The effect of presentation level on spectral weights for sentences

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Psychophysical data indicate that spectral weights tend to increase with increasing presentation level at high frequencies. The present study examined whether spectral weights for speech perception are similarly affected by presentation level. Stimuli were sentences filtered into five contiguous frequency bands and presented at each of two levels (75 and 95 dB sound pressure level [SPL]). For the highest band (2807–10 000 Hz), normal-hearing listeners' weights were higher for the higher presentation level. Weights for the 95-dB-SPL level resembled those previously estimated for hearing-impaired listeners tested at comparably high levels, suggesting that hearing loss itself may not play a large role in spectral weighting for a sentence recognition task.

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I. INTRODUCTION

Speech recognition tests are a common part of standard audiological practice (ASHA, 2006). These tests allow the clinician to evaluate listener performance for both speech recognition and speech reception thresholds. However, speech recognition tests do not provide information regarding which spectral information contributed the most to the listener's performance on the task. Measuring listeners' perceptual weights can provide insight into how different spectral regions contribute to a listener's recognition of the speech (e.g., Doherty and Turner, 1996). For example, a high perceptual weight on one spectral band would indicate that band contributed relatively more to the listeners' performance on the task than other spectral bands given lower weights. Calandruccio and Doherty (2007, 2008) have argued that perceptual weights for a sentence recognition task differ between listeners with normal hearing and listeners with sensorineural hearing loss. That is, they reported data consistent with the idea that perceptual weights for sentence recognition are affected by sensorineural hearing loss, with hearing-impaired listeners placing relatively more weight on the highest-frequency band than normal-hearing listeners. If listeners with hearing loss weight speech information differently from normal-hearing listeners, this would have important implications for optimal amplification. One difference between the studies from Calandruccio and Doherty (2007) and Calandruccio and Doherty (2008) was the higher overall presentation level used for the listeners with hearing loss compared to the overall presentation level used to test the normal-hearing listeners. Whereas normal-hearing listeners heard speech at a conversational level (75 dB sound pressure level [SPL]; Calandruccio and Doherty, 2007), hearing-impaired listeners heard speech at a higher level, amplified either through a loudspeaker or a hearing aid (92.0 to 99.8 dB SPL; Calandruccio and Doherty, 2008). Higher levels in the later study with hearing-impaired listeners were meant to ensure audibility across frequency based on each listener's audiogram, but it is also possible that differences in presentation levels between groups could have affected the weights. Support for this possibility comes from psychophysical studies showing that perceptual weights can differ as a function of presentation level (e.g., Kortekaas *et al.*, 2003; Lentz, 2007; Leibold *et al.*, 2009). The purpose of the present study was to determine how presentation level affects normal-hearing listeners' perceptual weights for masked sentence recognition.

Doherty and Lutfi (1996) obtained perceptual weights for listeners with normal hearing and listeners with sensorineural hearing loss on a non-speech level discrimination task. They tested two six-tone complexes, composed of tones at octave frequencies between 250 and 8000 Hz, in which the level of the tones randomly varied across trials. Listeners completed a two alternative-forced choice (2AFC) task to indicate which multi-tone complex had the higher overall intensity level; this task is sometimes referred to as sample discrimination, because the listener's task is to determine which distribution a sample was drawn from (signal or the no-signal). The methodology used for these experiments was consistent across the two listener groups, except for the mean level of each tone within the complex. That is, the mean level for each tone was 65 and 62.5 dB SPL for signal and non-signal complexes, respectively, for listeners with normal hearing; in contrast, for the listeners with sensorineural hearing loss the stimulus levels were either 80 and 75 dB SPL or 80 and 72.5 dB SPL (dependent upon listeners' discrimination ability) for signal and no-signal complexes, respectively. The listeners with normal hearing applied approximately equal weights to each of the component tones while completing the sample discrimination task. However,

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the listeners with hearing loss tended to place a greater weight on the higher frequency components in comparison to the lower frequency components when deciding which multi-tone complex was drawn from the distribution with higher overall intensity. It was assumed that the difference in observed weights between the two listener groups was due to differences in hearing acuity.

