Aging-related attention deficits in frequency discrimination amid task-irrelevant stimulus differences

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1. Introduction

Difficulty ignoring irrelevant auditory information (IAI) such as speech babble at a social gathering is a cognitive deficit that aggravates with aging [1], possibly reflecting a pervasive inhibitory deficit [2] that clutters and disrupts the capacity-limited human information processing [3]. Research on this deficit has employed mostly speech stimuli that are ecologically meaningful but fail to reveal the specifics of how task-relevant and task-irrelevant speech information interact with one another at the perceptual level, resulting in failure to ignore the latter [4]. As a result, unveiling basic mechanisms accounting for failure to ignore IAI has remained elusive. To circumvent this limitation, in young and older adults, we are studying the ability to ignore IAI with psychoacoustic discrimination tasks and well-controlled stimuli [5,6]; here, we studied aging effects on the ability to ignore task-irrelevant level or duration differences while participants focused on task-relevant frequency differences. In order to engender task-irrelevant information in frequency-discrimination tasks the stimuli must include systematic (rather than random) and discernible differences along the task-relevant and a task-irrelevant dimension (e.g., level or duration). In addition, the differences along the two dimensions must convey *conflicting* information so that, to respond correctly, participants must succeed both at attending to the relevant dimension and at ignoring the irrelevant one, enabling them to extricate relevant from the irrelevant information at the perceptual level [1].

In forced-choice frequency discrimination tasks with two observation intervals (2I/2AFC), irrelevant information can be engendered by including irrelevant differences in the signal level, either within trials, between trials, or both [7,8]. Compared to fixed-level conditions, random within-trial level differences increase the frequency discrimination thresholds (FDTs) of well-trained young adults by a small but significant amount; i.e., they can ignore irrelevant level differences with modest difficulty. We modified the 2I/2AFC paradigm to assess aging effects on the ability to ignore irrelevant stimulus differences. The 3-observation interval, 2-alternative forced-choice (3I/2AFC) task presented a standard (S) tone followed

by two comparison tones (C1 and C2), one of which included a task-relevant frequency difference (ΔF_r) relative to the S frequency. In the absence of task-irrelevant stimulus differences, participants had to report which comparison included ΔF_r . In addition to ΔF_r , in conditions including task-irrelevant differences, both C1 and C2 included also a task-irrelevant difference in duration (ΔT_i) or in level (ΔL_i) relative to S. Thus, both C1 and C2 were different from S in terms of duration or level, but in terms of frequency only one was different from S (i.e., one comparison conveyed ΔF_r plus ΔT_i or ΔL_i); responding correctly required ignoring ΔL_i or ΔT_i and attending selectively to ΔF_r . Using the 3I/2AFC task, in a sample of young and one of older adults, we measured FDTs in the absence and in the presence of task-irrelevant level (ΔL_i) or duration (ΔT_i) differences. Since interactions between pitch and loudness are stronger than between pitch and duration [5,6], we predicted that ignoring ΔL_i would be much harder than ΔT_i , especially in older adults. Testing this prediction would determine if the older adult's attention deficit is all-inclusive entailing all combinations of task-relevant and task-irrelevant differences, or is specific entailing some combinations but not others; this test would unveil possible mechanisms accounting for failure to ignore irrelevant information.

2. Method

2.1. Equipment

An Apple computer running LabVIEW-2 software synthesized and gated the pure tones. Analog signals from the D/A converters were low-pass filtered, amplified, attenuated, and fed to earphones (TDH-49). LabVIEW-2 specified the pure tones frequency and duration, and a programmable attenuator controlled the level. Tones were presented monaurally, and participants responded on a computer keyboard in keeping with instructions and feedback displayed on a monitor; the computer controlled all experiment events.

2.2. Experimental task

For 1,000-Hz, 80-ms, 75-dB SPL target tones, we measured FDTs for positive frequency differences presented either in the absence or in the presence of task-irrelevant differences in level (ΔL_i) or duration (ΔT_i). For 1,000-Hz tones, FDTs decrease with increasing duration up to 80–

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Fig. 1 Trial structure in the Control, ΔT_i , and ΔL_i conditions. Horizontal line segments depict the target-tone frequency (ordinate) and duration (abscissa). Each trial includes a standard (S) followed by two comparison (C1 and C2) tones, respectively, in the 1st, 2nd and 3rd observation interval. Control condition (top): C1 includes a task-relevant frequency difference (ΔF_r) but no irrelevant differences. Irrelevant duration (center): C1 includes ΔF_r , and both C1 and C2 include ΔT_i (long segments). Irrelevant level (bottom): C1 includes ΔF_r , and both C1 and C2 include ΔL_i (thick segments); C1 includes a frequency increment relative to S and C2 and both comparisons are louder than S; inter-observation intervals scaled to 1/10 of 500 ms.

