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The Effects of Venting and Low-Frequency Gain Compensation on Performance in Noise with Directional Hearing Instruments

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Abstract

The present study investigated the effects of gain compensation and venting on front-to-back ratios (FBRs), speech understanding in noise, and acceptance of noise in 19 listeners with hearing impairment utilizing directional hearing instruments. The participants were separated into two groups based on degree of low-frequency hearing sensitivity. Subjects were fitted binaurally with Starkey Axent II programmable behind-the-ear hearing aids and full-shell earmolds (select-a-vent). Results demonstrated that gain compensation and venting significantly affected FBRs for both groups; however, acceptance of noise was not significantly affected by gain compensation or venting for either group. Results further demonstrated that speech understanding in noise was unaffected by venting but may be improved with the use of gain compensation for some listeners. Clinical implications are discussed.

Key Words: Acceptance of background noise, directional hearing aids, front-to-back ratio, low-frequency gain compensation, speech understanding in noise, venting

Abbreviations: AI-DI = articulation index-weighted DI; ANL = acceptable noise level; BNL = background noise level; BTE = behind-the-ear; DI = directivity index; FBR = front-to-back ratio; HINT = Hearing in Noise test; ITE = in-the-ear; MCL = most comfortable level; SII = Speech Intelligibility Index; SNR = signal-to-noise ratio

Sumario

El presente estudio investigó los efectos de la compensación de la ganancia y del venting en las tasas frente-atrás (FBR), en la comprensión del lenguaje en ruido, y en la aceptación del ruido, en 19 sujetos con hipoacusia que utilizaban instrumentos auditivos direccionales. Los participantes fueron separados en dos grupos con base en el grado de sensibilidad auditiva a las bajas frecuencias. A los sujetos se les adaptaron curvetas retroauriculares programables Starkey Axent II, con moldes de concha completa (select-a-vent). Los resultados demostraron que la compensación de la ganancia y el venting afectaban efectivamente la FBR en ambos grupos; sin embargo, la aceptación del ruido no fue completamente afectada por la compensación de la ganancia o por el venting en ningún grupo. Los resultados demostraron también que la comprensión del lenguaje en ruido no era afectada por el venting pero que podía mejorar con el uso de compensación de la ganancia en algunos sujetos. Se discuten las implicaciones clínicas.

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Palabras Clave: Aceptación del ruido de fondo, auxiliares auditivos direccionales, tasa frente-atrás, compensación de la ganancia en las bajas frecuencias, comprensión del lenguaje en ruido, venting

Abreviaturas: AI/DI = Indice de articulación/ponderación DI; ANL = nivel de ruido aceptable; BNL = nivel de ruido de fondo; BTE = retroauricular; DI = índice de direccionalidad; tasa frente-atrás; HINT = Prueba de audición en ruido; ITE = intra-auricular; MCL = nivel más confortable; SII = Indice de Inteligibilidad del Lenguaje; SNR = tasa señal/ruido

Listeners with hearing impairment have difficulty understanding speech in the presence of background noise. Consequently, technological advances in hearing instrument design strive to diminish the effects of noise for hearing instrument wearers (Kochkin, 1993). One such technological advance is the directional microphone. Directional hearing instruments reduce the negative effects of background noise by providing greater amplification for signals arriving from the front of the listeners than signals arriving from the rear and/or sides of the listener (Kuk et al, 2000; Dillon, 2001).

The ability to understand speech in background noise can be improved through the use of directional microphone technology (Agnew and Block, 1997; Gravel et al, 1999; Kuk et al, 1999; Wouters et al, 1999; Ricketts and Mueller, 2000; Kuhnel et al, 2001). This improvement has been shown through improved signal-to-noise ratio (SNR) and improved speech recognition for words and sentences (Gravel et al, 1999; Valente et al, 2000). For example, making use of directional microphone technology, Valente et al (2000) found an average SNR improvement of 3.5 dB using the Hearing in Noise Test (HINT) (Soli and Nilsson, 1994). Gravel et al (1999) also found a significant directional advantage for the recognition of both words and sentences in background noise.

Directional microphones also increase the acceptance of background noise in hearing instrument users. Acceptance of background noise can be measured using a procedure developed by Nabelek et al (1991) termed "acceptable noise level" (ANL). ANL is a measure of an individual's willingness to accept background noise and is directly related to hearing aid usage (Nabelek et al, 1991). Individuals with small ANLs (e.g., 6 dB) are more likely to be successful hearing aid users, meaning they wear hearing aids on a regular basis. Individuals with large ANLs (e.g., 14 dB), however, are typically unsuccessful hearing aid users, meaning they do not wear hearing aids regularly (Nabelek et al, forthcoming). ANL is not related to age, gender, degree of hearing sensitivity, or speech perception in noise (Nabelek et al, 1991; Rogers et al, 2003). Whereas speech perception scores are improved by amplification, ANLs remain the same, indicating that ANLs and speech perception tasks measure two different reactions to background noise. Specifically, speech perception tasks demonstrate aided benefit, and ANL measures may predict pattern of hearing instrument use (Nabelek et al, forthcoming).