Leibold *et al.* (2009) suggested that the weighting differences between listener groups (normal vs impaired) reported in Doherty and Lutfi (1996) were not due to hearing thresholds, but rather to differences in the mean stimulus levels that were used to test the two groups of listeners. Leibold *et al.* (2009) replicated the Doherty and Lutfi (1996) study testing only normal-hearing listeners. In addition to the low-level six-tone complex presented in quiet, they included three additional listening conditions in which the complex was presented at a higher level (80/75 dB SPL for mean signal/no-signal complexes, respectively): one in quiet, one that included a masking noise to simulate a sloping high-frequency hearing loss, and one that used a masking noise to simulate a reverse sloping low-frequency hearing loss. Similar to the results observed in Doherty and Lutfi (1996), listeners tended to apply uniform weights to each tone for the 65/62.5 dB SPL complex presented in quiet. However, for all three conditions associated with the higher presentation levels listeners tended to apply greater weight to the higher frequency components in the complex, regardless of sensation level. These results suggested that neither sensorineural hearing loss nor differences in sensation levels could account for the shift in weights observed by Doherty and Lutfi (1996), yet differences in overall presentation level did seem to change the shape of the listeners' perceptual weights.

The finding of greater weights given to higher than lower frequency components at high overall presentation levels does not appear to be limited to sample discrimination tasks. Lentz (2007) tested five listeners with normal hearing on a spectral-shape discrimination. Stimuli were six-tone complexes presented at three different stimulus levels (35, 60, and 85 dB SPL/component). The six tones were spaced equidistantly on a logarithmic scale (between 700 and 4000 Hz). In standard intervals all six tones were equal in amplitude. In signal intervals the three lowest-frequency tones were lower in amplitude than the three highest-frequency tones. Psychometric function data were collected on listeners using a 2AFC task in which listeners were asked to report which interval contained the signal stimulus. Similar to results seen for sample discrimination, there was a trend for listeners with normal hearing to put more weight on high-frequency than low-frequency components when discriminating spectral shape as presentation level increases.

Recently, Jesteadt *et al.* (2014) also showed a similar pattern for perceptual weights for loudness. Listeners in this experiment performed a sample discrimination task, with 5-dB separation between the signal and no-signal distributions, and a loudness task, where stimuli in both intervals were drawn from the same distribution. In both tasks the stimulus was a six-tone complex composed of octave frequencies from 250 to 8000 Hz. The level of the tones within the complex was randomly selected from a blocked presentation of a mean sound pressure level of 45, 55, 65, or 75 dB. Listeners' weights were similar in the sample discrimination task and the loudness task, with a shift in weight from low to high frequency tones as presentation level increased. The greater weight for high-frequency components of the complex as presentation level increases is consistent with the results of Leibold *et al.* (2009).

Because of the psychophysical data described above, it is unclear whether the difference in spectral weights for sentences observed between the listeners with hearing loss and listeners with normal hearing were due to differences in hearing sensitivity (i.e., cochlear differences resultant from hearing loss) or to differences in stimulus presentation level (Calandruccio and Doherty, 2007, 2008). In the current study, spectral weights for sentence recognition were estimated for normal-hearing listeners at 75 and 95 dB SPL, with the higher level comparable to that previously used to obtain weights in hearing-impaired listeners (Calandruccio and Doherty, 2008). One goal was to determine whether the weight applied to high-frequency speech bands increases with increasing presentation level, as might be the case if speech weights are affected by level in the same way as weights in psychophysical tasks. Another goal was to obtain data from normal-hearing listeners at a high presentation level to distinguish effects related to sensorineural hearing loss from those related to presentation level in the published data on hearing-impaired listeners. To that end, the results obtained with normal-hearing listeners were compared with those obtained by Calandruccio and Doherty (2008) using the same stimuli and methods. In that study listeners with sensorineural hearing loss were tested unaided or with their hearing aids, using linear gain (no compression) and programmed to NAL-R targets (Byrne and Dillon, 1986). The effective presentation level was ∼95 dB SPL in both cases; in the unaided condition stimuli were calibrated in the free field, and in the aided condition real-ear measures were used.

II. METHODS

A. Subjects

Spectral weights were determined for eight normal-hearing adults, ages 18–28 (mean age = 22 years old; six females and two males), all of whom had previously participated in the study of Calandruccio and Doherty (2007). These listeners were native speakers of American English and had thresholds better than or equal to 15 dB hearing level between 250 and 8000 Hz, bilaterally (ANSI, 2004).

