Abstract
A recurring problem in aging research is separating the effects of age per se from the effects of high-frequency hearing loss. One approach is to present test stimuli in the presence of a high-pass masker to control confounding differences in high-frequency audibility across age groups. However, there is evidence that such maskers may affect older and younger listeners differently. In this study, pure-tone thresholds were measured for younger and older listeners in the presence of high-pass maskers. The age groups were carefully selected based on similar unmasked thresholds at each frequency. Thresholds were measured in quiet and in seven masker conditions. Both younger and older listeners showed increased threshold shift below the masker passband as the masker level increased. The degree of threshold shift was not greater for older versus younger listeners. Results suggest that high-pass maskers may be used to reduce high-frequency sensitivity differences between younger and older listeners without introducing differential masking effects.

Key Words: Aging, hearing loss, masking, threshold

Effects of Decreased Audibility Produced by High-Pass Maskers in Younger and Older Adults

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It is well known that older listeners have more difficulty than younger listeners discriminating speech in background noise (CHABA, 1988). It is more difficult to distinguish between the effects of age per se and the poor thresholds that typically accompany aging. One strategy is to recruit normal-hearing listeners for the older and younger groups. This approach is often difficult to implement due to the limited availability of older (> 65 years) listeners with truly normal hearing (ASHA, 1990). Even when older adults with “normal” pure-tone thresholds (25 dB HL or better) are recruited, audibility differences may still exist between groups. For example, older listeners with hearing thresholds of 25 dB HL are still at a disadvantage relative to younger listeners with hearing thresholds of 0 dB HL.

An alternative method takes decreased hearing sensitivity into account by comparing older and younger hearing-impaired groups matched as closely as possible for audiometric thresholds. Although this method may control for the confounding effects of hearing sensitivity across age groups, it may be difficult to find younger hearing-impaired listeners with hearing losses similar in configuration to age-related hearing loss. If thresholds are not closely matched, differences in audibility can result in erroneous conclusions. For example, it has been frequently reported that aging affects the ability to use contextual information (Cohen and Faulkner, 1983; Pichora-Fuller et al, 1995). However, Dubno et al (2000) recently demonstrated that age-related differences are absent if audibility is carefully equated across age groups.

One way to address this problem is to present younger listeners with a masking noise spectrally shaped to mimic older listeners’ quiet thresholds (e.g., Humes et al, 1987; Dubno and Schaefer, 1995). However, each group is actually performing a different task—speech in quiet for the older listeners, speech in noise for the younger listeners. To avoid this situation, researchers sometimes present test materials in the presence of high-frequency masking noise designed to minimize audible cues to the same extent for all listeners (e.g., Van Tasell and Turner, 1984; Souza and Turner, 1994; Horwitz et al, 2002). High-pass maskers in particular are used because it is most difficult to match between-group thresholds above 3 kHz. This approach is attractive because it provides a convenient way to minimize audibility differences between age groups who are otherwise well matched, yet presents all listeners with the same perceptual task.

One concern is the potential for the masker to have greater consequences (i.e., a differential masking effect) for older than for younger adults. Numerous studies have shown that older adults have more difficulty detecting a signal in the presence of competing sounds than do younger adults (Dubno et al, 1984; Stach et al, 1991; Gordon-Salant and Fitzgibbons, 1993; Gates et al, 1995; Chmiel and Jerger, 1996; Fisher et al, 2000; Jerger, 2000; Alain et al, 2001; DeChicchis et al, 2002). Specifically, the ability to selectively attend to stimulus in the presence of competing sounds declines with age (Jerger et al, 1995). A straightforward approach to determining whether older listeners are differentially affected by such maskers is to compare threshold elevation in the presence of a masker for older versus younger listeners. One factor of interest is the degree to which threshold shift occurs for tones outside the passband of the masker (i.e., spread of masking). Both upward spread of masking (threshold shift at frequencies above the masker passband) and downward spread of masking (threshold shift at frequencies below the masker passband) have been implicated in reduced speech discrimination (Summers and Leek, 1997; Noordhoek et al, 1999, 2000) and previous investigators have suggested that such effects may partially account for differences in speech discrimination across age groups (e.g., Patterson et al, 1982). Although older listeners do not show greater spread of masking for lower-frequency maskers (Klein et al, 1990; Cheesman et al, 1995; Dubno et al, 1995), there are no data available on age-related masking effects within the high-frequency portion of the auditory system.

