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Age effects in discrimination of intervals within accented tone sequences differing in accent type and sequence presentation rate

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The study measured listener sensitivity to increments in the duration of one or two target silent intervals embedded within unaccented tone sequences and sequences that featured a single accented component. The baseline unaccented sequences consisted of six 1000-Hz 40-ms tone bursts that were separated equally by silent intervals to establish a slower tone sequence rate, with tonal inter-onset intervals (IOIs) set to 200 ms, or a faster rate with tonal IOIs set to 100 ms. Stimulus accent was created by doubling the baseline duration of a single sequence component, either the second tone burst (tonal accent), or the second tonal IOI (interval accent). Duration difference limens for increments of the target interval(s) were measured adaptively by varying a single inter-tone silent interval or co-varying two successive inter-tone silent intervals; target intervals occurred at the third, or third and fourth, sequence locations. Listeners included younger normal-hearing adults and groups of older listeners with and without hearing loss. Discrimination for the two older groups was equivalent and poorer than that of the younger listeners, especially for the faster accented sequences. Discrimination was best for stimuli with two successive target intervals, indicating that target repetition within accented sequences acts to improve listener temporal sensitivity.
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[VB] Pages: 3819–3826

I. INTRODUCTION

The present study investigates some effects of component accent and rhythmic variation within tonal stimulus sequences on temporal sensitivity in younger and older listeners. A specific goal of the study is to examine the extent to which the listeners are affected in their response to different sources of component accent while processing temporal cues embedded within stimulus sequences. It is reasonably well known from psychophysical detection and discrimination studies that older listeners frequently exhibit performance deficits in various temporal processing tasks conducted with simple sound stimuli (Schneider *et al.*, 1994; Snell, 1997). As an example, older listeners are observed to show diminished temporal sensitivity to changes in the duration of simple sounds, whether the sounds are presented in isolation or embedded as target components within longer context sequences (Fitzgibbons and Gordon-Salant, 1995). Sensitivity to duration cues is equally important for accurate speech processing, with vowel and silent-interval durations being examples of important temporal cues underlying listener recognition of certain phoneme attributes. Additionally, for longer stimulus sequences, speech or non-speech, segment durations and temporal spacings play an important role in defining stress or accent patterns, as well as the rhythmic and rate characteristics of the sequences as a whole. Although less well studied, these more global properties of stimulus sequences could be additional sources of processing difficulty for many older listeners.

For speech, however, little of the research emphasis has centered specifically on investigations of stress and timing characteristics of sequences that could influence the processing of older listeners. This situation is due in part to the acoustic complexity of natural speech, rendering it difficult to control the stimulus variables of research interest. It is possible, however, to investigate some of these overall sequence characteristics using simpler non-speech auditory sequences that permit a greater degree of experimental control. For example, some findings from an earlier psychophysical study of sequential processing with tone sequences revealed that older listeners exhibit large changes in processing accuracy depending on the rhythmic properties of the stimulus sequence (Fitzgibbons and Gordon-Salant, 1995). That study used sentence-length sequences of tones differing in pitch and found that older listeners had more difficulty discriminating changes in the duration of a single embedded tonal component than did younger listeners. The younger listeners in that study invariably reported that overall rhythmic alterations in the stimulus sequences, induced by the changes of tonal duration, served as a primary discrimination cue regardless of the sequence location of the embedded tonal component. By comparison, older listeners in the experiment appeared less able to make use of the same overall rhythmic changes to enhance their overall sequence discrimination performance.

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A more recent investigation revealed that even simple changes to accent patterns within an auditory sequence could alter measures of temporal sensitivity in a group of older listeners (Fitzgibbons and Gordon-Salant, 2010). This study used sequences of six brief tone bursts separated equally by silent intervals to form isochronous patterns with overall durations that approximated those of short speech sentences. Within the sequences the tone bursts were equal in frequency and duration, except that in some patterns the duration of one tonal component was doubled to produce a perception of component stress, or accent, within the sequence. The lengthening of the accented tonal component was implemented to be consistent with the relative degree of increase in duration observed for stressed syllables in spoken English (Fant *et al.*, 1991). With the accented sequences, younger and older listeners in the study were asked to discriminate changes in the duration of a single targeted inter-tone silent interval located at different sequence positions. The discrimination results were then compared to corresponding measures collected with unaccented control sequences that lacked the elongated tonal component. Results collected from the younger listeners revealed relatively small effects of tonal accent on interval discrimination, with little or no influence of either the sequence position of the accented tonal component, or the target interval. By comparison, the older listeners in the study exhibited poorer discrimination than younger listeners, and also showed significant discrimination deficits in sequences that featured an accent compared to corresponding conditions with no accent. For older listeners, it was anticipated that the effects of accent, if any, would be observed for target intervals located at, or adjacent to, the sequence position of the accented component. Instead, the results showed that the simple presence of accent within sequences, independent of location, influenced temporal sensitivity for the target interval at several distributed sequence locations, independent of proximity to the accented component. It became evident that, despite the uniformity of timing within the stimulus sequences, the longer accented component introduced a degree of perceived rhythmic variation within the sequences that affected the discrimination performance of the older listeners. In this case, it appeared that the older listeners found it difficult to ignore rhythmic changes when attempting to process temporal cues associated with individual sequence components.