B. Stimuli

The stimuli were generated using the same procedures described in detail in Calandruccio and Doherty (2007). The target speech comprised Harvard/Institute of Electrical and Electronics Engineers (IEEE) sentences (IEEE, 1969), spoken by a female, and the masker was a spectrally matched noise. Both target and masker stimuli were filtered into five contiguous bands (111–561, 562–1113, 1114–1788, 1789–2806, and 2807–11 000 Hz). Bands were associated with approximately equal intelligibility based on the Speech Intelligibility Index (SII; ANSI, 1997), using a frequency-importance function for normal-hearing listeners and sentence materials (Bell *et al.*, 1992).

Speech was presented at either 75 or 95 dB SPL. On each trial, the noise added to each band of speech took on one of five randomly selected levels, resulting in signal-to-noise ratios (SNRs) that were equally distributed over a 12-dB range. For example, the most common range included −14, −11, −8, −5, and −2 dB SNR. In this example, −8 dB SNR is the midpoint. The SNR range differed between listeners, but the same range was used for all bands and for both presentation levels within a listener. The midpoint of the range of the SNRs for each listener was selected to elicit 60%–80% correct performance.

C. Procedure

Listeners were seated in a double-walled sound treated booth, 1 m in front of a custom-made loudspeaker with a flat-frequency response (within ±4 dB) up to 10 000 Hz. On each trial listeners were presented with a masked sentence and asked to repeat back what they heard. Listeners' responses were scored by an examiner outside the booth based on five keywords in each sentence.

The SNR associated with 60%–80% correct for each listener was based on pilot testing using 30 sentences presented at 75 dB SPL. Once a range of SNRs was identified for a particular listener it remained fixed for all further testing (i.e., the same SNR range was for both presentation levels). Listeners' spectral weights were obtained for each presentation level based on a total of 2000 keywords (80 sentences × 5 SNRs × 5 keywords = 2000 keywords). All listeners completed the 75-dB-SPL conditions prior to the 95-dB-SPL conditions, with up to 6 months between conditions. The 75-dB-SPL data reported here are a subset of the data reported by Calandruccio and Doherty (2007).

D. Analysis

The proportion of keywords correct for each sentence was correlated with the associated SNR in each band. A positive slope indicates better performance when the SNR in the associated band was high than when it was low. For ease of comparison across listeners, the weight assigned to each band was expressed as the normalized correlation. Repeated-measures analysis of variance (rmANOVA) was used to compare weights across frequency for each level condition, as well as the effects of level on weights applied to each band. A significance level of $\alpha = 0.05$ was adopted.

III. RESULTS

Following the methods employed in Calandruccio and Doherty (2007, 2008), the goal was for each listener to obtain 60%–80% correct for the midpoint SNR in the 75-dB-SPL presentation level condition; those midpoints ranged from −9 to −6 dB across listeners. Mean percent correct for the two presentation levels was 76.7% (75 dB SPL) and 62.9% (95 dB SPL), a difference that was significant when evaluated using a paired-samples t-test ($t_7 = -5.25$, $p = 0.001$).[1] For comparison, the hearing-impaired listeners tested by Calandruccio and Doherty (2008) had mean scores of 71.5% (aided) and 78.7% (unaided).

Normalized mean weights for each of the five bands are shown in Fig. 1, for both the 75-dB-SPL (down-pointing triangles) and the 95-dB-SPL (up-pointing triangles) presentation levels. Data from Calandruccio and Doherty (2008) are also shown for hearing impaired listeners tested either with or without their hearing aids (open and filled circles, respectively). Recall that the effective stimulus level was approximately 95 dB SPL in both cases, measured either in the free field (unaided condition) or in the ear canal (aided condition). Error bars indicate plus or minus one standard deviation.

An rmANOVA was performed on the data from normal-hearing listeners, including the between-subjects factors level (75 and 95 dB SPL) and band (1–5). There was no main effect of level ($F_{1,7} = 0.08$, $p = 0.785$), but there was a main effect of band ($F_{4,28} = 51.85$, $p < 0.001$) and an interaction between level and band ($F_{4,28} = 3.74$, $p = 0.015$). Simple main effects testing indicates that band 5 was the only band associated with a significant effect of level ($p = 0.003$), consistent with the prediction that higher presentation levels are associated with greater relative weight applied to the highest band. Evaluating the change in performance across the 12-dB range of SNRs in band 5 in each listener, performance changed by an average of 26 percentage points at the 75-dB SPL level and 36 percentage points at the 95-dB-SPL level.