With respect to the frequency content of the masker, physiological changes associated with age have considerably greater effects on high- rather than on low-frequency coding (Willott, 1984; Saitoh et al, 1994; McFadden et al, 1997). Some previous work suggested an age-related broadening of auditory filters (e.g., Patterson et al, 1982; Matschke, 1990),
while other authors argue that this phenomenon is due to high-frequency threshold elevation rather than age per se, implying that masking effects may be similar for older and younger listeners with equivalent high-frequency quiet thresholds (Peters and Moore, 1992a, 1992b; Sommers and Humes, 1993). However, previous studies examined auditory filters only through 2 kHz. Thus, there is still a concern that high-frequency maskers may have differential effects for younger versus older listeners.

Despite these concerns, maskers are routinely used to equate audibility between younger and older listeners. Therefore, the purpose of this study was to determine whether the presence of a high-pass masker would introduce an age bias in terms of signal audibility. Specifically, do older listeners show differences in threshold shift in the presence of a high-pass masker when compared with younger listeners? If so, are there specific masker levels or cutoff frequencies that should be avoided? Clinically, this information is critical because unaccounted age effects could result in artificial threshold elevations and poorer performance, making it an ineffective control measure for older adults.

**METHOD**

**Participants**

Participants were six younger normal-hearing listeners, aged 19 to 33 years (mean age 26 years), and six older normal-hearing listeners, aged 60 to 74 years (mean age 67 years). Mean thresholds for these groups are shown in Figure 1. Normal hearing was defined as pure-tone thresholds of 25 dB HL or better (ANSI, 1996) from 0.25 to 8 kHz. Participants were carefully selected by matching audiograms to ensure that both groups (younger and older) had equivalent thresholds up to 8 kHz. Differences in mean thresholds between the younger and older group were less than 5 dB. Mean unmasked thresholds were statistically equivalent between groups ($F[1,10] = .91, p = .363$). All participants had normal hearing bilaterally. The ear that most closely fit the desired group mean was tested. None of the participants had any previous experience in psychoacoustic experiments.

**Stimuli and Procedures**

Test stimuli were digitally generated pure tones at .25, .5, 1, 2, 3, 4, 6, and 8 kHz, sampled at 44.1 kHz and low-pass filtered at 10 kHz. Pure tones were 250 msec in duration, including a 20 msec onset and 20 msec offset. The masker was a white noise (Tucker-Davis Technologies [TDT] WG1) that was high-pass filtered at cutoffs of 3 or 4 kHz (TDT FT5, 96 dB/octave slope) and mixed with the test tones (TDT SM3) prior to presentation.

Thresholds were measured in quiet and at masker levels of 60, 70, and 80 dB SPL for each masker cutoff. To examine the possibility that high-level noise may introduce remote masking effects (Bilger and Hirsh, 1956), we included a 90 dB SPL masker in the 3 kHz masker cutoff condition only. Thus, all normal-hearing participants completed a total of eight threshold conditions: unmasked; three levels each of two masker cutoffs; plus an additional high-level masker in the 3 kHz masker cutoff condition. Thus, all normal-hearing participants completed a total of eight threshold conditions: unmasked; three levels each of two masker cutoffs; plus an additional high-level masker in the 3 kHz cutoff condition. Threshold testing was always completed first in quiet, followed by the masked conditions in random order. Participants typically completed one condition per two-hour visit, with one to two visits scheduled per week. Within a condition, test frequencies were presented in a fixed order. According to convention, 1 kHz was presented first, followed by the higher frequencies in.
ascending order, then the lower frequencies
in descending order (Martin and Clark, 2003).

The amplitude of the signal was controlled
using a combination of programmable and
manual attenuators (TDT PA4). A two-correct
step-down, one-incorrect step-up rule
determined the change in signal level. A
change in the direction of signal attenuation
was termed a reversal. The signal level was
initially adjusted in 10 dB steps. After three
reversals the step size was reduced to 2 dB,
and seven reversals were obtained. The first
three reversals were discarded and threshold
calculated using the last seven reversals. The
procedure estimated the 71 percent correct
point on the psychometric function (Levitt,
1971). A running standard error of the reversal
mean was computed and used to monitor the
variability of the response. Only thresholds
with standard errors of less than 4 dB were
considered acceptable. If the standard error
of any frequency exceeded 4 dB, that threshold
was retested until it met the criterion.

Participants were seated in a double-
walled sound-attenuating booth and listened
to the signals presented monaurally through
a Sennheiser HD25SP headphone. Stimulus
presentation, response identification, and
scoring were computer controlled. Each
threshold was measured using a four-interval
forced-choice adaptive threshold procedure.
A four-button response box was used with
each interval indicated sequentially by a
light. Participants responded by depressing
the button corresponding to the interval
containing the signal. Silent time between
masker intervals was at least 500 msec. If
participants required more time between
intervals, the interval sequence was
lengthened. To minimize the time spent
listening to continuous noise in the masked
conditions, the masker was turned on 800
msec before the signal and turned off 800
msec after the signal using a programmable
switch (TDT SW1). The total duration of the
masker was identical in each interval,
differing only in the presence or absence of
the test tone. Correct answer feedback was
provided on each trial.