The above two psychophysical experiments utilized tonal stimulus patterns that featured isochronous timing, with rhythmic variation introduced by changes in the duration of a single tonal component. In each study, the discrimination performance of older listeners was found to be significantly poorer than that of younger listeners, although the underlying reasons for the age-related performance deficits appeared to differ in the two experiments. That is, in one task, the older listeners seemed unable to utilize available rhythmic cues to enhance their discrimination performance, while the other task revealed an apparent inability of older listeners to ignore rhythmic cues, when doing so could have improved their performance. Whether or not these particular outcomes were related to the timing characteristics of the stimulus sequences, or the manner of accent creation, are unknown. The present study addresses some of these questions by comparing the effects of tonal accents to those of interval accents, using tonal stimulus sequences that feature both regular and irregular timing of tonal onsets. A simple interval accent can be introduced within a uniformly timed tonal sequence by extending a single inter-tone silent interval to produce a brief pause that alters rhythmic characteristics by effectively disrupting the regularity of sequence timing. For these sequences, the extended pause interval is perceived by listeners as being stressed, or accented, in a manner similar to that of lengthening a tonal duration. Similar observations were made some time ago by Hirsh (1990) and Monahan and Hirsh (1990) in their initial studies of auditory timing with simple tonal patterns.

One goal of the present investigation was to determine if tonal accents and interval accents produce similar effects on temporal sensitivity among older listeners. Also, the currently available information concerning stimulus accent and listener temporal sensitivity is limited to the single sequence presentation rate examined in the earlier study (Fitzgibbons and Gordon-Salant, 2010). Therefore, another goal of the present investigation was to explore the potential interaction of stimulus accent and sequence presentation rate on age-related differences in temporal sensitivity. An additional question examined in the present investigation concerns the potential for younger and older listeners to benefit from repetition of a temporal cue within an accented stimulus sequence, as evidenced by improved discrimination performance. For example, it is generally observed with unaccented stimulus patterns that the repetition of a temporal cue within an isochronous sequence leads to improved cue discrimination performance in younger listeners (Drake and Botte, 1993; Miller and McAuley, 2005). This outcome has been explained previously by invoking multiple-look models derived from statistical decision theory (Green and Swets, 1988), which predict that discrimination performance for isochronous sequences with a given number (N) of target-interval repetitions should improve by the square root of N. However, it is presently not certain that similar benefits of cue repetition would be observed for discrimination performance of younger and older listeners when measured within the context of accented stimulus sequences. As a result, each discrimination condition of the present study will measure the effects of cue repetition on listener temporal sensitivity for both slower and faster sequence presentation rates.

II. METHOD

A. Participants

A total of 40 adults participated in the experiment. These individuals were assigned to three groups based on age and hearing status. Two of the groups had normal hearing, defined as pure tone thresholds $\leq$ 25 dB hearing level (HL) from 250 to 4000 Hz (re: ANSI, 2010). A young normal-hearing group (Yng Norm, n = 14) included individuals aged 18–27 years (mean = 20.9 years) and an older normal-hearing group (Older Norm, n = 13) included listeners aged 66–80 years (mean = 69.5 years). A third group, older hearing impaired (Older Hrg Imp, n = 13) included adults aged 65–80 years (mean = 71.8 years) with bilateral mild-to-moderate sloping high-frequency sensorineural hearing losses from 250–4000 Hz. Mean hearing thresholds in dB HL at the1000-Hz stimulus frequency for the respective listener groups were 3.1 dB (Yng Norm), 11.7 dB (Older Norm), and 24.6 dB (Older Hrg Imp). All listeners had a negative history of otologic disease, noise exposure, family history of hearing loss, and were native English speakers. The probable etiology of hearing loss in the older listeners is presbycusis.