Freyaldenhoven et al (2005) showed an average ANL decrease of 3.5 dB when comparing ANLs obtained using an omnidirectional instrument to ANLs obtained with a directional hearing aid (i.e., listeners accepted more noise in the directional mode). The amount of ANL directional benefit, however, varied from -4 to 12 dB. The large variability in ANL benefit may have been due to the fact that the participants were tested using their personal hearing aids, which did not control for hearing aid style, type of directional microphone, vent size, compression, or low-frequency gain compensation.

Research has demonstrated that directional hearing aids may improve performance in noise; however, two factors that remain a concern when fitting directional hearing instruments are low-frequency gain compensation and vent size. First, directional hearing instruments provide less low-frequency gain than their omnidirectional counterparts (Thompson, 1999; Dillon, 2001; Ricketts, 2001). The reduced sensitivity to the low frequencies is typically referred to as "directional roll-off," which occurs due to frequency-dependent differences in phase alignment of the signal after the internal delay has been applied. Directional roll-off affects low-frequency signals more than high frequencies because low-frequency signals sampled near one another in space will be more similar in phase than high-frequency signals when reaching each microphone port of the hearing aid. As a result, less gain is applied to low-frequency signals, which might affect audibility of the signal for some listeners (Ricketts and Henry, 2002). Directional hearing instruments may compensate for this gain reduction by increasing low-frequency gain at the amplifier or microphone preamplifier stage (Ricketts and Dittberner, 2002). Gain compensation resulting in no frequency response difference between directional and omnidirectional modes is referred to as an equalized directional frequency response (Ricketts and Henry, 2002).

Low-frequency gain compensation in directional hearing instruments has been evaluated objectively (i.e., speech recognition threshold and sentence recognition tasks) and subjectively (i.e., sound quality judgments) in quiet and in noise with in-the-ear (ITE) hearing instruments. Results demonstrated that directional benefit from low-frequency gain compensation was dependent on the degree of low-frequency hearing loss of the listener (Ricketts and Henry, 2002). Based on these results, it was recommended that listeners with low-frequency hearing poorer than 40 dB HL utilize gain compensation when using directional hearing instruments. Low-frequency gain compensation has not, however, been evaluated perceptually in behind-the-ear (BTE) hearing instruments. Also, the effects of low-frequency gain compensation on ANL have not been examined.

Second, directional benefit may also be reduced if venting is utilized during the hearing instrument fitting (Ricketts, 2000; Killion, 2004). The low-frequency in situ response of a hearing instrument is determined by the vent transmission path while the remainder of the in situ frequency response is determined by the amplified transmission path. Since directivity is maximized in the low frequencies, directional benefit may be compromised by low-frequency components passing through the vent instead of the hearing aid. These effects may be worse if high-level, low-frequency components pass through the vent instead of the hearing aid, and the intensity level of the signal transmitted through the vent is similar to the intensity level of the amplified signals, essentially masking the signal picked up by the hearing instrument. Therefore, closing the vent in a directional hearing instrument may significantly improve directional benefit, while opening the vent in a directional hearing instrument may significantly reduce directional benefit (Ricketts, 2000; Dillon, 2001).

The effect of venting directional hearing instruments has only been evaluated electroacoustically. Directivity index (DI) values were significantly reduced below 1000 Hz when the vent size was increased from no vent to an open earmold in a BTE hearing aid. (Ricketts, 2000). Likewise, DI values for an ITE hearing instrument were significantly reduced when vent size was increased from no vent to a 3 mm vent (Mueller and Wesselkemp, 1999). Articulation index-weighted DI (AI-DI) scores, an enhancement of DI scores that assign more weight to frequencies most important for speech intelligibility (Killion et al, 1998), were also reported by Ricketts (2000). AI-DI scores decreased by only 1.6 dB when venting was used with a directional BTE hearing instrument. Based on this finding, Ricketts (2000) suggested that venting may not significantly reduce perceptual benefit from directional hearing instruments. However, the perceptual effects of venting a directional hearing aid have not yet been studied.

In summary, directional hearing instruments provide less low-frequency gain than their omnidirectional counterparts. Research has demonstrated that compensating for this reduced low-frequency gain improves speech perception and subjective quality ratings for listeners with significant low-frequency hearing loss wearing ITE hearing aids. The effect of low-frequency gain compensation on acceptance of background noise is, however, unknown. It is possible that gain compensation, which was not controlled by Freyaldenhoven et al (2005), may provide greater ANL reductions, thereby significantly increasing a listeners' success with hearing aids.