RESULTS

Mean thresholds measured in each
category are shown in Figure 2 for the
3 kHz masker cutoff and in Figure 3 for the
4 kHz masker cutoff. In each figure, filled
symbols represent data for the younger group,
and open symbols represent data for the older
group. The error bars show variability for
each group. Even though there appeared to
be little difference between mean threshold and variability for each group, a three-factor analysis of variance (ANOVA) was completed for each masker cutoff frequency to determine if there was any statistical difference. The between-subjects factor was group (older vs. younger) and within-subjects (repeated-measures) factors were frequency and masker level.

For the 3 kHz masker cutoff (Figure 2), the three-way interaction (group x frequency x masker level) was not significant ($F[28,252] = 1.08, p = .365$). Additionally, threshold differences between younger and older listeners did not vary significantly with masker level ($F[4,36] = 0.46, p = .766$) or frequency ($F[7,63] = 0.92, p = .499$). For the 60 dB SPL masker level, there was little threshold shift outside the passband of the masker (i.e., below 3 kHz), reflecting the sharp tuning of auditory fibers. The effect of the masker outside the passband increased at higher masker levels ($F[28,252] = 50.35, p < .0005$). For both groups, threshold increased with increasing masker level ($F[3,30] = 163.93, p < .0005$). There was no overall threshold difference for the younger versus older participants ($F[1,9] = 0.92, p = .362$).

Results for the 4 kHz masker cutoff (Figure 3) were similar to the 3 kHz condition. The three-way (group x frequency x masker level) interaction was not significant ($F[21,210] = .93, p = .554$). Similarly, the interactions between age and masker level ($F[3,30] = 0.17, p = .915$), or between age and frequency ($F[7,70] = 1.00, p = .441$), were not significant. However, the pattern of threshold shift at each frequency was dependent on masker level ($F[21,210] = 119.22, p < .0005$). Thresholds above 2 kHz increased with increasing masker level ($F[3,30] = 228.99, p < .0005$). There was no overall threshold difference for younger versus older participants ($F[1,10] = .96, p = .351$).

**DISCUSSION**

A persistent problem in aging research is providing equivalent signal audibility across age groups. Differences in audibility can result in erroneous conclusions about the effects of aging, independent of hearing loss. This study measured the utility of one approach to equating audibility: use of a high-pass masker.

Older and younger listeners with matched hearing sensitivity demonstrated equivalent masked thresholds in the presence of a high-pass masker. This was true for thresholds within and below the masker passband. From a practical standpoint, these results suggest that the high-pass masker conditions presented here can be used to reduce high-frequency sensitivity differences between younger and older groups. The data here can also be used to select a masker cutoff frequency and level, depending on the desired effect. For example, an 80 dB SPL, 4 kHz cutoff masker produced maximal threshold shift in the high-frequency region with little or no threshold shift at 2 kHz. This masker would be a good choice if unmasked pure-tone thresholds of subjects were well matched through 2 kHz yet divergent at higher frequencies.

The relatively low spectrum level of the maskers in this study also did not result in remote masking (Bilger and Hirsh, 1956), in which threshold shift can occur at frequencies far removed from the passband at high masker levels. A similar finding (i.e., absent remote masking effects) was reported by Horwitz et al (2002) using a 59 dB SPL masker with a high-pass filter cutoff of 3.75 kHz.

Our data clearly demonstrated that equivalent audibility could be provided across age groups using a high-pass masker. It is well established that audibility is the primary determinant of speech discrimination (e.g., Pavlovic, 1984; Kamm et al, 1985; Dirks et al, 1986; Dubno and Dirks, 1989). Although speech recognition was not measured in this study, data by Souza and Turner (1994) and Horwitz et al (2002) suggest that appropriately selected high-pass maskers will have very minimal, if any, negative impact on speech discrimination.

Finally, although this study demonstrated that high-pass masking can be used to control audibility in specific frequency regions, this method does not take into account central auditory changes due to age-related peripheral hearing loss. That is, simulated hearing loss through use of a masker does not mimic the decreased frequency, intensity, and temporal resolution that can accompany organic sensorineural hearing loss (Scharf, 1978a, b; Dreschler and Plomp, 1985; Thibodeau, 1991).
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