Additional criteria for subject selection included monosyllable word recognition scores in quiet exceeding 80% (Northwestern University Auditory Test No. 6, Tillman and Carhart, 1966). The participants also exhibited tympanograms with peak admittance, pressure peaks, tympanometric width, and equivalent volume within normal values for adults (Roup *et al.*, 1998), and acoustic reflex thresholds that were within the 90th percentile for a given pure tone threshold (Gelfand *et al.*, 1990). These criteria were established to ensure that listeners with hearing loss had primarily a cochlear site of lesion, and that all listeners had normally functioning middle ear systems. The listeners were in general good health, with no history of stroke or neurological impairment, had at least a high-school education, and showed normal performance on a screening test of cognitive function (Short Portable Mental Status Questionnaire: Pfeiffer *et al.*, 1977). Additionally, each listener possessed sufficient motor skills to provide responses using a computer keyboard.

B. Stimuli

All tonal sequences for the experiment were generated using an inverse fast-Fourier transform (FFT) procedure with a digital signal processing board (Tucker-Davis Technologies, AP2) and a 16-bit D/A converter (DD1, 20-kHz sampling rate) that was followed by low-pass filtering (Frequency Devices 901F, 6000-Hz cutoff, 90 dB/octave). For control conditions of the study, unaccented isochronous sequences were constructed using six 1000-Hz tone bursts separated equally by silent intervals, with fixed tonal durations of 40 ms that included 5-ms cosine-squared rise/fall envelopes. The use of brief tone bursts of fixed frequency and duration in stimulus construction was implemented to minimize stimulus complexity in creating sound sequences that allowed for control of timing patterns in order to examine the effects of presentation rate on listener discrimination performance. For these control sequences, two presentation rates were established by adjusting the silent intervals between successive tones to achieve equal tonal inter-onset interval (IOI) values of 200 ms for the slower sequence rate, and values of 100 ms for the faster rate. Overall sequence durations for these slower and faster rates were 1040 and 540 ms, respectively.

The accented stimulus sequences were created by modifying a single component of the unaccented control sequences to produce a localized accent within the sequence. For sequences featuring a tonal accent, the second tone burst of the sequence was doubled in duration from 40 to 80 ms, with each of the other five tone bursts remaining fixed at their original durations of 40 ms. Elongation of the second tone burst was accompanied by an equivalent reduction of the following inter-tone silent interval, which effectively preserved overall sequence durations and the uniform tonal IOIs within sequences at their respective values for the faster and slower presentation rates. The doubling of duration for the elongated tone was sufficient to produce a perceived location of stress, or accent, within the sequence. In a similar manner, an interval accent was created within sequences by doubling the second tonal IOI of the unaccented sequences, from 200 to 400 ms for the slower rate sequences, and from 100 to 200 ms for the faster rate sequences. These changes in IOI were produced by increasing the second inter-tone silent interval, leaving the other sequence tonal IOIs, and all tonal durations, at their original values for the respective faster and slower sequence rates. Creation of the interval accents also produced corresponding increases of 200 and 100 ms, respectively, to overall sequence durations cited above, for slower and faster rate sequences. As with tone-burst elongation, interval elongation also produced a perception of localized emphasis, or accent, within the tonal sequences, a perception reported by all listeners participating in the study.

The unaccented and accented stimulus sequences were used in separate experimental conditions in which the listener's task was to discriminate changes in the duration of one or two of the non-accented sequence silent intervals, designated as target intervals, in order to measure duration difference limens (DLs). The designated target intervals were the third sequence IOI, or the third and fourth sequence IOIs for the discrimination conditions featuring one or two targets, respectively. Thus, for the accented stimulus patterns, the location of the target interval(s) always followed the location of the accented tone, or the accented interval. Figure 1 shows a schematic of the timing patterns for the stimuli that served as standard sequences in the discrimination conditions. Sequences in Fig. 1 depict the unaccented patterns with uniform timing of tonal onsets, the tone-accented sequences with uniform timing and elongated second tone, and the interval-accented sequences with elongated second interval and non-uniform timing; downward arrows in the figure indicate the sequence locations of the embedded target intervals, with one target depicted in sequences of the top row and two targets in sequences of the bottom row. For each discrimination condition, the duration of the target interval(s) within a sequence was varied adaptively across listening trials to measure a duration DL. Each of the six sequence conditions reflected in Fig. 1 were tested at both the slower and faster sequence rates, giving a total of 12 discrimination conditions for the experiment.

