)
1000	2.2 (2.6)	7.5 (6.3)	30.0 (21.3)	23.0 (10.0)
2000	0.0 (2.5)	8.0 (6.7)	39.5 (20.2)	33.0 (13.8)
4000	2.2 (2.6)	12.5 (4.9)	51.0 (14.7)	51.0 (8.4)

Note. From "Selected Cognitive Factors and Speech Recognition Performance Among Young and Elderly Listeners," by S. Gordon-Salant and P. J. Fitzgibbons, 1997, *Journal of Speech, Language, and Hearing Research*, *40*, p. 425. Copyright 1997 by American Speech-Language-Hearing Association. Reprinted with permission.

Three stimulus conditions were used to examine discrimination of tonal temporal order differences. One of these used tone sequences with unidirectional frequency shifts (UNI condition), with the rising sequence LMH and the falling sequence HML serving as the standard and comparison stimuli, respectively, for discrimination trials. A second discrimination condition utilized stimulus sequences containing bidirectional frequency shifts (BI condition), with MHL and HLM used as the respective standard and comparison sequences. For the third discrimination condition, the random (RAN) condition, stimulus sequences changed each trial, with the standard and comparison sequences of a given trial representing different random selections from the pool of six possible tone-order permutations (LMH, LHM, MHL, MLH, HML, HLM). The three discrimination conditions were selected to reflect different degrees of stimulus complexity, with those featuring unidirectional frequency shifts being intended as the least complex, and those with randomly changing frequency patterns the most complex.

Stimulus sequences used for the temporal order identification task were the same randomly ordered tonal patterns as described above for the RAN discrimination condition. However, for identification testing, sequence component durations were fixed within a block of listening trials and were varied across trial blocks.

Procedures

Temporal Order Discrimination

Temporal order discrimination was measured using adaptive three-interval cued two-alternative forced-choice procedures. For all discrimination conditions, each listening trial included three observation intervals with the standard tone sequence always presented in the first interval; the comparison sequence appeared with equal probability in the second or third interval on each trial, with the remaining interval containing a replication of the standard sequence. Listeners used a keyboard to indicate which interval, 2 or 3, sounded different from interval 1. The intervals of a trial were separated by 500 ms and were marked by a visual display on a computer monitor that also provided feedback on the correctness of response.

Temporal thresholds for the discrimination trials were obtained using an adaptive rule for changing the duration of each tonal component in the standard and comparison sequences on the basis of the listener's response on previous trials. The rule stipulated a decrease in tone durations following two correct-response trials and an increase in durations after each incorrect response. The tracking procedure estimated a threshold duration corresponding to 70.7% correct discrimination (Levitt, 1971). Testing was conducted in 65-trial blocks with initial tone durations of 250 ms and an initial step size for duration changes of 15 ms that was reduced to 2 ms after three reversals in the direction of duration changes. A threshold estimate was calculated by averaging duration values of the reversal points of the final 10 reversals associated with the small step-size changes in the tracking procedure. An average of six separate threshold estimates was used to determine a final estimate for each listener and discrimination condition, with the conditions tested in a different randomly selected order for each listener. Additionally, each listener received 2–3 hrs of practice in each condition before data collection. Although no formal analysis of practice data was undertaken, discrimination performance of listeners in each group showed no systematic improvement after six to eight trial blocks.

Temporal Order Identification

Procedures for the temporal order identification task were implemented subsequent to completion of discrimination testing. The identification trials were single interval, in which one stimulus sequence was presented with a tone order selected randomly from six possible permutations of the three tone frequencies. Using procedures adapted from Divenyi and Hirsh (1974), listeners identified the stimulus sequence for each trial by keyboard response, selecting one of six keys (each labeled with a different sequence frequency order: HML, HLM, MHL, MLH, LMH, LHM); a simple line drawing above each response key was also provided as a visual aid to depict the pitch-shift directions associated with each sequence ordering. The identification trials were listener paced, with a 3-s inter-trial interval following each listener response; and the stimulus presentation interval was marked by visual display on a computer monitor. Percent-correct feedback was provided to listeners following each block of identification trials, but not for individual trials.