100 ms [9]; thus, the 80-ms tone helped the elders to master the task. In the 3I/2AFC task, each trial presented a standard (S) followed by two comparisons (C1 and C2), respectively, in the 1st, 2nd, and 3rd observation interval, separated by 500 ms of silence (see Fig. 1). A frequency increment (ΔF_r) was added to one comparison, chosen randomly with equal probability, and participants had to indicate the interval (2nd or 3rd) that included ΔF_r ; this control condition did not include task-irrelevant differences. In the irrelevant level-difference (ΔL_i) condition, ΔF_r was added again to one comparison but both comparisons included also positive 7.0- or 14.0-dB irrelevant level differences (ΔL_i); in all trials, the size of ΔL_i was the same for both comparisons. In the irrelevant duration-difference (ΔT_i) condition, both comparisons included also positive 50- or 100-ms duration differences (ΔT_i). Figure 1 depicts the trial structure of the 3 conditions studied: control, ΔT_i and ΔL_i ; in terms of level or duration, both comparisons were different from S, but in terms of frequency only one comparison was different from S. To respond correctly, participants had to attend to ΔF_r while

attempting to ignore ΔL_i or ΔT_i [5,6]. In the 3I/2AFC task, the level or duration difference was only between the standard and the two comparisons, and the latter two were always equal in level or duration; participants could respond correctly by attending to the frequency difference between the two equal-level or equal-duration comparisons. Since both comparisons conveyed large irrelevant differences, they were salient to all participants. Within each trial block (i.e., adaptive staircase), the irrelevant difference dimension (level or duration) was held constant but the irrelevant-difference size (7 or 14 dB; 50 or 100 ms) was sampled randomly with equal probability. The test order of the 3 conditions was counterbalanced to control for practice and fatigue effects.

2.3. Frequency discrimination thresholds (FDT)

On each trial, the size of ΔF_r was specified by an adaptive rule [10] estimating FDTs at the 71%-correct level. For young adults, the adaptive rule started with a 50-Hz ΔF_r that decreased by 2.0 Hz after 2 consecutive correct responses; ΔF_r increased by 2.0 Hz after an error or a correct response followed by an error. For older adults, the same rule was used but starting with a 70-Hz ΔF_r to facilitate mastering the task. An FDT estimate was defined as the average of the frequency increments specified in the last five reversals of adaptive tracks comprising eight reversals; FDT estimates from 8 tracks were averaged to compute the FDT of the control, ΔL_i , and ΔT_i condition. With each participant, a total of 24 adaptive tracks (8 per condition) were collected on a single 1.0–1.5 h test session, breaks included. To take into account accuracy differences between young and older adults in the control condition, the age groups were matched in terms of training amount or number of adaptive tracks, and the effects of ΔT_i or ΔL_i were assessed against the control FDT of each group.

2.4. Participants

The older adults included ten 64–74 years old (mean = 70.3), healthy participants (9 female); 8 normal hearing and 2 mild-to-moderate, high-frequency hearing impaired, but not exceeding the 1,000-Hz norm by ≥ 30 dB. Thus, in all participants the 75-dB, 80-ms, 1,000-Hz target tone was ≥ 35 dB above detection threshold and clearly audible. All older adults scored $\geq 90\%$ correct in a mental-status questionnaire [11], ruling out cognitive deficits. The young-adult group comprised ten normal-hearing graduate students, 22–31 years old (mean = 24.5; 6 female). The OUHSC Institutional Review Board approved the study protocol; participants consented in writing and were paid for listening.

3. Results

For both age groups, Fig. 2 shows the mean FDTs measured without (control) and with task-irrelevant differences in duration (ΔT_i) or level (ΔL_i). Because our goal was comparing effects of irrelevant stimulus differences in young and older participants matched in terms of training amounts, the FDTs do not represent best-possible differential sensitivity; this would require far more training in older than in young adults [6] and confound the aging effect. Without irrelevant differences, the control FDTs of both age groups are larger than those measured in highly-trained participants [12], and the elder's FDTs far exceed those of the young adults in all

Fig. 2 Columns show the mean FDT of young (criss-cross) and older (slant) adults in the control, irrelevant-duration (ΔT_i), and irrelevant-level (ΔL_i) difference conditions. Error bar is the standard error of the mean.

three conditions. Thus, within each age group, the irrelevant-difference effects were assessed in relation to the control FDTs. In both groups, FDTs measured in the midst of ΔT_i are nearly equal to those of the control FDTs; although it was large, ΔT_i was easily ignored by all participants. However, in the presence of ΔL_i the mean FDTs are clearly larger than the control FDTs, especially in older adults.

