

# Relationship Between In-Situ Distortion and Hearing Aid Benefit

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## Abstract

In-situ hearing aid distortion is defined as distortion measured in the ear canal with stimulus inputs and hearing aid settings that are similar to those the hearing aid wearer will experience in daily life. This preliminary study examined possible relationships between in-situ distortion and benefit for appropriately fitted contemporary hearing aids. Simulated in-situ distortion was determined for 97 hearing aid fittings, divided among three typical listening environments: living room, classroom lecture, and social event. Measures included intermodulation, harmonic, and transient distortion. Overall results of between- and within-subject analyses of data suggested that there was a significant relationship between distortion and benefit in both reverberant and noisy environments similar to a classroom lecture and a social event, respectively. This outcome was seen despite the fact that distortion was quite low in absolute terms. Analyses also suggested that in-situ harmonic distortion was most closely related to benefit and that the other types of distortion measured did not make additional contributions to benefit prediction. We propose that measurements of in-situ harmonic distortion might be a valuable addition to hearing aid evaluations.

**Key Words:** Benefit, distortion, hearing aid, hearing loss, intelligibility

Cox and Alexander (1991) reported the hearing aid benefit obtained in three everyday environments for hearing-impaired listeners. Each subject wore three different hearing aids, each with a different frequency response prescription. Although there were no significant group trends for one prescription to give superior results, there were a large number of significant differences between hearing aids when the data were evaluated for each individual. Articulation indices computed for the aided conditions were not predictive of these differences. In seeking an explanation for these results, the authors hypothesized that measured benefit might have been influenced by the distortion produced by the hearing aids under the particular conditions in which they were used.

All of the hearing aids used by Cox and Alexander (1991) performed according to their specifications when harmonic distortion was measured in the standard manner (ANSI, 1987). However, standard performance measurements are limited to harmonic distortion and are made with input levels and gain settings that are not necessarily reflective of everyday use. Studebaker and Marinkovich (1989) reported that harmonic distortion measured in the standard manner was not related to intelligibility results. However, when hearing aid distortions were measured under life-like use conditions, harmonic distortion was related to intelligibility derived from high-frequency speech elements, and intermodulation distortion was related to intelligibility derived from low-frequency speech elements.

It is important to note that the subjects in the Studebaker and Marinkovich (1989) study were all normal hearing. It is possible that these results would not be observed in listeners with impaired hearing. There has been considerable speculation over the years about whether hearing-impaired listeners are as sensitive to distortion as are normal-hearing listeners.

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Levitt et al (1987) noted that distortion products might have negative effects only when they result in more distortion than would be generated by the ear itself for the undistorted signal. Because of the dual effects of higher listening levels and auditory pathology, we could anticipate that hearing aid wearers would produce a higher level of internally generated distortion than normal-hearing listeners. Thus, hearing aid-generated distortion might be less detrimental for the hearing impaired than for normal hearers. On the other hand, Lindblad (1982) reported that thresholds for detection of distortion were essentially equal for hearing-impaired and normal-hearing listeners. This would suggest that the effects on intelligibility of a given amount of distortion might be about the same for both types of listeners.

It is also possible that laboratory measurements of distortion effects might not be predictive of real-world effects because laboratory tests are often undertaken in quiet, sound-treated rooms, whereas typical listening situations range from slightly to very noisy. In everyday listening, distortion products might not be expected to interfere with intelligibility unless they exceed other maskers in the listening environment. This is supported by the study by Jirsa and Norris (1982) in which low-frequency intermodulation distortion of 34 percent did not affect intelligibility for sentences in noise (+ 5 dB SNR) but did reduce corresponding intelligibility scores in quiet.