Research has also shown that venting decreases low-frequency gain and low-frequency directivity; however, the effects of venting on behavioral benefit with directional hearing instruments remain unclear. Ricketts (2000) concluded that venting a directional hearing instrument should not significantly affect perception; however, these effects have not been measured on individuals with hearing impairment. Furthermore, the effect of venting directional hearing aids has been not evaluated in terms of ANL. It is possible that venting, which Freyaldenhoven et al (2005) did not control, may affect ANLs, therefore significantly altering a listeners' success with hearing aids. Therefore, the purpose of the present study was to examine the effects of low-frequency gain compensation and venting on listener performance in noise using directional hearing instruments. The following research questions were addressed:

1. Does venting and/or low-frequency gain compensation affect speech understanding in noise in listeners with hearing impairment using directional hearing instruments?
2. Does venting and/or low-frequency gain compensation affect acceptance of background noise in listeners with hearing impairment using directional hearing instruments?
3. Are the effects of low-frequency gain compensation and/or venting related to the degree of low-frequency hearing loss of the listener?

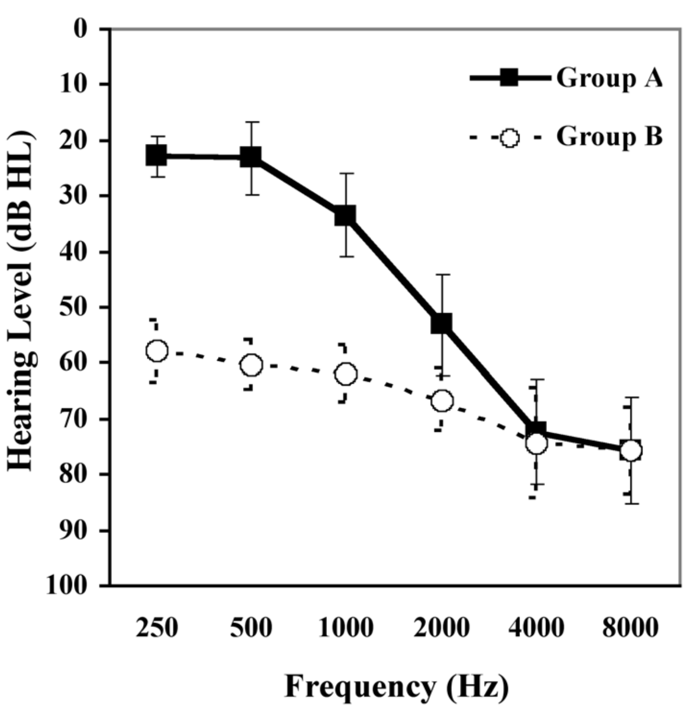

Figure 1. Mean binaural air conduction thresholds and standard deviations of the participants in Groups A and B.

METHODS

Participants

Nineteen adults participated in this experiment. The participants were divided into two groups (Group A [9 participants: mean age = 73.5 years; range = 62–83 years] and Group B [10 participants: mean age = 69.3 years, range = 53–83 years]). The criteria for inclusion in Group A included: (1) sensorineural hearing impairment with no more than a 15 dB HL difference in pure-tone thresholds at any octave frequency from 250 through 8000 Hz between ears (ANSI S3.6-1996; American National Standards Institute, 1996); (2) current binaural hearing instrument user; (3) native English speakers with no known neurological, cognitive, or learning deficits as reported by the subjects; and (4) two adjacent hearing thresholds better than 45 dB HL from 250 through 1000 Hz. The inclusion criteria for Group B differed from that of Group A in one aspect: two adjacent hearing thresholds were poorer than 45 dB HL from 250 through 1000 Hz (Figure 1). All qualification and experimental testing was conducted in a sound-treated examination room (IAC, model #404A; 2.7 X 2.5 meters) with ambient noise levels appropriate for testing unoccluded ears (ANSI S3.1-1991; American National Standards Institute, 1991).

Earmolds

Prior to experimental testing, qualified subjects were fit binaurally with custom full-shell earmolds made of Emplex II. (Note: Emplex II is a soft, pliable material typically recommended for severe to profound hearing losses.) A 4 mm select-a-vent and #13 standard wall (.076 X .122) tubing were used for all earmolds (Emtech Laboratories Incorporated). All earmolds were made the same length with the same bore size by one technician.

Hearing Instruments

Two digital BTE hearing instruments with dual microphones (fixed cardioid polar plot) and multiple memory capability (Starkey J13 Axent II AV) were utilized in the study. The same two hearing instruments were used for each participant. The audiometric data of each participant was used to program each hearing instrument using the National Acoustic Laboratories (NAL-R) fitting strategy (Byrne and Dillon, 1986) (Note: Linear processing was utilized to prevent differential effects caused by compression [Ricketts, 2000]). Two memories of the digital hearing instruments were programmed for each participant (Starkey QuickFit). All fitting parameters of Memory 1 were identical to all fitting parameters of Memory 2; however, low-frequency gain compensation was utilized in only one of the two memories. This resulted in one memory in which low-frequency gain compensation was utilized, and one memory in low-frequency gain compensation was not utilized. All other fitting parameters were held constant across the two memories. The noise suppression feature was deactivated for the entire experiment, and the volume control setting was unchanged during all experimental testing.

