Effects of irrelevant level fluctuation on frequency discrimination by young and older adults

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1. Introduction

The present experiments assessed effects of irrelevant fluctuation in signal level on *frequency discrimination thresholds (FDTs)* of young and older adults; more generally, age effects on the ability to ignore irrelevant auditory information were studied in psychoacoustic discrimination tasks. Previous research suggests that this ability degrades with aging, and that performance decrements induced by irrelevant auditory information are more severe in older than in young adults [1–3]. However, most of the evidence comes from studies using *speech-recognition* tasks; *frequency discrimination* tasks with simple sinusoids have not been employed thus far.

In order to convey irrelevant information, the auditory display must include two or more sources of *discernible* information. In addition, the sources must provide *conflicting* information so that, to respond correctly, subjects must succeed both at attending to one (relevant) source and at ignoring the other (irrelevant) sources. That is, subjects must be able to extricate relevant and irrelevant information at the perceptual level. The mere addition of noise, stimulus context or variability does not necessarily create irrelevant information; to do so, systematic stimulus differences that are *discernible* yet *inconsistent* with relevant information must be displayed also [4,5].

In two-interval, two-alternative, forced-choice (2IAFC) frequency discrimination tasks, irrelevant information can be engendered by fluctuation in the signal level, either within trials, between trials, or both [6,7]. Previous research shows that such random fluctuation has only small effects in the *FDTs* of well-trained young adults; compared to the fixed level condition, Weber fractions increase by a factor of 2.7 on average. That is, young adults have little difficulty ignoring random irrelevant level fluctuation in 2IAFC frequency-discrimination tasks.

In the present study, a modification of the above paradigm was used to compare the ability to ignore irrelevant auditory information of young and older adults; in both groups, *FDTs* were measured with and without fluctuation in signal level. The effects of level-fluctuation polarity (positive or negative) and training were also studied. Because target information always consisted of positive frequency increments, it was assumed that the positive irrelevant level differences would be harder to ignore than the negative, owing to similarity and

contrast effects. These effects would be of significance if the ignoring of irrelevant information were dependent on attention-like filtering mechanisms tuned to parameters of the target increment. On the other hand, irrelevant level differences could be difficult to ignore because they increase the stimulus set size, and thereby the amount of information and memory-capacity load [1,8]. If so, age effects on the ability to ignore irrelevant differences could be accounted for in terms of memory-capacity constraints; however, in contrast to the attention-filtering hypothesis, the predicted effects are not dependent on polarity. Finally, training effects were studied to determine if the ability to ignore irrelevant information depends on how familiar subjects are with the stimuli and task.

2. Method

2.1. Experimental task

The experiments measured frequency discrimination thresholds (*FDTs*) for 1,500-Hz, 40-ms, 70–80 dB SPL targets tones (*T*) presented in quiet. In the three-interval, two-alternative, forced-choice (3I/2AFC) task, each trial presented a “standard” followed by two “comparisons,” respectively, in the 1st, 2nd, and 3rd observation interval, with 500-ms of silence between intervals (see Fig. 1). A positive *frequency* increment was added to one comparison, selected randomly with equal probability, and subjects had to decide whether the increment was in the 2nd or 3rd interval; this is the baseline condition without irrelevant level fluctuation.

In level-fluctuation conditions, a positive *target frequency* increment was added again to one comparison, but *both* comparisons conveyed also positive or negative *level differences*. Figure 1 depicts a trial with 40-ms targets having simultaneous increments in frequency and irrelevant differences or fluctuation in level. In both comparisons there are positive irrelevant level differences (ΔL), but only in the first there is a target frequency increment (ΔF). In terms of level, both comparisons are different from the standard, but in terms of frequency, only one comparison is different from standard. To respond correctly, listeners had to attend to the target frequency increment while attempting to ignore the irrelevant level differences [9,10].