There were four order-identification conditions defined by the sequence component tone durations of 750 ms, 500 ms, 250 ms, and 100 ms. The conditions were tested separately in a different randomly selected order across listeners. Each condition was examined using 50-trial blocks, with tone durations fixed within blocks. The results from four trial blocks per condition were averaged to calculate a performance score for each listener. Before data collection, each listener was familiarized and trained with the identification task. Listeners practiced for 6–10 hrs in 2-hr sessions that included 10–12 trial blocks per session using tonal sequences that featured 1-s component durations.

The listeners were tested individually in a sound-attenuating chamber. Stimulus sequences for the discrimination and identification tasks were presented at

85 dB SPL, which corresponded to a minimum sensation level of 25–30 dB at 4000 Hz for the listeners with high-frequency hearing loss. The stimuli were delivered to listeners through an insert earphone (Etymotic ER-3A) calibrated in a 2-cm^3 coupler (B&K, DB0138). The transducer was selected for listener comfort and to avoid possible collapsing of ear canals, particularly in the older listeners. Testing was monaural in the better ear of listeners with hearing loss and in the preferred ear of listeners with normal hearing. Excluding practice sessions, total time for data collection was about 10 hrs, scheduled in 2-hr sessions. Participants were reimbursed for their participation in the experiments.

Results

Temporal Order Discrimination

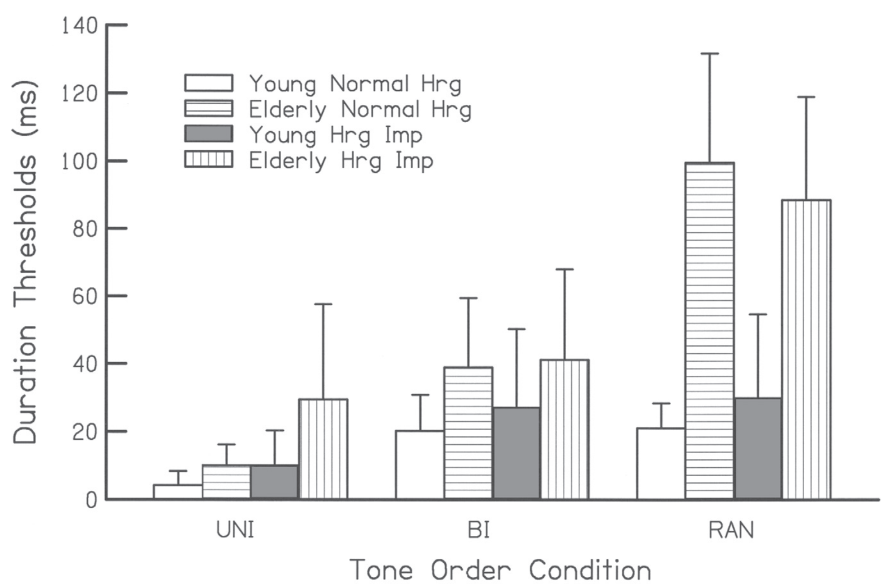
Results of the temporal order discrimination experiments are displayed in Figure 1. The figure shows the mean tonal duration thresholds and standard deviations for each group of listeners for the three discrimination conditions: UNI, BI, and RAN. An analysis of variance (ANOVA) was performed on the raw data using a repeated-measures design with 2 between-subjects factors (age and hearing status) and 1 within-subjects factor (discrimination condition). The analysis revealed significant main effects of listener age [$F(1, 36) = 43.00$, $p < .01$], discrimination condition [$F(2, 72) = 71.84$, $p < .01$], and a significant interaction between these two factors [$F(2, 72) = 32.29$, $p < .01$]. The main effect of hearing loss on discrimination thresholds was not significant [$F(1, 36) = 1.15$, $p = .29$]. The hearing loss factor was also not involved in any significant interactions.