Stimuli

The Hearing in Noise test (HINT) (Nilsson et al, 1994) served as the stimuli for evaluating speech understanding in noise. The HINT consisted of 25 lists of 10 English sentences. An adaptive presentation was utilized to determine the sentence reception threshold in terms of SNR for each participant using sentence blocks.

A recording of male running speech (Arizona Travelogue, Cosmos, Inc.[1]) and multitalker babble (Revised Speech Perception in Noise; Kalikow et al, 1977) served as the stimuli for evaluating acceptance of background noise. An adaptive presentation was utilized to determine the most comfortable listening level (MCL) for speech and the maximum acceptable background noise level (BNL) for each participant. The difference between the MCL for speech and the BNL served as the acceptable noise level (ANL) for each participant (see Freyaldenhoven et al [2005] for review).

All speech stimuli and background noise were produced by a compact disc player and routed through a two-channel diagnostic audiometer (GSI-16) to loudspeakers located in the sound-treated examination room. Speech stimuli were presented from 0° azimuth and background noise was presented from 180° azimuth. The output levels of the speech stimuli and background noise were calibrated at the vertex of the listener and were checked periodically throughout the experiment.

Probe Microphone Measures

To determine the effects of venting and low-frequency gain compensation on directionality, binaural probe microphone measurements (Audioscan RM500) were conducted for each participant. Participants were seated 1.5 m from the loudspeaker located at 0° azimuth. The loudspeaker on the probe microphone system was deactivated, and the HINT background noise was presented at 65 dB SPL from the loudspeaker located at 0° azimuth. Probe microphone measurements were conducted with the participant facing the loudspeaker and then with the participant's back to the loudspeaker for each venting (open and closed) and low-frequency gain compensation (compensated and uncompensated) condition. Therefore, a total of eight measurements were made for the four conditions. All probe microphone measurements consisted of 65 data points measured in 1/12th octave steps over a frequency range of 200 Hz to 8000 Hz. Data for output levels recorded at the tympanic membrane were stored in the probe microphone system and downloaded to a personal computer for subsequent data analysis.

Speech Understanding in Noise

Speech understanding in noise was assessed for each venting and low-frequency gain compensation condition. Participants were seated 1.5 m from each loudspeaker (0° and 180° azimuth) in the sound-treated room. The HINT was administered at 65 dB SPL for each venting/low-frequency gain compensation condition. The sentences were presented through an ear-level loudspeaker located at 0° azimuth while the HINT background noise was presented through an ear-level loudspeaker located at 180° azimuth. The HINT protocol utilized in the present study reflected a slight modification of the original HINT protocol in that noise levels were varied and speech levels were fixed. This protocol variation ensured that speech levels were consistent between the HINT and the ANL stimuli. Two HINT trials were conducted for each experimental condition. An average of the two trials served as the mean HINT score for that participant in the given condition.

Acceptance of Background Noise

Acceptance of background noise was also assessed for each venting and gain compensation condition. Participants remained seated 1.5 m from each loudspeaker (0° and 180° azimuth) in the sound-treated room. ANLs were determined for each venting/low-frequency gain compensation condition. The male running speech was presented through an ear-level loudspeaker located at 0° azimuth while the multitalker speech babble was presented through an ear-level loudspeaker located at 180° azimuth. Two ANL trials were conducted for each experimental condition. An average of the two trials served as the mean ANL for that participant in the given condition.

Prior to data collection, an experimental schedule was generated for each participant listing a completely randomized assignment for each venting/low-frequency gain compensation condition. ANL and HINT procedures were then counterbalanced within each experimental condition (Note: HINT sentences were assigned at random). Upon completion of performance in noise measures, binaural probe microphone measurements were made for each condition.

RESULTS

Probe Microphone Measures

Probe microphone measurements obtained with the participant's back to the loudspeaker were subtracted from measurements obtained with the participant facing the loudspeaker to quantify directional effects for each experimental condition. Difference curves were averaged across ears for the 19 participants for each condition. Results revealed similar performance per condition for frequencies above 2000 Hz; however, differences in directivity were evident per condition for frequencies below 2000 Hz. Therefore, an overall front-to-back ratio (FBR) was calculated for each venting and low-frequency gain compensation condition by averaging values from 250 to 2000 Hz for each participant (Figure 2).