A pair of rmANOVAs was performed to compare weights for the 95-dB-SPL condition obtained from normal-hearing listeners with those obtained previously from hearing-impaired listeners at 95 dB SPL (Calandruccio and Doherty, 2008). In these analyses, listener group was an across-subjects factor. For the hearing-impaired data obtained *with* hearing aids, there was a main effect of band ($F_{4,64} = 45.78$, $p < 0.001$), no main effect of group ($F_{1,16} = 0.37$, $p = 0.552$), and no interaction between band and group ($F_{4,64} = 1.07$, $p = 0.381$). For the hearing-impaired data obtained *without* hearing aids, there was a main effect of band ($F_{4,64} = 70.76$, $p < 0.001$), no main effect of group ($F_{1,16} = 0.12$, $p = 0.728$), and a significant interaction between band and group ($F_{4,64}$

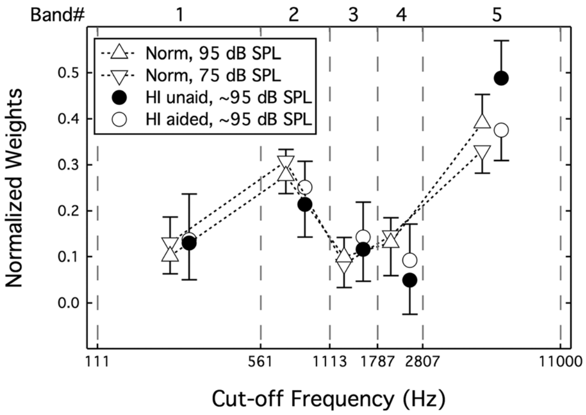

FIG. 1. Mean normalized weights and standard deviations for eight listeners with normal hearing at two levels. Dashed-vertical lines indicate filter cutoff frequencies. Data of hearing-impaired listeners are taken from Calandruccio and Doherty (2008).

$= 4.30$, $p = 0.004$). Simple main effects testing was performed to understand this interaction. Compared to normal-hearing listeners, hearing-impaired listeners tested *without* their hearing aids had higher weights for band 5 ($p = 0.013$) and lower weights for band 2 ($p = 0.042$) and band 4 ($p = 0.032$).

Despite the large number of Harvard/IEEE sentence lists, it was necessary to repeat a subset of sentences to obtain the data reported here. To evaluate the possible effects of prior exposure to particular stimuli, performance in the 95-dB-SPL condition was compared for sentences that were and were not repeated for each individual. Across listeners, this difference (novel – repeated) spanned a range of −3.4% to 2.8% (mean, −0.4%); these differences were nonsignificant for all listeners ($p = 0.392$ to $p = 0.972$). On the basis of these analyses, it does not appear that presenting sentences more than once affected listeners' recognition scores in this dataset.

IV. DISCUSSION

In this study, spectral weights for a sentence recognition task were measured for eight listeners with normal hearing. Target sentences were presented at either 75 or 95 dB SPL, and the SNR in each of five bands was jittered on a presentation-by-presentation basis by adjusting the levels of each masker band independently. Weights applied to band 5 (2807–11 000 Hz) were higher for the higher presentation level. This finding is broadly consistent with psychophysical data showing increased weight on higher spectral components for sample discrimination, spectral shape discrimination, and loudness (Kortekaas *et al.*, 2003; Lentz, 2007; Leibold *et al.*, 2009; Jesteadt *et al.*, 2014). It is also consistent with the idea that overall presentation level played an important role in the finding that listeners with hearing loss tested at ∼95 dB SPL place more weight on band 5 than normal-hearing listeners tested at 75 dB SPL (Calandruccio and Doherty, 2007, 2008).