The irrelevant level differences were ± 5 , or ± 10 dB and the resulting loudness changes were easily noticed by all

Fig. 1 Trial structure of the three-interval, two-alternative, forced-choice discrimination task. Each trial displayed a “standard” followed by two “comparison” target tones, respectively, in the 1st, 2nd and 3rd observation interval. In this depiction, comparison 1 conveys a *target frequency* increment (ΔF), represented by the elevation of the target along the ordinate. Comparisons 1 and 2 convey irrelevant *differences* in T level (ΔL), represented by heavy bars. The listeners had to decide in which comparison was the target frequency higher than that of the standard, while attempting to ignore the irrelevant level differences.

normal-hearing subjects. In all cases, the size and polarity of the irrelevant *level difference* were the same for the two comparisons of a given trial. Within each trial block, *polarity* was held constant but the irrelevant-difference *size* (5 or 10 dB) was sampled randomly with equal probability. *Baseline* conditions without irrelevant level differences were studied also.

2.2. Threshold estimation

The size of the target increment presented on a given trial was specified by an adaptive rule [11] that estimated frequency discrimination thresholds (*FDTs*) near the 71 percent-correct level. *FDT* estimates were defined as the average of the frequency increments specified in the last six reversals of adaptive tracks comprising a total of eight reversals. *FDT* estimates from 5–6 adaptive tracks were averaged to obtain each *FDT* or data point [e.g., 12]. A minimum of 10 *FDT* estimates per experimental condition was collected on each subject. In all conditions, data collection terminated when: a) in a series of eight *FDT* estimates, subjects produced six *FDTs* approaching asymptotic values reported in the literature; or b) subjects completed 50 *FDT* estimates without meeting the previous criterion. Experimental sessions lasted 1–2 h and rest periods were allowed every 10–15 min.

2.3. Equipment

Sinusoidal tones, gated with 4-ms rise-fall times, were synthesized (20,000 samples/s) with a signal-processing software package (LabVIEW 2) installed on a Macintosh IIfx computer. The analog signals coming out of the computer’s 12-bit D/A converters were low-pass filtered at 4,500 Hz, amplified, attenuated, and fed to earphones (Telephonics TDH-49). Stimuli were presented monaurally and calibrated

with a Quest-155 SPL meter, a frequency counter, and an oscilloscope. Subjects worked at listening stations in a sound-treated room, and responded on a computer keyboard in accordance with instructions and feedback displayed on a CRT monitor. The LabVIEW software implemented the increments in frequency, and a programmable attenuator (TDT-PA1) implemented the differences in level. The Macintosh computer controlled all experimental events, including stimulus presentation, response recording, timing, and feedback.

2.4. Subjects

Six 65–74 years old (mean = 67) subjects, in good health, comprised the older-adult group (3 were in the active work-force and 3 on retirement). Six graduate students, 21–39 years old (mean = 24.5) enrolled at a metropolitan university health center comprised the young-adult group. In the audiometric frequencies, all six young and four older adults had hearing thresholds within the normal range. The other two elders’ hearing thresholds were within the normal range in the 0.25–4.0 kHz frequencies, but outside the normal range above 4.0 kHz. Hearing thresholds did not exceed the ANSI-1996 standard [13] by more than 15 dB at the target signal frequency. In all subjects, the 1,500-Hz target tone was clearly audible with a sensation level of 50–55 dB. All older adults scored above 90% correct in a mental-status questionnaire [14].

3. Results

All subjects were run in the *baseline* condition (without irrelevant level differences) until the *FDTs* approached asymptotic values reported in the literature [15]. This was followed by two conditions with either *positive* or *negative* irrelevant level differences. The test order of polarity conditions was randomized across trial blocks of each experimental session; within each trial block, all irrelevant differences had the same polarity.

Figure 2 depicts, as a function of training, the group-average *FDTs* measured in conditions having *positive* or *negative* irrelevant level differences; the *baseline FDTs* are shown also. In this Figure, the abscissa values represent the number of trial blocks completed by each group; each block yielded a single *FDT estimate* based on 14–54 trials (mean = 32). The amount of training increases directly with the number of trial blocks.

In the *baseline* condition, the older adults’ *FDTs* were only slightly larger than the 2.0–2.5 Hz *FDTs* of young adults. In all subjects, the *baseline FDTs* were lower than 3.5 Hz, in agreement with *FDT* values reported earlier for frequencies higher than 1,000 Hz [e.g., 15]. Achieving these low *FDTs* required far more training in older than in young adults, however this procedure served the purpose of matching the *baseline* performance of the two age groups, prior to presenting irrelevant differences.