C. Procedure

The measurement of the duration DLs for the target IOIs in each of the 12 sequence discrimination conditions was obtained using an adaptive three-interval, two-alternative forced-choice procedure. Each discrimination trial contained three listening intervals spaced 750 ms apart. The first listening interval of each trial contained a sample of the

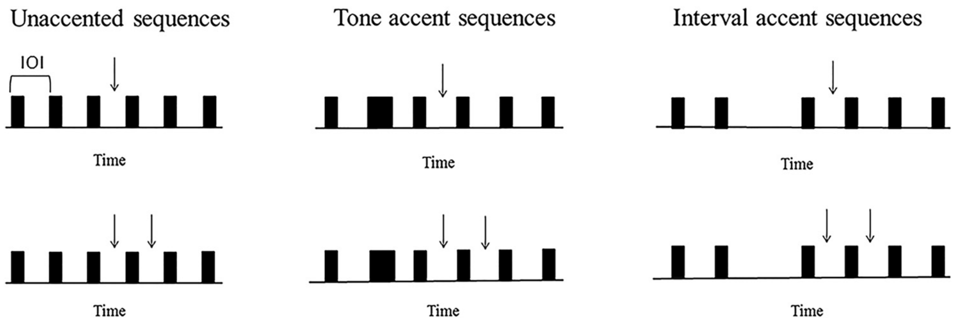

FIG. 1. Schematic diagram of three accent conditions with one target interval (top row) or two target intervals (bottom row), as designated by downward arrows in the figure.

standard tonal sequence, with the second and third listening intervals containing samples of the standard and comparison tone sequences in either order selected randomly across listening trials. In each condition, the standard and comparison sequences of a listening trial differed only by the duration of the target IOI, which was always longer in the comparison sequence. Within a block of listening trials, the sequence location of the target was always fixed as the third sequence IOI for sequences with one target, or fixed as the third and fourth sequence IOIs for sequences with two targets. On each trial, listeners used a keyboard to identify the comparison sequence in the second or third listening interval as being different from the standard sequence in the first interval. Each listening interval of a trial was marked by a visual display that also provided correct-response feedback for each trial.

Estimates of all duration DLs in ms were obtained using an adaptive rule for varying the target IOI(s) in the comparison sequences, such that the IOI(s) decreased in magnitude following two consecutive correct responses by the listener and increased in magnitude following each incorrect response. Changes in the target IOI(s) were accomplished by varying either a single silent interval between tones, or co-varying two successive silent intervals for sequence conditions featuring two targets; all tone burst durations remained fixed. Threshold estimates obtained by this adaptive rule corresponded to values associated with 70.7% correct discrimination (Levitt, 1971). Testing in each condition was conducted in 50-trial blocks with a starting value of the silent interval 1.5 times the reference value and a step size for interval change that decreased logarithmically over trials to produce rapid convergence on threshold values. Following the first three reversals in direction of interval change, a threshold estimate was calculated by averaging the reversal-point interval values associated with the remaining even-numbered reversals. An average of three threshold estimates was used to derive a final DL for each discrimination condition. Prior to data collection, each listener received approximately 1–2 h of practice for sequence discrimination, with all listeners showing performance stability after 3 or 4 trial blocks in each condition.

The listeners were tested individually in a sound-treated booth. The 12 discrimination conditions were tested in a different order for each listener. The sequence stimulus levels were fixed at 85 dB sound pressure level in order to insure adequate signal audibility for the listeners, including those with hearing loss, who exhibited relatively mild degrees of sensitivity losses in the 1000-Hz frequency region of the stimuli. All testing was monaural through an insert earphone (Etymotic ER-3A) that was calibrated in a 2-cm^3 coupler (DB0318). All listening was conducted in 2-h sessions over the course of several weeks. Total test time varied across listeners, but averaged about 6 h. Listeners were given frequent breaks as needed. The experimental protocol was approved by the Institutional Review Board of the University of Maryland.