Recall that the midpoint of the range of SNRs used for each listener were selected to produce 60%–80% correct at the 75-dB-SPL presentation level, and that the same range was used for both presentation levels. Performance at the middle of the SNR range was significantly poorer for the 95-dB-SPL than the 75-dB-SPL presentation level, consistent with previous reports that speech perception is degraded at higher than average conversational levels (e.g., Pollack and Pickett, 1958; Studebaker *et al.*, 1999). While it is possible that differences in the weight applied to band 5 could be related to differences in performance rather than presentation level, two observations cast doubt on that possibility. First, Calandruccio and Doherty (2007) reported that one normal-hearing listener repeated data collection with two different SNR ranges, one associated with 59% correct and the other with 75% correct; in both cases the weights were similar. Second, higher weights for band 5 were observed in datasets associated with lower overall percent correct scores in normal-hearing listeners, but the opposite trend was observed in the published hearing-impaired data (Calandruccio and Doherty, 2008). Normal-hearing listeners placed higher weights on band 5 when tested at 95 than 75 dB SPL, conditions associated with mean performance of 62.9% and 76.7% correct at the middle SNR, respectively. In contrast, hearing-impaired listeners placed higher weights on band 5 when tested without their hearing aids than with them, conditions associated with mean performance of 78.7% and 71.5% correct at the middle SNR, respectively (Calandruccio and Doherty, 2008). The most parsimonious explanation for these results is that the higher presentation level is responsible for elevated weights on band 5.

There is some indication in the literature that presentation level affects the quality of speech cues available to the listener in a frequency-dependent manner for speech presented in both quiet and in noise (Summers and Molis, 2004; Hornsby and Ricketts, 2006; Summers and Cord, 2007). For example, Molis and Summers (2003) reported presentation level effects for filtered speech by testing the recognition of low- and high-pass filtered sentences in quiet at four different presentation levels (75, 85, 95, and 105 dB SPL) in listeners with normal hearing. They found that a 30-dB increase in presentation level had a larger detrimental effect on high-pass (HP) than low-pass (LP) filtered speech, changing performance by 25 (HP) and 7 (LP) percentage points, respectively. Hornsby and Ricketts (2006) reported a similar frequency-dependent effect of presentation level. They found that overall consonant recognition decreased with increasing presentation level (65–100 dB SPL), but the use of speech recognition cues that were dominated by low frequency information (e.g., voicing) were relatively immune to the detrimental effects of increasing presentation levels. These findings raise the possibility that the higher weights applied to high-frequency bands of speech presented at a high level may be closely related to the reduced quality of high-frequency speech cues.

The primary goal of the present study was to evaluate the possible role of presentation level in the previously observed difference in spectral weights applied by normal-hearing and hearing-impaired listeners (Calandruccio and Doherty, 2007, 2008). A caveat to keep in mind when comparing data across groups is that although the speech targets were presented at approximately the same level for the two groups (∼95 SPL), the overall level differed due to the use of different SNR ranges. The average SNR midpoint for listeners with normal hearing in the present study was −8 dB SNR, compared to average midpoints of +1 and +3 dB SNR for listeners with hearing loss tested with and without hearing aids, respectively (Calandruccio and Doherty, 2008). The lower SNRs for normal-hearing listeners were achieved by increasing the masker level, such that the overall level of the combined speech and noise was higher for the normal-hearing listeners than the listeners with hearing loss. Differences in overall level notwithstanding, when both groups heard speech targets at a relatively high presentation level (∼95 dB SPL), there was no difference in weights applied to band 5 for hearing-impaired listeners tested with their hearing aids. A difference was observed, however, when hearing-impaired listeners were tested unaided. This result could be interpreted as evidence that the frequency shaping provided by the hearing aid helped listeners with hearing loss weight the spectral information more similarly to listeners with normal hearing.

Another factor to consider when comparing data between listener groups is differences in sensation levels. Sensation level (SL) differs between normal-hearing and hearing-impaired listeners when both groups are tested at a comparable presentation level. For the speech to be both audible and comfortable for a hearing-impaired listener with sloping hearing loss, like those tested by Calandruccio and Doherty (2008), the SL of the speech in the higher frequencies tends to be much lower than the SL in the lower frequencies. Figure 2 shows stimulus level in SL in $\frac{1}{3}$ octave bands for the normal-hearing listeners tested at 75 and 95 dB SPL in the present study, as well as the hearing-impaired listeners tested by Calandruccio and Doherty (2008). Comparing Figs. 1 and 2, there is no clear relationship between presentation level in SL and spectral weights. Although higher weights were associated with higher SLs for normal-hearing listeners, the SL was not predictive of differences in weights between normal-hearing and hearing-impaired listeners, or differences associated with aided vs unaided listening conditions (Calandruccio and Doherty, 2008). For example, levels in SL for band 5 were markedly different for hearing-impaired listeners tested with their hearing aids and normal-hearing listeners tested at 95 dB SPL, but weights were similar for these two datasets. In contrast, levels in SL for band 5 were similar for the aided and unaided hearing-impaired test conditions, but the weight on band 5 was higher for the unaided test condition. This pattern of results implicates presentation level in dB SPL, as opposed to dB SL, in the increased weight given to band 5. The finding that sensation level has no apparent effect on high-frequency weights for speech is consistent with psychophysical data (Lentz and Leek, 2003; Leibold *et al.*, 2009). For example, Leibold *et al.* (2009) induced sloping and reverse sloping hearing loss on their normal-hearing listeners by using a shaped masker noise. They, too, failed to find a correlation between SL and weights in a sample discrimination task.