Subsequent analysis of simple main effects revealed that the thresholds of older listeners were significantly larger than those of the younger listeners for the complex conditions BI and RAN [$F(1, 108) = 5.91$, $p < .01$; $F(1, 108) = 12.41$, $p < .001$, respectively], but not for the UNI condition [$F(1, 108) = 3.48$, $p = .065$]. Simple main-effects analyses also showed that the effect of condition was significant for both younger and older listeners [$F(2, 72) = 4.80$, $p < .01$; $F(2, 72) = 81.49$, $p < .001$, respectively]. Multiple comparison testing (Student-Newman-Keuls) further indicated that the young listeners performed best on the UNI condition and significantly poorer but equivalently on the two more complex conditions BI and RAN ($p < .05$). The older listeners also performed best on the UNI condition and significantly poorer on the BI and RAN conditions ($p < .05$), but there was a further significant performance decrement on the RAN condition compared to the BI condition ($p < .05$).

Temporal Order Identification

The temporal order identification task proved to be quite difficult for many of the listeners. Despite the slow presentation rate for training sequences (1-s component durations) and the extent of listening practice, 3 listeners from each of the younger groups and 4 listeners from each of the older groups failed to achieve consistent, above-chance identification performance (16.7% correct

Figure 1. Mean tonal duration thresholds and standard deviations, obtained from the four listener groups in the three temporal order discrimination conditions (UNI = unidirectional pitch change, BI = bi-directional pitch change, RAN = random pitch change).

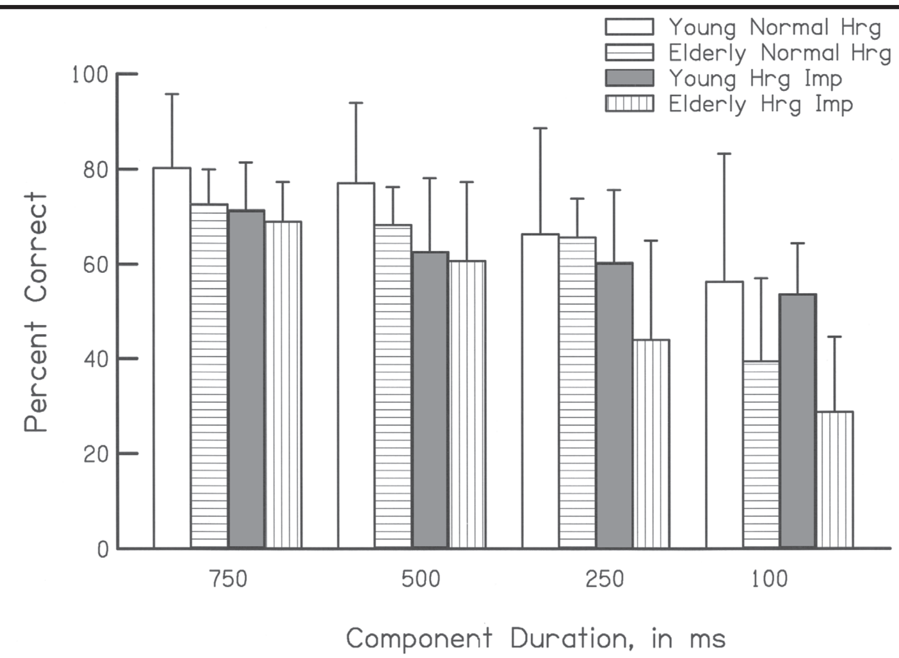


for the six-choice task). For these listeners, the problem appeared to be specific to difficulties in labeling sequence orders according to relative pitch change; pilot trials using tonal sequences with greater component frequency spacing (e.g., 1 octave) proved equally difficult. Therefore, these listeners were excluded from further testing, and participation in the identification conditions was restricted to those listeners who achieved a performance accuracy of 90% or better on the training trials. Results of the temporal order identification measurements are displayed in Figure 2. The figure shows the mean percent-correct scores and standard deviations from the four stimulus duration conditions for the groups of younger (n = 7 each) and older (n = 6 each) listeners. An ANOVA was performed on arcsine transforms of the raw percent-correct data (Kirk, 1968), using a repeated-measures design with 2 between-subjects factors (age and hearing status) and 1 within-subjects factor (duration condition). Results of this analysis revealed a significant main effect of condition [$F(3, 66) = 56.94, p < .001$] and a significant three-way interaction of the factors age, hearing status, and duration condition [$F(3, 66) = 3.88, p < .01$]. The main effects of age and hearing failed to reach significance [$F(1, 22) = 2.63, p = .12$; $F(1, 22) = 2.27, p = .146$, respectively]. Subsequent analyses of simple main effects revealed a significant condition effect for each listener group [$F(3, 72) > 4.89, p < .01$ for all four groups], which multiple-comparison testing confirmed resulted from a progressive decline in performance between almost all successive conditions of decreasing tonal duration for each of the four listener groups ($p < .05$). Age effects were restricted to the most difficult condition (100-ms durations), on which older listeners generally performed poorer than younger listeners; this difference, however, reached significance only for the groups of younger and older listeners with hearing loss [$F(3, 72) = 5.84, p < .001$]. With one exception, effects of hearing loss were not apparent in the data. The exception was for older listeners in the 250-ms condition, where listeners with hearing loss performed significantly poorer than those with normal hearing ($p < .05$).