Many investigators have tried to establish critical levels of distortion, which, if exceeded, can be expected to have a negative impact on intelligibility or quality. Consensus has not emerged from this work. For example, Crain and Van Tasell (1992) reported that both normal-hearing and hearing-impaired subjects can tolerate 30 to 40 percent of distortion before speech quality or intelligibility are adversely affected, whereas Lindblad (1982) recommended a maximum allowable distortion of 3 to 6 percent. To further confound practitioners, some studies have shown that intermodulation distortion products can actually facilitate the intelligibility of certain consonants and vowels for persons with steeply sloping hearing loss (Lindblad, 1987; Smaldino, 1979).

The disparity of outcomes in distortion research is probably due to the use of different speech tests, distortion measures, calibration methods, and heterogenous hearing-impaired subjects. In various studies, distortion has been expressed in terms of 6-cm<sup>3</sup> coupler levels, 2-cm<sup>3</sup>

coupler levels, and voltage levels, but rarely has it been measured in the milieu with the highest face validity—the ear canal. Similarly, distortion measurements rarely have been made at use-gain settings. Studebaker and Marinkovich (1989) demonstrated that measured distortion at use-gain volume control settings may not be predictable from standard distortion measures. Furthermore, Nielsen et al (1990) reported that distortion measurements made in ear canals were sometimes quite different, and unpredictable, from those obtained in the 2-cm<sup>3</sup> coupler used for standard performance measurements.

Based on these considerations, Cox and Alexander (1991) hypothesized that, despite the fact that all hearing aids in their study were in compliance with specifications that allowed relatively small amounts of harmonic distortion, the observed differences in hearing aid benefit might partly be explained by differences among the hearing aids in the amount of intermodulation, harmonic, and/or transient distortions produced under conditions encountered in actual listening. This paper reports a preliminary study to evaluate that hypothesis. A second research goal was to evaluate the extent to which any of these three types of distortion data might be useful in a model predicting hearing aid benefit in daily life situations.

## METHOD

To distinguish it from distortion measured using standardized performance tests, distortion observed under life-like conditions is here called in-situ distortion. Ideally, we would measure in-situ distortion in the subject's ear canal during the same test session in which hearing aid benefit is measured. In the present exploratory study, this was not possible, because the hypothesis concerning distortion was generated after collection of the benefit data. However, the hearing aids and earmolds worn by subjects were retained and, by mounting these on an ear-simulator coupler in exactly the same configuration as worn by the subject, it was possible to generate a rather accurate estimate of distortion that would have been observed in a typical real ear canal. It is appropriate to refer to these data as simulated in-situ distortion measurements.

## Subjects

The study encompassed 33 subjects, divided into three groups of 11. The individuals were

mostly elderly and all had bilateral, mostly symmetrical, sensorineural hearing losses. Audiograms revealed mild to moderately severe sloping configurations. Based on the case histories, it was presumed that most of the hearing losses were due to presbycusis, perhaps in combination with noise exposure in many cases. The three groups were matched as closely as possible on the following variables: audiometric configuration, speech reception threshold, word recognition, age, and previous hearing aid use. See Cox and Alexander (1991) for further details.

### Hearing Aids

Each subject was fitted unilaterally with three different hearing aids. The frequency-gain responses of the three instruments differed by a total range of 8 dB/octave with the middle slope prescription derived from the MSU prescriptive method, version 3.0 (Cox, 1988). The accuracy of the fittings was verified using probe-microphone measurements. A total of 18 different hearing aid models were used in a variety of configurations to achieve the 99 fittings. All of the instruments were nondirectional, behind-the-ear, linear amplifiers with peak-clip limiting. The maximum output of each hearing aid was set at its highest value to minimize the likelihood of saturation. See Cox and Alexander (1991) for further details.

### Benefit Measurements

Hearing aid benefit was defined as the difference between aided and unaided speech intelligibility under realistic listening conditions. Intelligibility was measured using the Connected Speech Test (Cox et al, 1988). This test consists of 10-sentence passages of speech produced by a female talker of average intelligibility. The competing message is a six-talker babble. Each passage contains 25 scoring words. Six passages were used per score. For this study, benefit was measured under audio-only conditions (i.e., no visual cues).