Regardless of polarity, irrelevant differences in target level failed to elevate the young adults’ *FDTs*, and target frequency discrimination was very precise in all conditions, in close agreement with earlier studies [6]. A recent paper [16] did report significant *FDT* elevations, but the signal level fluctuation (8–20 dB) was much larger than the one used here (5–10 dB). At the beginning of training, positive and negative

Fig. 2 For irrelevant level-difference conditions, the average *FDTs* of young (triangles) and older (circles) adults are shown as a function of training, expressed in terms of number of trial blocks. Open and solid symbols depict data for positive and negative irrelevant level differences, respectively. The horizontal lines (bottom) depict the average baseline *FDTs* of young (dotted line) and older adults (dashed line).

irrelevant level differences elevated the elders' *FDTs* to an average of 17 Hz. Though the elevations tended to decrease with training, the elders showed *FDTs* of 8–14 Hz after completing an average of 50 trial blocks or $\approx 1,500$ trials on each polarity condition. The elders' *FDT* elevations were consistently lower with positive than with negative irrelevant level differences, but this trend did not reach statistical significance (see below).

In what follows, the terms *initial* and *final FDT* will designate the *FDTs* measured near the beginning and ending of the training period allotted to each irrelevant-difference condition. For each polarity condition, repeated-measures ANOVA were performed on the *initial* and *final FDTs* of both groups. On each ANOVA, the factors were age group and irrelevant difference, with 2 and 3 layers, respectively (the term "layer" is used here to avoid confusion with "level" difference). The layers of the irrelevant-difference factor were *initial* and *final FDT*, plus the *baseline FDT* measured in conditions without irrelevant differences. That is, the *baseline FDT* was treated as a layer in which the irrelevant difference was equal to *zero*. Paired comparison of *baseline* and *initial FDTs* assessed the significance of irrelevant-difference effects. The significance of training effects was assessed by paired comparison of *initial* and *final FDTs*, and by the Spearman-rank correlation between *FDTs* and training (i.e., number of trial blocks).

For *positive* irrelevant-difference conditions, the ANOVA revealed significant main effects of irrelevant difference [$F(2, 20) = 13.7$, $p < 0.0002$] and age [$F(1, 20) = 11.61$, $p < 0.0067$]. The interaction between age and irrelevant difference was significant also [$F(2, 20) = 11.69$, $p < 0.0004$], meaning that only the elders showed a significant irrelevant-difference effect. In older adults, Student-Newman-Keuls (SNK) tests reached significance with paired comparisons of *baseline* and

initial, *initial* and *final*, but not of *baseline* and *final FDTs*; that is, the significant elevations in the *initial FDTs* were lowered by the significant training effect. In agreement with the ANOVA, the Spearman-rank correlation between *FDTs* and training was significant in all older adults. In young adults, neither the SNK paired-comparison tests nor the Spearman-rank correlation reached significance, because the irrelevant differences failed to elevate the baseline *FDTs*.

For *negative polarity* conditions, the ANOVA yielded trends similar to those with *positive polarity*. There were significant main effects of irrelevant difference [$F(2, 20) = 10.11$, $p < 0.0009$] and age [$F(1, 20) = 9.47$, $p < 0.0117$], and a significant interaction between age and irrelevant difference [$F(2, 20) = 8.71$, $p < 0.0019$]. For older adults, SNK tests reached significance with paired comparison of *baseline* and *initial*, *baseline* and *final*, but not of *initial* and *final FDTs*. The SNK test for training effects did not reach significance; however, the Spearman-rank correlation between *FDTs* and training was significant in all but one subject. This discrepancy occurs because the SNK test takes into account only the *initial* and *final FDT*, while the Spearman-rank correlation takes into account the entire set of *FDTs* collected over the training period. For young adults, neither the paired-comparison tests nor the Spearman-rank correlation reached significance because, across conditions, the *FDTs* were very similar.