III. RESULTS

For the purpose of analysis and comparison of results across discrimination conditions, absolute values of the measured duration DLs (ms) for the target interval(s) were divided by the relevant sequence reference IOI value (100 or 200 ms) to produce relative IOI DL values (i.e., Weber fractions). The conversion of absolute DLs to relative DLs is useful for evaluating data collected with auditory sequences, particularly when comparing temporal discrimination performance across reference sequence intervals that differ in magnitude (Hirsh *et al.*, 1990; Drake and Botte, 1993; Fitzgibbons and Gordon-Salant, 2010). All results are shown in Fig. 2 for the slower sequence rates (IOIs = 200 ms), and Fig. 3 for the faster sequence rates (IOIs = 100 ms). Each figure displays the mean relative DLs for each listener group as a function of the

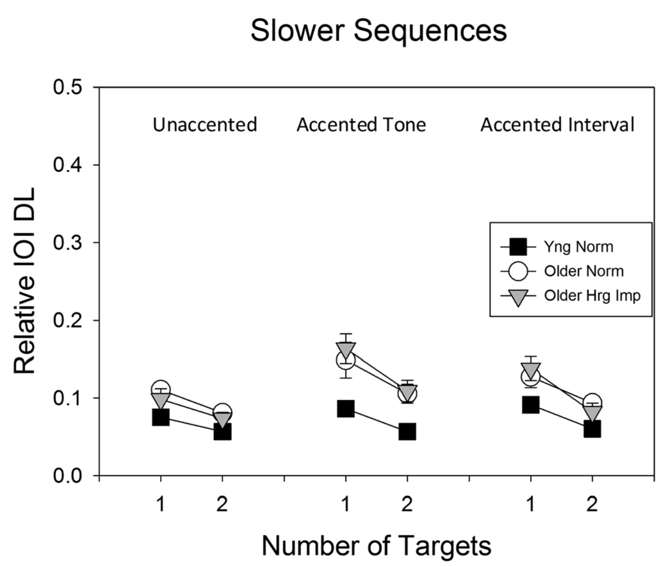

FIG. 2. Relative IOI DL as a function of number of targets for the three accent conditions at the slower sequence rate. Data shown are means for the three listener groups; vertical bars represent standard errors of the mean.

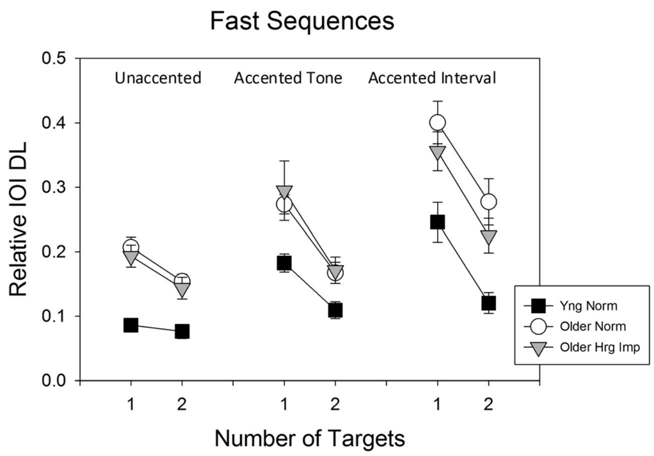

FIG. 3. Relative IOI DL as a function of number of targets for the three accent conditions at the faster sequence rate. Data shown are means for the three listeners groups; vertical bars represent standard errors of the mean.

number of sequence targets in each of the three stimulus sequence conditions (unaccented, accented tone, and accented interval); error bars in the figures represent standard errors of the means. An analysis of variance (ANOVA) was conducted on the individual relative DL values used to calculate the means displayed in each figure using separate repeated measures designs (i.e., one for each presentation rate), each with two within-subject variables (sequence condition with three levels: unaccented, tone accent, interval accent, and number of targets with two levels: 1 target, 2 targets) and one between-subjects variable (listener group).

Results of the ANOVA for the slower-rate sequences (Fig. 2) revealed significant main effects of sequence condition [F(2,74) = 12.24, $p < 0.001$], number of targets [F(1,37) = 126.27, $p < 0.001$], and listener group [F(2,37) = 6.33, $p < 0.01$]. Additionally, a significant interaction between sequence condition and listener group was observed [F(3,74) = 2.60, $p < 0.05$]. The main effect of target number reflected the outcome that relative DLs measured for two sequential target intervals were significantly smaller than those measured for one target interval in each corresponding sequence condition. Follow-up analysis of the interaction between sequence condition and listener group revealed that significant performance differences among the listener groups were restricted to the sequences featuring tonal accents for one and two target intervals ($p < 0.01$), and interval accents for one target only ($p < 0.05$). For these conditions, multiple-comparison testing (Bonferroni) revealed that the relative DLs of the younger listeners were significantly smaller than those of the older listeners ($p < 0.05$), with no significant performance differences between the two older groups.