Relationships Between Measures

Because identification performance is presumably dependent upon a listener's ability to discriminate relevant stimuli, a correlation analysis was conducted to determine the extent to which discrimination ability is related to recognition performance for tone sequences with equivalent complexity and durations. For the purposes of this comparison, discrimination performance on the RAN condition was compared to identification performance, with the random sequences featuring 100-ms tones. Durations of this magnitude equaled or exceeded those required for accurate performance in the discrimination task for each listener group. The listeners' pure tone thresholds at 4000 Hz were also included in the correlational analysis to examine the extent to which auditory acuity influenced discrimination thresholds and identification performance for stimuli in this frequency region. A significant correlation was observed between duration thresholds for order discrimination

Figure 2. Mean percent correct scores and standard deviations from the four listener groups in four stimulus duration conditions (750 ms, 500 ms, 250 ms, 100 ms).



and the percent-correct order identification scores (r = –.54, $p < .01$). Correlations between the pure tone threshold at 4000 Hz and either the discrimination threshold (r = .22) or the identification score (r = –.20) were not significant.

Discussion

The experiments were designed to examine age-related differences in sequential processing by assessing temporal order perception within the context of discrimination and identification tasks. Evidence for age-related differences in temporal order perception emerge in many of the performance measures collected. However, the observed age effects in the data differ somewhat across tasks. The presence of hearing loss did not affect performance for either younger or older listeners. Additionally, the tasks of order discrimination and identification appear to reflect different levels of difficulty for all of the listeners.

The discrimination results reveal the clearest effects of both listener age and stimulus complexity. Stimulus sequence orders featuring rising and falling frequency patterns in the UNI condition proved to be easiest to discriminate for all listeners. For this condition, the young listeners with and without hearing loss produced a mean duration threshold of 7.2 ms, with several individual estimates observed to be as small as 2–3 ms. For these same listeners, discrimination performance was poorer and equivalent for the more complex frequency patterns of the BI and RAN conditions, with thresholds showing values of 23.7 ms and 25.5 ms, respectively. The older listeners produced a mean duration threshold of 19.8 ms for the UNI condition. However, this value was largely inflated by poor performance of a few older listeners; most others produced threshold estimates comparable to those of the younger listeners. The results were quite different for BI and RAN conditions, in which the older listeners required mean tone durations of 40.1 ms and 94.2 ms, respectively, to discriminate order differences. Each of these values reflects significantly diminished performance relative to that of the younger listeners.

The discrimination results also reveal that some tonal patterns are considerably easier to distinguish than others. This is particularly true for the UNI condition, in which the observed duration thresholds for the majority of younger and older listeners closely approximated reported estimates for auditory temporal acuity (Green, 1971). At these brief durations the rising/falling patterns of the UNI condition are perceived as singular spectral glides, rather than a succession of three tones. However, listeners could still perform the discrimination on the basis of frequency differences between the initial and/or final tones in the standard and comparison sequences of a listening trial. These frequency-difference cues were also available, though less salient, in the BI condition; and they varied in an unpredictable manner in the RAN condition. For these latter two conditions, threshold durations were sufficient to hear tones in succession, and the younger listeners discriminated order differences equally well on both. The much larger duration thresholds of older listeners for BI and RAN conditions are suggestive of both slower processing and a strong influence of stimulus complexity and/or uncertainty.