The significance of the FDT disparities across age groups and across irrelevant-difference conditions (control, ΔL_i , and ΔT_i) was assessed by a fixed-effects ANOVA with age as between-group factor (2 layers, this term avoids confusion with “dB level”) and irrelevant-difference as a within-group factor (3 layers). The ANOVA revealed significant main effects of age [$F(1, 18) = 4.73$, $MS = 5,415$, $p = 0.04$], irrelevant-difference condition [$F(2, 36) = 11.61$, $MS = 443.3$, $p < 0.001$], and a significant interaction between age and irrelevant difference [$F(2, 36) = 4.1$, $MS = 156.70$, $p < 0.025$]. Across age groups, pairwise tests (Student’s *t*-test, $p \leq 0.05$) showed significantly larger FDTs in older than in young adults in the control ($p \leq 0.03$, one-tail), irrelevant-duration ($p \leq 0.03$, one-tail), and irrelevant-level ($p \leq 0.03$, two-tail) conditions. As expected, in all conditions the elder’s FDTs were larger than the young adult’s (thus validating the one-tail significance levels); elders underperform even without irrelevant differences. Within the young group, in the presence of ΔL_i , the mean FDT was not significantly larger than the control FDT ($p \leq 0.09$, two-tail), but was significantly larger than the mean FDT in the midst of ΔT_i ($p \leq 0.01$, two-tail). Within the older group, in the presence of ΔL_i , the mean FDT was significantly larger than both the control FDT ($p \leq 0.02$, two-tail) and the FDT in the midst of ΔT_i ($p \leq 0.01$, two-tail); the latter FDT was not significantly larger than the control FDT ($p = 0.23$, two-tail). That is, the elders easily ignored ΔT_i , but had considerable difficulty ignoring ΔL_i . This is consistent with inability to ignore irrelevant information in older adults; however, this deficit is not observed amid ΔT_i . In addition, the standard

error of the means are much larger in older than in young adults, pointing to wider FDT variability in the elders.

4. Discussion and conclusions

In older but not in young adults, our results show that the ability to attend to and discern task-relevant frequency differences (ΔF_r) is degraded by the simultaneous presentation of task-irrelevant level differences (ΔL_i). This degradation inflated the FDTs, relative to those measured without ΔL_i ; however, attention deficits did not obtain with simultaneous presentation of irrelevant-duration differences (ΔT_i). Thus, rather than generalized, the degradation seems to be specific to the particular combination of relevant- and irrelevant-difference dimensions. Attention deficits were observed in elders with normal hearing and cognitive ability, and with adequate training in the irrelevant-difference tasks. Since peripheral-receptor injury cannot account for the elders’ attention deficit, their difficulty ignoring irrelevant differences must be linked to central-processing constraints; to account for this, two possible mechanisms are described below.

Strength of pitch-loudness interactions. Ignoring the ΔL_i in frequency discrimination tasks could be difficult partly because loudness and pitch interact with one another, and this interaction could be stronger in older than in young adults; that is, their ability to separate these dimensions at the perceptual level would be reduced compared to that of young adults. It has been proposed [7,8] that frequency discrimination is based on detecting changes in excitation level along the low-frequency slope of the excitation pattern, and that the FDT corresponds to a 1-dB change along this slope. Thus, in the present tasks, the positive 7–14 dB ΔL_i would tend obscure the much smaller excitation-level changes associated with relevant frequency differences, thereby increasing the FDT. In frequency discrimination of tones lower than 2.0 kHz, an increase in level tends to cancel out the pitch shift induced by a positive frequency increment, but a decrease in level tends to enhance the pitch shift [13]; that is, the irrelevant-level differences may lessen the perceptual effect of positive task-relevant frequency differences. In pitch-classification tasks [5], young adults perceive high-pitched, loud sounds as being more congruent than high-pitched, soft sounds; that is, pitch increments are perceived as been more similar to an increase than to a decrease in loudness.

Inflexible perceptual strategy. Without irrelevant differences, each trial presented three tones and participants could discern ΔF_r based on comparing, within trial, the memory traces of the standard and the two comparison tones. This strategy would work well in the midst of ΔT_i because it did not alter the frequency and pitch relations between S and C1, C2; in the midst of ΔT_i , perceiving them as a single group and relying on within-trial comparisons would not hinder discrimination accuracy. If anything, by lengthening the C1 and C2 duration, ΔT_i would improve discrimination (i.e., lower FDTs) because the task-relevant frequency difference lasted 50–100 ms longer than in the control condition. In fact, in the midst of ΔT_i , the elder’s FDTs were slightly but not significantly lower than in the control condition. In addition, lengthening the C1 and C2 duration slows down the presentation rate, which can also facilitate ΔF_r discrimina-

tion, especially in older adults. In contrast to the ΔT_i , the ΔL_i alter both the level and the pitch of C1 and C2; thus, the standard tone may no longer function as a reference that is effective to discern ΔF_r in one of the comparisons. In this case, the best strategy would be to ignore the standard and focus attention on C1 and C2; that is, to separate perceptually the standard from C1 and C2 and decide which of these two includes ΔF_r . Frequency discrimination between comparisons would be more accurate than between the standard and the comparisons. However, accomplishing this perceptual segregation is difficult because the tones are of short duration, similar in frequency, and close in time. In addition, because the ΔL_i are large and salient, they tend to draw attention away from the relevant frequency difference. Performing this perceptual segregation could be more difficult for older than young adults, thereby limiting their ability to ignore ΔL_i and increasing the FDTs. The basic mechanism would be limited cognitive flexibility that prevents elders from re-orienting attention [14].

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