Results of the ANOVA for the faster-rate sequences (Fig. 3) revealed significant main effects of listener group [F(2, 37) = 17.10, $p < 0.001$], sequence condition [F(2,74) = 44.15, $p < 0.001$], number of target intervals [F(1, 37) = 78.80, $p < 0.001$], and a significant interaction between sequence condition and number of target intervals [F(2,74) = 15.66, $p < 0.001$]. *Post hoc* one-way ANOVAs and multiple comparison testing (Bonferroni) of the listener-group effects revealed that the relative DLs of the younger listeners were significantly smaller than those of the older listeners in each of the three sequence conditions ($p < 0.001$, each comparison). Additionally, no significant performance differences between the two groups of older listeners were evident in each sequence condition. Analysis of the interaction between sequence condition and number of target intervals was performed using pairwise comparisons (t tests with Bonferroni corrections) and revealed that for each sequence condition the relative DLs for two target intervals were significantly smaller than those measured for one target interval ($p < 0.01$). Additionally, performance comparisons across sequence conditions revealed that the relative DLs for the respective one and two-target sequences increased progressively and significantly between the unaccented sequences and the accented-tone sequences, and between the accented-tone sequences and the accented-interval sequences ($p < 0.01$, each comparison).

IV. DISCUSSION

The investigation was designed to examine questions about the influence of component accent and rhythmic variation within auditory stimulus sequences on the abilities of younger and older listeners to discriminate temporal properties of the sound patterns. For purposes of experimental control, all stimuli were created as sequences of six brief tone bursts of equal frequency and intensity. The sequences also featured tones of equal duration and temporal spacing for the case of unaccented patterns, or featured a single elongated component for the case of accented patterns. Within the accented stimulus patterns, the elongated component was either the second tone burst of a sequence (tonal accent), or the second inter-tone silent interval of a sequence (interval accent), each of which added a perceived stress, or accent, to the elongated component. Each type of stimulus pattern, unaccented and accented, was used to assess the ability of younger and older listeners to discriminate changes in the duration of one or two tonal inter-onset intervals (targets) located at fixed sequence locations. Additionally, all discrimination measures were collected for slower and faster sequence presentation rates to examine the hypothesis that the performance of older listeners with diminished temporal processing capacity would exhibit the greatest influence of sequential accent in listening conditions that required rapid stimulus processing. Overall, results of the experiment revealed that the presence of accent within a stimulus sequence can have a detrimental effect on the temporal discrimination abilities of many listeners in the study. However, the magnitude of the accent-related performance deficits among listeners varied with the source of sequence accent, the sequence presentation rate, and the age of the listener. Differences in hearing sensitivity among listeners did not prove to have a significant influence on discrimination performance, as DLs for target intervals were observed to be equivalent in each stimulus condition for the groups of older listeners with and without hearing loss. This result is consistent with earlier observations (Fitzgibbons and Gordon-Salant, 2010), and is not entirely surprising given the high audibility levels of the stimuli and the relatively mild degrees of hearing loss among the older listeners in the frequency region of the stimulus sequences.

A. Younger listeners

The discrimination performance of the younger listeners was relatively stable across stimulus conditions for sequences presented at the slower rate (Fig. 2). With the unaccented control sequences, these younger listeners produced mean relative DLs of 7.5% for the single 200-ms target interval, and a smaller DL value of 5.6% for the 2-target discrimination condition. These relative DL values for the single target interval are in line with those reported previously for a 200-ms target interval embedded within isochronous tone sequences featuring the same presentation rate as the slower sequences in the present experiment (Hirsh *et al.*, 1990; Fitzgibbons and Gordon-Salant, 2010). In these earlier studies, it is worth noting that the component tone burst durations in the isochronous sequences used by Hirsh *et al.* (20 ms), and Fitzgibbons and Gordon-Salant (50 ms) differed from those of the present experiment (40 ms), but the reported relative DLs in each study were equivalent for the same reference target intervals. This equivalence of results across studies points to the relevance of the tonal inter-onset interval, rather than the absolute tone-burst duration, or the inter-tone silent interval, in listener discrimination of intervals within isochronous stimulus sequences. It is noteworthy also that the close agreement between the present single-target DLs and those reported by Hirsh *et al.*, 1990) is apparent despite differences in procedure wherein Hirsh *et al.* lengthened a single sequence target interval by tonal displacement without consequent changes in overall sequence duration. This outcome provides evidence against the possible argument that listeners use overall sequence duration as a primary cue in discriminating changes to embedded target intervals. Additionally, Drake and Botte (1993) used isochronous tone sequences with multiple co-varying target intervals and provided convincing evidence that sequence discrimination by their younger listeners was not based on changes in overall sequence durations.