A three-way repeated measures analysis of variance (ANOVA) was performed to evaluate the effects of venting, low-frequency gain compensation, and hearing sensitivity on measures of FBR. The dependent variable was the FBR. The within-subject factors were venting with two levels (open and closed) and gain compensation with two levels (uncompensated and compensated). The between-subject factor was group with two levels (Group A and Group B). The analysis revealed significant main effects for venting ($F_{1,17}$ = 10.41, p = 0.005) and gain compensation ($F_{1,17}$ = 6.88, p = 0.018). However, there were no significant main effects for group ($F_{1,17}$ = 0.84, p = 0.372) or

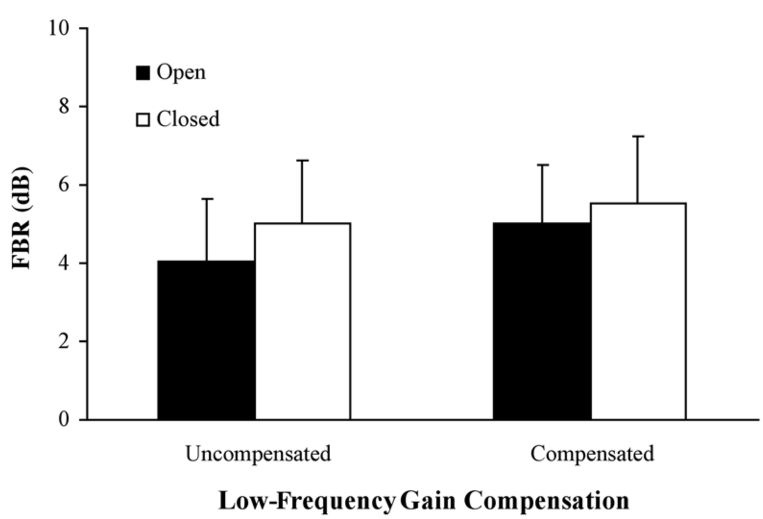

Figure 2. Mean binaural FBR measures and standard deviations for all 19 participants obtained using an input signal level of 65 dB SPL for the venting/gain compensation conditions.

for the venting by group ($F_{1,17}$ = 0.01, p = 0.943) or gain compensation by group ($F_{1,17}$ = 0.12, p = 0.733) interactions. These results indicated that closing the vent significantly increased the FBR below 2000 Hz. Results further suggested that compensating low-frequency gain significantly increased the FBR below 2000 Hz as well.

Speech Understanding in Noise

One purpose of the present study was to determine if venting and/or low-frequency gain compensation affected speech understanding in noise. The HINT was conducted at 65 dB SPL for each venting/gain compensation condition. The HINT was replicated for each condition, and a mean HINT score was determined for each participant. Mean HINT scores for each group and condition are shown in Figure 3. To determine the test-retest reliability of HINT scores, an Average Measure Intraclass Correlation Coefficient based on the consistency definition was calculated for HINT scores between the two trials. The correlation coefficient was r = 0.92 (p < 0.001), indicating a high test-retest reliability of SPIN scores obtained between trials.

A three-way repeated measures ANOVA was performed to evaluate the effects of venting, low-frequency gain compensation, and hearing sensitivity on speech understanding in noise. The dependent variable was the HINT score. The within-subject factors were venting with two levels (open and closed) and gain compensation with two levels (uncompensated and compensated). The between-subject factor was group with two levels (Group A and Group B). The analysis revealed significant main effects for group ($F_{1,17}$ = 12.47, p = 0.003). No significant main effects or interactions were seen for venting ($F_{1,17}$ = 3.75, p = 0.070), gain compensation ($F_{1,17}$ = 2.07, p = 0.168), or for the venting by group ($F_{1,17}$ = 0.49, p = 0.492) or gain compensation by group ($F_{1,17}$ = 1.81, p = 0.196) interactions. These results indicated that listeners with less hearing impairment performed significantly better than listeners with more severe hearing impairment and that speech understanding in noise was not significantly affected by venting or low-frequency gain compensation for either group.

Acceptance of Background Noise

Another purpose of the present study was to determine if venting and/or gain compensation affected acceptance of background noise. The ANL was obtained twice for each venting/gain compensation condition, and a mean ANL was determined for each participant. Mean ANLs for each group and condition are shown in Figure 4. To determine the test-retest reliability of ANLs, an Average Measure Intraclass Correlation Coefficient based on the consistency definition was calculated for ANL measures between the two trials. The correlation coefficient was r = 0.94 (p < 0.001), indicating a high test-retest reliability of ANLs obtained between trials.