The significance of differences between *polarity* conditions was assessed with separate three-factor, repeated-measures ANOVA. The factors were age group, irrelevant-difference polarity, and training, with 2 layers each. Rather than the actual *FDT* values, the data for this ANOVA consisted of *FDT differences* between the *baseline FDT* and the *initial* or *final irrelevant-difference FDTs*. The ANOVA yielded significant main effects of age [$F(1, 10) = 10.98$, $p < 0.0078$] and training [$F(1, 10) = 20.38$, $p < 0.0011$], but not of irrelevant-difference polarity [$F(1, 10) = 1.78$, $p < 0.212$].

4. Discussion and conclusions

Irrelevant fluctuation in signal level elevated the *FDTs* of older but not of young adults; the tenfold elevations reported here are much larger than the tripling reported for young adults in previous studies [6,7]. Positive and negative irrelevant level differences yielded roughly the same effects in both age groups, though the elders' *FDTs* tended to be lower in the positive than in the negative polarity condition. While young adults are able to focus attention on target frequency increments and ignore irrelevant level differences, older adults have difficulty doing so. The *FDT* elevations induced by irrelevant level fluctuation suggest that interactions between pitch and loudness are stronger in older than in young adults; their ability to separate these dimensions at the perceptual level is reduced. Because the *FDT* elevations decreased with training, the ability to ignore irrelevant stimulus differences seems to depend also on prior knowledge about stimulus characteristics and long-term memory.

Peripheral-receptor injury cannot account for the elders' *FDT* elevations because their hearing sensitivity was normal; in addition, in the baseline condition, both age groups achieved virtually the same *FDTs*. This suggests that the

inability to ignore irrelevant differences is linked to central-processing constraints, such as memory capacity and selective attention. In the baseline condition, discerning frequency increments may depend on within-trial comparisons of T memory traces activated on each observation interval. In level-fluctuation conditions, the irrelevant level differences could be either 5 or 10 dB, and have negative or positive polarity. Thus, relative to baseline, the level-fluctuation conditions conveyed 1.0 extra bit of information, computed as the $\log_2$ of the number of irrelevant-difference values (i.e., $\log_2 2$). Because the extra stimulus information increases the memory-capacity demands, one could assume that age effects reflect memory deficits. In agreement with the present results, this hypothesis does not predict polarity-dependent age effects because the increase in stimulus information is roughly equal for both polarities. The hypothesis is consistent also with the claim that working-memory capacity may be reduced in older adults [1,8]; irrelevant information draws on limited capacity working-memory resources, thereby degrading target-frequency discrimination.

On the other hand, on each irrelevant-difference trial, the target-frequency increments occurred in one of two stimulus contexts: in negative-polarity conditions, T was softer in the comparisons than in the standard T ; in positive-polarity conditions, T was louder in the comparisons than in the standard. Therefore, irrelevant differences also established a context, which could have an impact on selective attention. Selective-attention deficits could account for limitations in the elders' ability to ignore irrelevant information [17,18].

Selective attention and memory capacity are closely intertwined, and extricating one from the other may not be possible. However, because the amount of stimulus information does not depend on polarity as the context effects do, the present results seem more in line with a memory-capacity than a selective-attention impairment: the elders' FDT elevations differed little across polarities, and keeping polarity constant throughout each trial block did not improve performance.

An attention-deficit account predicts polarity effects: since target frequency increments were positive in all cases, ignoring negative irrelevant-level differences was expected to be easier than the positive; the present trends are almost the opposite. Similarity between target and irrelevant information plays a major role in informational-masking paradigms [19]. In pitch-classification tasks [20], 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. In pitch matching tasks with 40-ms, 200–3200 Hz pure tones, pitch tends to decrease if the probe-tone level is higher than the standard, but it tends to increase if the level is lower than the standard [21]. Finally, in frequency discrimination of signals below 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 [16]. The elders' weak polarity effects suggest that the main performance constraint is memory capacity rather than selective attention.

Improvements in the ability to ignore irrelevant information could be explained on the assumption that, with training,

young adults develop long-term memory stimulus traces. Once established, these traces may allow listeners to anticipate what to listen for and what to ignore in the stimulus pattern, reduce the sensory- or working-memory load, and yield improved frequency discrimination [22].

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