The results displayed in Fig. 2 also reveal that, for the younger listeners, the slower stimulus sequences that featured an accented component produced results that were not substantially different from those collected with the unaccented control patterns. That is, for sequences with tonal accents, the relative DLs for the 1-target and 2-target conditions were 8.6% and 5.6%, respectively, while the corresponding DLs for the sequences with interval accents were 9.2% and 6.0%. These results for the tonal-accent condition agree with the essential findings reported in the initial study of sequential accent and temporal discrimination cited previously (Fitzgibbons and Gordon-Salant, 2010). That earlier study also used isochronous tone sequences with 200-ms tonal IOIs and found that the presence of an elongated (accented) tone produced prominent perceived rhythmic changes in a sequence, but had little influence on temporal discrimination performance of younger listeners. Similarly, the present results with the slower sequences also show that the presence of an interval accent had only minimal effects on discrimination performance of the younger listeners.

The results presented in Fig. 3 reflect discrimination performance for the faster sequence rates featuring reference tonal IOI values of 100 ms. With the unaccented control sequences, the younger listeners produced relative DLs of 8.7% and 7.9%, respectively, for the one-target and two-target discrimination conditions. These DL values are somewhat larger than the corresponding values observed with the slower stimulus sequences, but the differences are not large. Thus, the discrimination performance of the younger listeners was not substantially influenced by the increase in sequence presentation rate, at least for the unaccented patterns. This was not the case for the accented stimuli. For the faster sequences with the tonal accent, the younger listeners produced mean DLs of 18.3% and 10.9%, respectively, for the one- and two-target discrimination conditions, with corresponding values of 24.6% and 12.4% for the sequences with interval accents. Each of these DLs is significantly larger than those measured for the corresponding conditions with the unaccented stimulus patterns. Additionally, performance comparisons across accent conditions indicate that sequences with interval accents produced the largest discrimination DLs, and also the largest change in DL values between the one-target and two-target discrimination conditions.

B. Older listeners

In discrimination conditions featuring the slower unaccented stimulus sequences, the older listeners performed in a manner similar to the younger listeners. For these conditions, mean DLs of the older listeners were 10.4% and 7.9%, respectively, for 1-target and 2-target discrimination, values that are only 2%–3% larger than corresponding values of the younger listeners. This near equivalence in DLs between the younger and older listeners for the slower sequences indicates that, in the absence of accent, older listeners exhibited little difficulty in performing the baseline discrimination task. However, larger age-related performance differences became evident with the accented sequence conditions. For the sequences with tonal accents, Fig. 2 shows mean DLs of the older listeners to be 15.7% and 10.8%, respectively, for one-target and two-target conditions, values that are significantly larger than those for the younger listeners. These age-related discrimination deficits for sequences with tonal accents are consistent with those observed previously for similar slower-rate sequences featuring accented tonal components and single target intervals (Fitzgibbons and Gordon-Salant, 2010). For slower sequences with the interval accents in the present experiment, the mean DLs of older listeners were 13.2% and 8.8%, respectively, for the one-target and two-target conditions. Of these two DLs, however, only the value for the one-target condition proved to be significantly larger than the corresponding DL observed for the younger listeners.

With the faster sequences of Fig. 3, the older listeners exhibited significant performance deficits in each sequence condition, including with the unaccented sequences, which produced mean DLs of 20.1% and 14,9% for the one-target and two-target conditions, respectively. These values for the older listeners are approximately twice those of the younger listeners for the same unaccented conditions. The faster accented sequences produced more pronounced age-related performance differences. For example, with tonal accents, the mean DLs of older listeners for the one-target and two-target conditions were 28.5% and 16.9%, respectively, with corresponding DL values of 37.9% and 25.3% for the sequences with interval accents. Each of these DL values reflects a significant age-related discrimination deficit. Additionally, these results for the older listeners with the faster sequence presentation rate indicate that conditions with interval accents produced the largest DLs, a result that was also evident in the performance of the younger listeners with the faster stimulus sequences.