A three-way repeated measures ANOVA was performed to evaluate the effects of

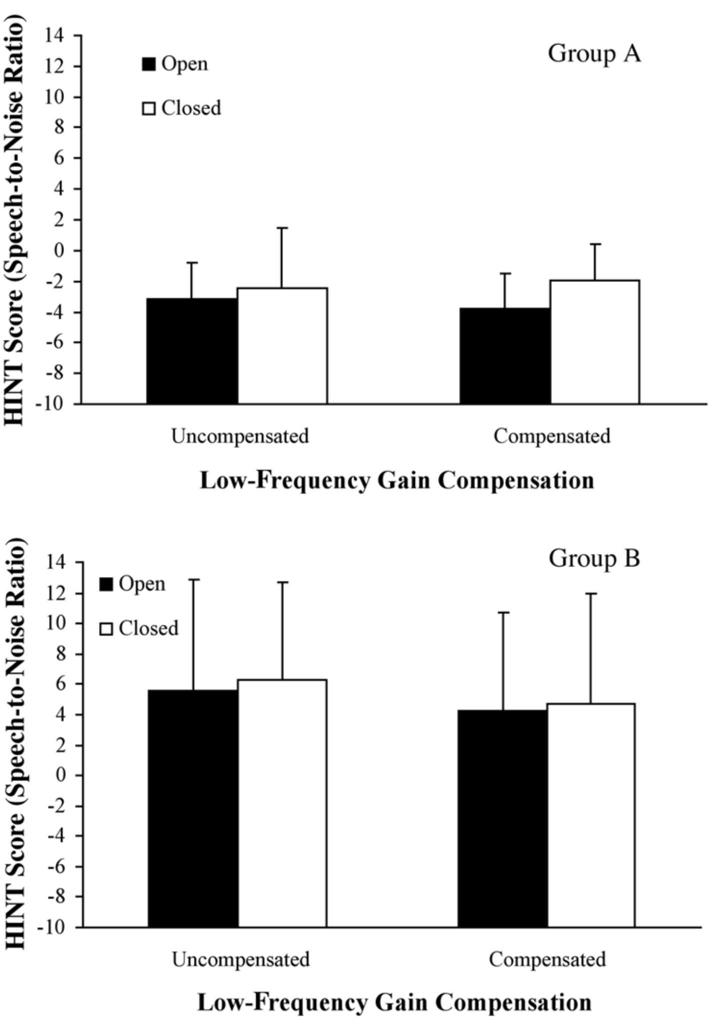

Figure 3. Mean HINT scores and standard deviations for Groups A and B for the venting/gain compensation conditions.

venting, low-frequency gain compensation, and hearing sensitivity on acceptance of background noise. The dependent variable was the ANL. The within-subject factors were venting with two levels (open and closed) and gain compensation with two levels (uncompensated and compensated). The between-subject factor was group with two levels (Group A and Group B). No significant main effects were seen for group ($F_{1,17} = 0.66$, $p = 0.427$), venting ($F_{1,17} = 0.31$, $p = 0.584$), gain compensation ($F_{1,17} = 0.50$, $p = 0.490$), or for the venting by group ($F_{1,17} = 1.07$, $p = 0.315$) or gain compensation by group ($F_{1,17} = 1.71$, $p = 0.208$) interactions. These results suggested that acceptance of background noise was not affected by venting, low-frequency gain compensation, or hearing sensitivity.

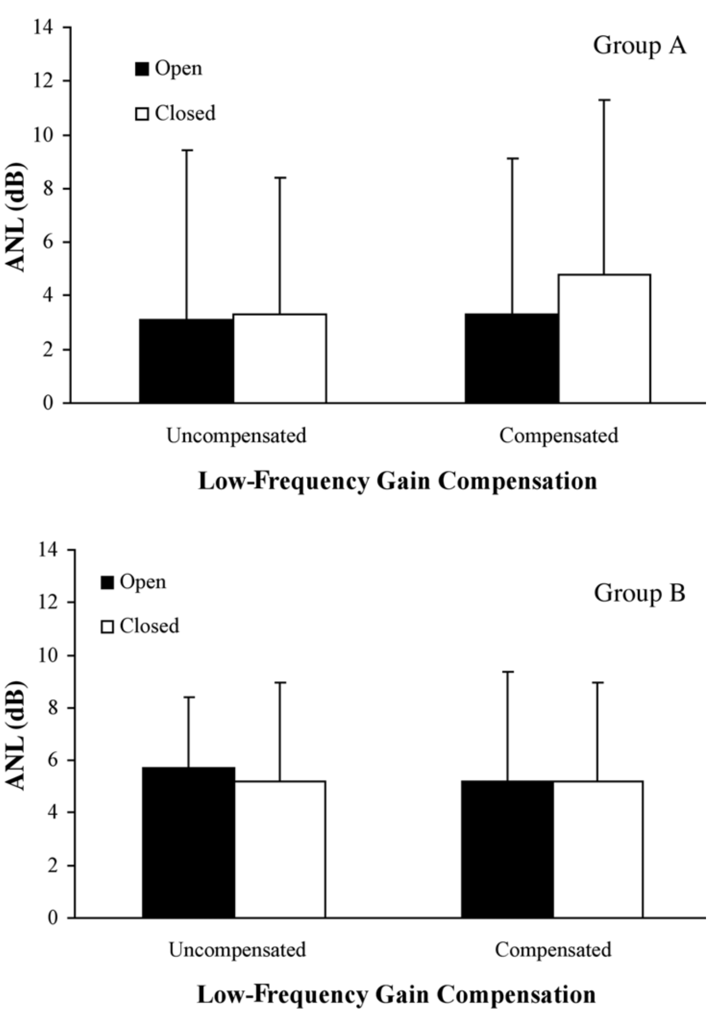

Figure 4. Mean ANLs and standard deviations for Groups A and B for the venting/gain compensation conditions.