There are inconsistencies in the literature regarding the importance of high-frequency information for speech understanding. Some authors have argued that providing high-frequency information may not be beneficial for some listeners with severe high-frequency hearing loss (e.g., Hogan and Turner, 1998; Vickers *et al.*, 2001; Amos and Humes, 2007), causing either no improvement in recognition, or in some cases a decrease in performance. However, others have pointed out that when listening in noise or listening in spatially separated noise sources, providing additional high-frequency information proves to be beneficial (e.g., Turner and Henry, 2002; Moore *et al.*, 2010; Levy *et al.*, 2015) even for those with reported cochlear dead regions (Pepler *et al.*, 2016). There is also evidence that at high presentation levels high-frequency information might be more important for certain speech features than for others (see Hornsby *et al.*, 2005). In addition, the current data set is consistent with the idea that the importance of high-frequency information may depend on the methods used to quantify band importance. Whereas the present correlation method indicates that at high presentation levels high-frequency bands contributed relatively more to the listeners' performance on the task than lower-frequency bands, this result is not observed when band importance is evaluated using filtered stimuli, with a range of low-pass and high-pass filter cutoffs (Studebaker and Sherbecoe, 2002; Molis and Summers, 2003; Summers and Cord, 2007). The correlation method allows for the presentation of a broadband signal as well as listening conditions that include different types of competing noise sources (e.g., broadband noise, as used here, and competing babble, see Gilbert and Michyel, 2005). Measuring spectral weights using a full-spectrum stimulus more closely resembles natural listening conditions, and therefore may be preferable for evaluating the importance of high-frequency information and determining when there is value to providing these cues to listeners with hearing loss. In particular, the current dataset highlights the importance of presentation level when interrupting results using the correlation method.

The present study systematically assessed the effects of presentation level on how listeners with normal hearing weight spectral information in sentences. Weights were estimated by evaluating the correlation between the SNR in a particular spectral band and correctness of the listener's response (Richards and Zhu, 1994; Lutfi, 1995). While this method has been used in a number of labs to better understand the cues listeners rely on for speech perception (e.g., Turner *et al.*, 1998; Apoux and Bacon, 2004; Gilbert and Micheyl, 2005; Fogerty, 2011), there are limitations to using the correlation method with speech stimuli. Notably, there is little reason to believe that the combination of speech cues is linear. Notwithstanding the method's limitations, the correlation method allows for testing multiple frequency bands simultaneously, rather than testing each frequency band in isolation. A broadband listening experience is what most listeners are faced with throughout their daily life, particularly when fitted with amplification. It is therefore valuable to understand how listeners use different spectral regions of the signal when listening to masked speech in a broadband condition.

The present data indicate that presentation level can affect spectral weights for speech recognition when computed using a correlation method. This finding is consistent with the results of previous psychophysical studies, showing

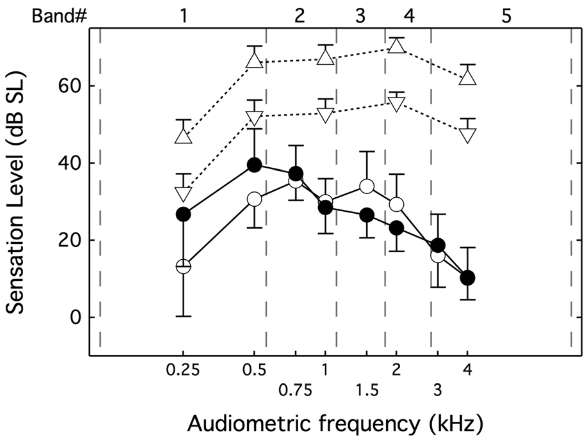

FIG. 2. Mean levels in dB SL for octave-wide bands. Error bars show one standard deviation. Data of hearing-impaired listeners are taken from Calandruccio and Doherty (2008).