C. Sequence rate and accent type

It is apparent from the results that sequence presentation rate had an important influence on most of the discrimination measures examined in the experiment. These include the magnitude of the discrimination DLs, the degree of age-related performance differences, the type of sequence accent, and the performance changes associated with temporal cue repetition. One aim of the experiment was to compare the relative effects of different types of sequential accent on listeners' ability to discriminate altered temporal intervals within stimulus sequences. The experimental outcomes indicated that both types of sequential accent, tonal, and interval could effectively diminish listener temporal sensitivity. The detrimental effects of accent were evident for older listeners with both the slower and faster sequence rates, while the effects on younger listeners were largely restricted to the faster sequences. Additionally, unlike the younger listeners, the older listeners demonstrated discrimination deficits with the faster unaccented sequences, indicating a general age-related processing limitation for rapid sequences independent of accent effects. The relative effects of the accent types also varied with sequence rate. For example, at the slower sequence rate, discrimination deficits among older listeners were generally larger for sequences with tonal accents, compared to those with interval accents. However, with the faster sequence rate, interval accents produced the largest discrimination deficits, an outcome observed for all listener groups. The larger effects of interval accents at faster rates could be due in part to differences in sequential timing characteristics. That is, sequences with interval accents featured a deviation from regular timing by virtue of having a single elongated inter-tone interval. This was not the case for sequences with tonal accents, which preserved equal timing between successive tonal onsets. The independent effects of these sequential timing variations on listener discrimination performance cannot be determined from the present results. However, earlier studies that have used tonal stimulus patterns have observed that variations from uniform sequence timing can have an important influence on listener performance for other related temporal processing tasks (Drake and Botte, 1993; Fitzgibbons and Gordon-Salant, 2004). Alternatively, it is possible that the relatively poor discrimination performance with the faster sequences featuring interval accents was partially due to the similarity of accent and the embedded targets, both of which were silent intervals. This similarity of accent and target characteristics may have been more disruptive to listener discrimination with the faster sequences than would be the case for slower sequences, or for sequences with tonal accents. Of course, each of these potential explanations applies only to the performance measures collected for the faster stimulus sequences, and thus do not generalize to results observed for the slower sequence rates.

Target-interval repetition also exerted an important influence on listener discrimination performance. It was anticipated on the basis of earlier discrimination studies that repetition of a target interval within the auditory sequences would lead to improved interval discrimination, an outcome predicted by multiple-look models. However, these anticipated effects of target repetition had not been demonstrated previously with stimulus sequences featuring rhythmic variation and component accents like those of the present stimulus sequences. The current findings do provide some clear evidence of a discrimination benefit resulting from target repetition in each sequence condition with both groups of listeners. Also, the magnitude of the performance benefit observed with target repetition was in relatively close agreement with multi-look predictions for most conditions of the experiment with both younger and older listeners. Overall, the effects of target repetition were found to be larger for the accented sequences compared to the unaccented sequences, and were larger for the faster sequences compared to the slower sequences. Also, in most conditions, the older listeners exhibited larger improvements in discrimination performance with target repetition than younger listeners. The one exception was for the faster sequences with interval accents, where target repetition produced large and equivalent performance shifts for the younger and older listeners.

D. Conclusions

The experiment was conducted to examine the extent to which component accent and consequent rhythmic variation within auditory sequential patterns influenced sensitivity of younger and older listeners to targeted temporal intervals within stimulus sequences. The results of the experiment revealed that the presence of an accented component within sequences effectively diminishes listener sensitivity to embedded target intervals. The degree of diminished discrimination performance depended on listener age, sequence rate, and source of accent, with poorest discrimination observed for faster rates, interval accents, and older listeners. The older listeners with and without hearing loss performed similarly, a result most likely attributed to the adequate audibility of the stimuli, and perhaps the nature of the discrimination task requiring the processing of changes in stimulus durations. The stimuli used in the present experiment were quite simple in terms of acoustic complexity, but were sufficient to demonstrate the need to consider global properties of a sequence, such as rhythmic and timing characteristics, when measuring listener sensitivity to individual sequence components. The application of the present findings to the processing problems of older listeners with more complex sequences, like speech, is not straightforward, especially given the added spectral and temporal complexity of speech. Nevertheless, it is reasonable to expect that the influence of component accent and rhythmic variation on temporal sensitivity observed with the tonal sequences would operate as well in limiting listener processing of temporal cues in speech.

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