Degree of Hearing Loss

Although analyses conducted using group data did not reveal significant effects due to venting and/or gain compensation, examination of individual subject data suggested that such effects may have been evident for listeners in Group B with low-frequency hearing thresholds of 55 dB HL or poorer. Therefore, two 2-way repeated measure ANOVAs were performed for the six listeners with low-frequency hearing loss poorer than 55 dB HL (Note: Low-frequency hearing loss was calculated by averaging 250, 500, and 1000 Hz). The dependent variable was the HINT score for the first analysis and ANL for the second analysis. The within-subject factors were venting with two levels (open and closed) and gain compensation with two levels (uncompensated and compensated) for both analyses.

Results from the first analysis revealed a significant main effect for gain compensation ($F_{1,5} = 7.56$, $p = 0.040$). No significant main effects were seen for venting ($F_{1,5} = 0.794$, $p = 0.414$) or for the venting by gain compensation interaction ($F_{1,5} = 0.083$, $p = 0.784$). These results suggested that low-frequency gain compensation significantly improved speech understanding in noise for listeners with low-frequency hearing thresholds of 55 dB HL or poorer.

Results of the second analysis revealed no significant main effects were seen for venting ($F_{1,5} = 0.652$, $p = 0.456$), gain compensation ($F_{1,5} = 2.952$, $p = 0.146$), or for the venting by gain compensation interaction ($F_{1,5} = 0.426$, $p = 0.543$). These results suggested that acceptance of background noise was not affected by venting or low-frequency gain compensation for listeners with low-frequency hearing thresholds of 55 dB HL or poorer.

DISCUSSION

Probe Microphone Measures

Probe microphone measures revealed that FBRs varied in the predicted direction when venting or low-frequency gain compensation was manipulated. FBRs were smallest when the vent was open and low-frequency gain was not compensated. Likewise, the FBRs were largest when the vent was closed and low-frequency gain was compensated. This suggests that the hearing aids and earmolds were functioning appropriately throughout the experimental testing. These results were expected based on venting results reported by Ricketts (2000) and low-frequency gain compensation results reported by Ricketts and Henry (2002). Ricketts (2000) calculated DI values on KEMAR using different vent sizes and found that as vent size increased, directivity (i.e., DI values) decreased. Furthermore, Ricketts and Henry (2002) calculated Speech Intelligibility Index (SII) difference values for noncompensated and compensated low-frequency gain and found that SII values were significantly lower when low-frequency gain was not compensated. Results from the present study further indicate that the effects of venting and low-frequency gain compensation on directional performance can be measured using routine, clinical probe microphone measurements like the FBR. It should be noted that FBR results may differ from the current findings in ITE hearing aids or hearing aids utilizing compression or other directional microphone arrays (Ricketts, 2000).

Speech Understanding in Noise

One purpose of the present study was to determine if venting and/or low-frequency gain compensation affected speech understanding in noise. Participants with low-frequency hearing sensitivity better than 45 dB HL (Group A) performed significantly better than those with low-frequency hearing sensitivity poorer than 45 dB HL (Group B) in all conditions. Furthermore, speech understanding in noise was unaffected by venting or low-frequency gain compensation for either group. These results suggested that listeners with better low-frequency hearing sensitivity can be expected to understand speech in the presence of background noise better than those with poorer low-frequency hearing sensitivity, independent of vent size or amount of gain compensation.

The fact that speech understanding was unaffected by venting might have been expected based on the AI-DI scores predicted by Ricketts (2000) for various vent conditions. Specifically, Ricketts (2000) predicted that changing the vent from no vent to an open earmold would have little effect on speech perception. In the present study, the vent size ranged from no vent to 4 mm and significantly changed the in situ response and the FBRs below 2000 Hz (Figure 2). However, these changes were not large enough to significantly impact speech understanding. Venting may have significantly affected speech understanding had a larger vent size been examined. For example, it is possible that open molds or open fittings may result in larger FBR reductions than observed in this study, thereby potentially reducing directional benefit (Kreisman et al, 2004). However, it is also possible that open fittings may produce FBRs similar to those observed in this study, thereby preserving directional benefit (Flynn, 2004).