an effect of level on high-frequency weights for sample discrimination (e.g., Leibold *et al.*, 2009), spectral shape discrimination (Lentz, 2007), and loudness (Jesteadt *et al.*, 2014). It is unclear what is responsible for this frequency-dependent level effect, but one possibility is that the increased loudness of high-frequency components with increased presentation level could result in greater perceptual saliency of high-frequency components; greater saliency could, in turn, result in greater weight applied to these high-frequency components. In the context of speech perception, the finding of greater high-frequency weights at higher presentation levels is particularly relevant to comparisons between normal-hearing listeners and listeners with hearing loss, groups that are often tested at different presentation levels to accommodate differences in sensitivity. Further, these data highlight the importance of considering high-presentation levels when testing the importance or benefit of high-frequency audibility.

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[1] This analysis was performed in rationalized arcsine units (RAUs; Studebaker, 1985) to stabilize error variance.

American Speech-Language-Hearing Association (**2006**). Preferred Practice Patterns for the Profession of Audiology [Preferred Practice Patterns], available from www.asha.org/policy.

Amos, N. E., and Humes, L. E. (**2007**). "Contribution of high frequencies to speech recognition in quiet and noise in listeners with varying degrees of high-frequency sensorineural hearing loss," J. Speech Hearing. Res. **50**, 819–834.

ANSI (**1997**). S3.5-1997, *American National Standard Methods for Calculation of Speech Intelligibility Index* (American National Standards Institute, New York).

ANSI (**2004**). S3.6-2004, *American National Standard Specification for Audiometers* (American National Standards Institute, New York).

Apoux, F., and Bacon, S. P. (**2004**). "Relative importance of temporal information in various frequency regions for consonant identification in quiet and in noise," J. Acoust. Soc. Am. **116**, 1671–1680.

Bell, T. S., Dirks, D. D., and Trine, T. D. (**1992**). "Frequency-importance functions for words in high- and low-context sentences," J. Speech Hear. Res. **35**, 950–959.

Byrne, D., and Dillon, H. (**1986**). "The National Acoustic Laboratories' (NAL) new procedure for selecting the gain and frequency response of a hearing aid," Ear Hear. **7**, 257–265.

Calandruccio, L., and Doherty, K. A. (**2007**). "Spectral weighting strategies for sentences measured by a correlational method," J. Acoust. Soc. Am. **121**, 3827–3836.

Calandruccio, L., and Doherty, K. A. (**2008**). "Spectral weighting strategies for hearing-impaired listeners measured using a correlational method," J. Acoust. Soc. Am. **123**, 2367–2378.

Doherty, K. A., and Lutfi, R. A. (**1996**). "Spectral weights for overall level discrimination in listeners with sensorineural hearing loss," J. Acoust. Soc. Am. **99**, 1053–1058.

Doherty, K. A., and Turner, C. W. (**1996**). "Use of a correlational method to estimate a listener's weighting function for speech," J. Acoust. Soc. Am. **100**(6), 3769–3773.

Fogerty, D. (**2011**). "Perceptual weighting of individual and concurrent cues for sentence intelligibility: Frequency, envelope, and fine structure," J. Acoust. Soc. Am. **129**, 977–988.

Gilbert, G., and Micheyl, C. (**2005**). "Influence of competing multi-talker babble on frequency-importance functions for speech measured using a correlational approach," Acta Acust. Acust. **91**, 145–154.

Hogan, C. A., and Turner, C. W. (**1998**). "High-frequency audibility: Benefits for hearing-impaired listeners," J. Acoust. Soc. Am. **104**, 432–441.

Hornsby, B. W. Y., and Ricketts, T. A. (**2006**). "The effects of hearing loss on the contribution of high- and low-frequency speech information to speech understanding. II. Sloping hearing loss," J. Acoust. Soc. Am. **119**, 1752–1763.

Hornsby, B. W. Y., Trine, T. D., and Ohde, R. N. (**2005**). "The effects of high presentation levels on consonant feature transmission," J. Acoust. Soc. Am. **118**, 1719–1729.