As stated previously, the temporal order identification task proved to be difficult for all listeners, and several listeners from each of the younger and older groups were not able to perform the task. Of those who met the criterion of 90% accuracy in the training session with 1-s component durations, identification accuracy was observed to decrease progressively from about 75% to 60% across conditions of decreasing tonal durations (from 750 ms to 250 ms). Across this range of tonal durations and/or sequence presentation rates, younger and older listeners performed essentially the same. For the 100-ms condition, age-related performance differences did emerge, with order recognition of the younger listeners showing an accuracy of 55% compared to 34% for the older listeners. However, inspection of the data from all listeners indicates that stimulus durations required for order identification are considerably larger than those required for order discrimination. Most of the listeners required sequence component durations of 250 ms or greater to achieve 60% recognition accuracy. This duration value is about an order of magnitude greater than that required for the young listeners to discriminate order differences with the same RAN sequences. For the elderly listeners, the differences between sequence durations required for identification and discrimination are much smaller, but this is due primarily to their elevated discrimination thresholds for the RAN condition.

It is not unusual in young listeners to observe large differences between component durations required for temporal order identification and discrimination, as revealed in several reviews of the relevant research literature (e.g., Divenyi & Hirsh, 1974; Pinheiro & Musiek, 1985; Warren, 1974). In particular, the duration thresholds associated with temporal order identification tasks can vary widely and depend on a large number of stimulus, procedural, and response factors. If, as in the present study, the identification task requires listeners to name or attach labels to individual components within stimulus sequences, then component durations of 150–500 ms are observed as necessary for moderately trained listeners to achieve accurate ordering performance (Warren, 1974). This range of values is consistent with present results collected from both younger and older listeners in the order identification task.

It is interesting to note that Divenyi and Hirsh (1974) used a procedure similar to the present identification task and observed that young listeners could be trained to identify order within three-tone sequences for component durations of 10 ms or less, depending on the pattern. Their results, however, were collected from a small sample of young adults with musical training who received extensive daily practice on the identification task over the course of many weeks. Divenyi and Hirsh also reported that their listeners were ultimately trained to identify permutations of tone order by discriminating variations in spectral patterns without the need to hear individual tones in succession. Therefore, it is perhaps not surprising that their threshold data for temporal order identification are similar in magnitude to those observed in the present order discrimination task, for the young listeners with normal hearing.

As mentioned above, Trainor and Trehub (1989) observed significant age effects in their temporal ordering tasks, although the magnitude of these effects was similar for order discrimination and identification tasks and were largely independent of changes in stimulus presentation rate. These results suggested that older listeners may exhibit a general difficulty in sequential pattern perception that is not strictly the result of processing speed deficits. It is possible, however, that the lack of strong task and stimulus rate effects in the Trainor and Trehub study may be due in part to the experimental procedures employed. Both the order identification and discrimination tasks that were utilized required listeners to distinguish between two alternatives of a four-tone sequence that differed only by the temporal ordering of two tonal components. Thus, the processing demands associated with each task featured a higher degree of similarity than required for the discrimination and identification tasks of the present study. Additionally, for each ordering task of Trainor and Trehub, stimulus presentation rate was varied randomly among eight values within each block of listening trials. This high level of stimulus uncertainty could have depressed overall listener performance and also have obscured observation of systematic stimulus rate effects. Thus, although the age effects observed by Trainor and Trehub are significant, the source of diminished performance with the older listeners is unclear.

Results of the present experiments indicate that age-related deficits in temporal processing are likely to depend on both stimulus complexity and processing speed. For the order discrimination task, no age effects were apparent for simple rising/falling tone orders, but significant age-related performance decrements existed for the more complex frequency patterns. For temporal order identification there was little or no age effect at the slower sequence presentation rates, although age-related performance differences did emerge at the fastest sequence rate examined. These identification results implicate a processing speed deficit in the older listeners rather than a general cognitive difficulty with serial pattern recognition. Additionally, the longer duration thresholds of the older listeners required for temporal order discrimination also could be interpreted as evidence for slowed processing. However, stimulus attributes play an important role. It seems possible that factors associated with stimulus complexity and stimulus rate interact in unknown ways to promote an information-processing-rate limitation in the older listeners. This limitation in information rate may account for various results from different studies indicating age-related performance deficits on tasks involving sequential processing.

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