Each group of subjects was examined in a different listening environment implemented in an appropriate room. The three environments were chosen to be typical of a home living room, a moderately reverberant room (classroom lecture), and a party or social event. For each environment, published data were used to determine appropriate talker level, noise level, talker-listener distance, and reverberation time.

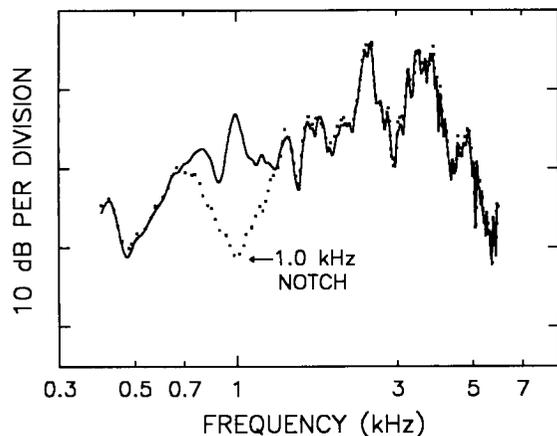
Cox and Alexander (1991) provide these and other details about each listening environment.

### Distortion Measurements

Methods were devised for measuring in-situ intermodulation, harmonic, and transient distortions. The hearing aids and earmolds were configured exactly as they were worn by the subjects for benefit measurements. Distortions were measured with each hearing aid attached to a Zwislocki-type ear simulator using the subject's earmold. The ear simulator was terminated with a 0.5-in. pressure-calibrated laboratory microphone and the sound field test signals were monitored at the hearing aid's input using an identical 0.5-in. laboratory microphone. To minimize the effects of ambient noise on the sound field test signals, distortion data were obtained in a sound-treated room.

*Intermodulation distortion* was measured using an adaptation of a method described by Burnett (1967). In this approach, the hearing aid is presented with a broad-band speech-like signal that contains a deep notch at the test frequency. Distortion is measured as the extent to which intermodulation products produced by the hearing aid fill the notch in the noise spectrum. In the present study, pink noise (125 Hz–12 kHz bandwidth) presented in the sound field at a level of 70 dB (determined with the sound level meter detector set to rms, fast) simulated the peak spectrum of speech. A  $\frac{1}{3}$ -octave band graphic equalizer (Klark Teknik, DN 360) was used to produce notches in the noise at each of three test frequencies: .5, 1, and 2 kHz. Notch depth was 26 dB at the input to the hearing aid. Initially, it seemed possible that there might be occasions when either hearing aid internal noise or ambient noise (rather than distortion products) would partly fill the notch. However, concurrent analyses of ambient and internal noise levels revealed that they could have had only minor effects on about 1 percent of intermodulation distortion measurements conducted with a 70-dB test signal (intermodulation distortion was not measured with a test signal lower than 70 dB because of the increased potential for contamination of the data by internal and/or ambient noise).

To determine intermodulation distortion at each test frequency, the hearing aid's output spectrum was ascertained for both notched and unnotched noise and the difference between the two spectra at the test frequency was measured. Figure 1 illustrates results for a test frequency



**Figure 1** Illustration of the method used to measure intermodulation distortion. The solid line depicts a hearing aid's output with pink noise input. The dotted line shows the corresponding output when the pink noise encompassed a 26-dB notch centered at 1 kHz.

of 1 kHz. In this example, the 26-dB notch in the input spectrum has been reduced to a depth of 17 dB at the hearing aid's output. Thus, the measure of intermodulation distortion at 1 kHz is 9 dB (26–17 dB). Using this metric, a larger value is indicative of more distortion.