IEEE (**1969**). "IEEE recommended practice for speech quality measurements," IEEE Trans. Aud. Electroacoust. **17**, 225–246.

Jesteadt, W., Valente, D. L., Joshi, S. N., and Schmid, K. K. (**2014**). "Perceptual weights for loudness judgments of six-tone complexes," J. Acoust. Soc. Am. **136**, 728–735.

Kortekaas, R., Buus, S., and Florentine, M. (**2003**). "Perceptual weights in auditory level discrimination," J. Acoust. Soc. Am. **113**, 3306–3322.

Leibold, L. J., Tan, H., and Jesteadt, W. (**2009**). "Spectral weights for sample discrimination as a function of overall level," J. Acoust. Soc. Am. **125**, 339–346.

Lentz, J. J. (**2007**). "Variation in spectral-shape discrimination weighting functions at different stimulus levels and signal strengths," J. Acoust. Soc. Am. **122**, 1702.

Lentz, J. J., and Leek, M. R. (**2003**). "Spectral shape discrimination by hearing-impaired and normal-hearing listeners," J. Acoust. Soc. Am. **113**, 1604–1616.

Levy, S. C., Freed, D. J., Nilsson, M., Moore, B. C. J., and Puria, S. (**2015**). "Extended high-frequency bandwidth improves speech reception in the presence of spatially separated masking speech," Ear Hear. **36**, e214–e224.

Lutfi, R. A. (**1995**). "Correlation coefficients and correlation ratios as estimates of observer weights in multiple-observation tasks," J. Acoust. Soc. Am. **97**, 1333–1334.

Molis, M. R., and Summers, V. (**2003**). "Effects of high presentation levels on recognition of low- and high-frequency speech," Acoust. Res. Lett. **4**, 124–128.

Moore, B. C., Füllgrabe, C., and Stone, M. A. (**2010**). "Effect of spatial separation, extended bandwidth, and compression speech on intelligibility in a competing-speech task," J. Acoust. Soc. Am. **128**, 360–371.

Pepler, A., Lewis, K., and Munro, K. J. (**2016**). "Adult hearing-aid users with cochlear dead regions restricted to high frequencies: Implications for amplification," Int. J. Aud. **55**, 20–29.

Pollack, I., and Pickett, J. M. (**1958**). "Masking of speech by noise at high sound levels," J. Acoust. Soc. Am. **30**, 127–130.

Richards, V. M., and Zhu, S. (**1994**). "Relative estimates of combination weights, decision criteria, and internal noise based on correlation coefficients," J. Acoust. Soc. Am. **95**, 423–434.

Studebaker, G. A. (**1985**). "A "rationalized" arcsine transform," J. Speech Hear. Res. **28**(3), 455–462.

Studebaker, G. A., and Sherbecoe, R. L. (**2002**). "Intensity-importance functions for bandlimited monosyllabic words," J. Acoust. Soc. Am. **111**, 1422–1436.

Studebaker, G. A., Sherbecoe, R. L., McDaniel, D. M., and Gwaltney, C. A. (**1999**). "Monosyllabic word recognition at higher-than-normal speech and noise levels," J. Acoust. Soc. Am. **105**, 2431–2444.

Summers, V., and Cord, M. T. (**2007**). "Intelligibility of speech in noise at high presentation levels: Effects of hearing loss and frequency region," J. Acoust. Soc. Am. **122**, 1130–1137.

Summers, V., and Molis, M. R. (**2004**). "Speech recognition in fluctuating and continuous maskers: Effects of hearing loss and presentation level," J. Speech Lang. Hear. Res. **47**, 245–256.

Turner, C. W., and Henry, B. A. (**2002**). "Benefits of amplification for speech recognition in background noise," J. Acoust. Soc. Am. **112**, 1675–1680.

Turner, C. W., Kwon, B. J., Tanaka, C., Knapp, J., Hubbartt, J. L., and Doherty, K. A. (**1998**). "Frequency-weighting functions for broadband speech as estimated by a correlational method," J. Acoust. Soc. Am. **104**, 1580–1585.

Vickers, D. A., Moore, B. C., and Baer, T. (**2001**). "Effects of low-pass filtering on the intelligibility of speech in quiet for people with and without dead regions at high frequencies," J. Acoust. Soc. Am. **110**, 1164–1175.