The fact that speech understanding was unaffected by gain compensation for listeners with low-frequency hearing poorer than 45 dB HL was not expected and appeared to be inconsistent with the Ricketts and Henry (2002) recommendation. Ricketts and Henry (2002) recommended that gain compensation should be utilized for listeners with low-frequency hearing loss poorer than 40 dB HL. Specifically, gain compensation significantly improved speech understanding in noise only for listeners with low-frequency hearing poorer than 60 dB HL; however, speech understanding in noise was not hindered when gain compensation was applied for listeners with low-frequency hearing poorer than 40 dB HL (Ricketts and Henry, 2002). It should be noted, however, that participants in the Ricketts and Henry (2002) study utilized vent sizes appropriate for their hearing loss; therefore, listeners with less low-frequency hearing loss used larger vent sizes than those with more low-frequency hearing loss. Consequently, Ricketts and Henry (2002) attributed the lack of speech understanding improvement from gain compensation in listeners with less low-frequency hearing loss to venting differences across the participants.

Results from the current investigation suggested that speech understanding improvement can be obtained from gain compensation when low-frequency hearing levels are 55 dB HL or poorer. Furthermore, listeners with low-frequency hearing better than 55 dB HL were not hindered by low-frequency gain compensation. Therefore, these results were in agreement with the results obtained by Ricketts and Henry (2002), which suggested that listeners with low-frequency hearing poorer than 55–60 dB HL should benefit from gain compensation. It should be noted, however, that vent size was controlled for each participant in the current study. However, speech understanding in listeners with less low-frequency hearing loss was not significantly improved by gain compensation when no venting was applied. Thus, the lack of improvement from gain compensation in listeners with less low-frequency hearing loss may not be attributed to venting. An alternative explanation may be that listeners with less low-frequency hearing loss require less low-frequency gain from their hearing instrument; therefore, since less gain is prescribed, the effects of gain compensation may be minimal. However, this theory warrants further study.

Acceptance of Background Noise

A second purpose of the present study was to determine if venting and/or gain compensation affected acceptance of background noise. ANL was not affected by venting, low-frequency gain compensation, or hearing sensitivity. These results agree with previous ANL studies, which found that ANL was unaffected by a listener's pure-tone average (Nabelek et al, 1991). Furthermore, these results suggested that a listener's acceptance of background noise, and thus their acceptance of hearing aids, may be unaffected by venting or low-frequency gain compensation as well.

Although gain compensation significantly improved speech understanding for listeners with low-frequency hearing poorer than 55 dB HL, acceptance of noise was not affected by either gain compensation or venting regardless of degree of low-frequency hearing loss. These results provide further support that speech perception tasks and acceptance of noise measure two different reactions to background noise.

As mentioned previously, Freyaldenhoven et al (2005) reported large between-subject variability in ANL benefit for individuals tested with their personal directional hearing instruments. Results of the present study suggest that the ANL variability seen by Freyaldenhoven et al (2005) was not due to venting or low-frequency gain compensation, at least for those individuals using BTE instruments with dual microphones and linear processing. Furthermore, it is possible that the effects of venting and gain compensation did not contribute to the variability seen in ANLs for ITE wearers, although this hypothesis warrants further investigation. Future research should also examine the effects of type of directional microphone and signal processing scheme on the acceptance of background noise with directional hearing instruments.

CLINICAL IMPLICATIONS

Results of the present study indicate that FBR measurements were affected by venting and low-frequency gain compensation; however, these effects did not transfer into perceptual differences for most listeners in the sample population. Acceptance of background noise was unaffected by changes in venting and/or low-frequency gain compensation. Likewise, speech understanding ability was unaffected by venting. Speech understanding in noise was, however, affected by degree of low-frequency hearing sensitivity and improved when gain compensation was utilized for listeners' with low-frequency hearing of 55 dB HL or poorer. These results suggest acceptance of noise (i.e., willingness to wear a hearing aid) is unaffected by venting and/or gain compensation. Results further suggest that individuals with better low-frequency hearing have better speech understanding ability and that activating compensation may improve speech understanding in noise for listeners with more significant low-frequency hearing loss. Therefore, clinicians can alter vent size based on patient report without (1) decreasing speech intelligibility or (2) decreasing the likelihood that the patient will "accept"/wear their hearing aids. Clinicians should, however, be aware that activating gain compensation may add to a listener's directional benefit if their low-frequency hearing is 55 dB HL or poorer.

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NOTE

1. Cosmos, Inc., is owned and operated by Robert McClocklin. A copy of the ANL CD can be obtained from him by contacting Robert McClocklin by email (rmcclock@shaw.ca), phone (1-866-764-7673), or by mailing a request to Robert McClocklin, 4744 West Ridge Dr., Kelowna, British Columbia, VIW3B5. In addition, a copy of the ANL materials can be found at http://web.utk.edu/%7Easpweb/faculty/nabelek/anl.shtml.

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