*Harmonic distortion* was measured for three pure-tone test frequencies: 500 Hz, 800 Hz, and 1200 Hz. Test tones were produced by a small, wall-mounted loudspeaker with a wide, flat-frequency response (Realistic Minimus-7). The hearing aid's output was routed to a spectrum analyzer (Hewlett Packard 35665A), which was configured to determine total harmonic distortion for the first three harmonics. Although standard harmonic distortion measurements are not required for hearing aids with a sharply rising frequency response (ANSI, 1987), measurements were made at all test frequencies in this study regardless of the shape of the frequency response, on the basis that these measurements reflect a legitimate aspect of the hearing aid's performance from the wearer's point of view. To achieve input levels appropriate for the different listening environments, test tones were presented at 60 dB SPL for hearing aids tested in the living room setting and at 70 dB SPL for hearing aids tested in the classroom and party settings. With the 70-dB input, total harmonic distortion generated by the loudspeaker producing the tones and measured at the test point was 0.7 percent, 0.5 percent, and 0.4 percent for the 500-, 800-, and 1200-Hz test tones, respectively.

*Transient distortion* was quantified using an adaptation of the method described by Smaldino (1979). Brief (4.4 msec) pulses were produced at the rate of three per second (Tektronix pulse generator PG 501), transduced by a compression driver (University Sound ID60), and presented to the hearing aid at a level of 70 dB (determined with the sound level meter detector set to impulse response). The duration of the pulse in the sound field at the hearing aid's input was 11.2 msec. The hearing aid's output was routed to a digital oscilloscope (Panasonic VP5730P), where the pulse trace was stored and its duration measured. Transient distortion was quantified as the average duration of three such pulses. Again, a larger value was indicative of more distortion.

## RESULTS

Data could not be obtained for 2 of the 99 hearing aid fittings because the hearing aids were malfunctioning. Thus, the final data set encompassed 31 fittings in the living room setting, 33 fittings in the reverberant room setting, and 33 fittings in the party setting. The data distributions were inspected and a few outliers (> 3 standard deviations from the mean) were noted. These points were winsorized (Kirk, 1982, p. 139) to prevent their exerting an undue influence on the statistical tests. In winsorizing, an outlier is replaced by the next most extreme data point. Eleven of the 776 data points were winsorized. Even so, many of the distributions of distortion data were markedly skewed because most of the values were relatively low.

Table 1 gives final descriptive statistics for the seven distortion measurements and the benefit data in each listening environment. Benefit is expressed in rationalized arcsine units (rau) as described by Studebaker (1985). This transformation minimizes the relationship between variance and score in the benefit distributions while producing percentage-like data for most of the measurement range. It is of interest to note that mean harmonic distortion for 500 and 800 Hz was highest in the living room environment, even though the test input level was lower for these hearing aids than for those used in the two other environments. This result must be attributed to the particular sample of hearing aids used in each environment (the reader should recall that different hearing aids were used for each subject, as called for by their hearing loss).

**Table 1 Hearing Aid Benefit Data and Descriptive Statistics for Seven Measures of Hearing Aid Distortion in Three Listening Environments**

<i>Distortion</i>	<i>Living Room</i>	<i>Reverberant Room</i>	<i>Party</i>	<i>Unit</i>
Intermodulation (.5 kHz)	14.5 (8.0)	5.9 (8.9)	8.2 (9.1)	dB
Intermodulation (1 kHz)	7.9 (5.9)	3.9 (6.0)	6.1 (8.2)	dB
Intermodulation (2 kHz)	1.4 (3.4)	0.4 (2.2)	0.4 (2.3)	dB
Harmonic (.5 kHz)	9.0 (9.3)	4.2 (4.2)	7.9 (9.8)	%
Harmonic (.8 kHz)	9.6 (10.9)	4.4 (6.3)	6.4 (7.8)	%
Harmonic (1.2 kHz)	2.7 (2.4)	3.7 (5.2)	3.9 (3.8)	%
Transient	30.0 (6.8)	26.9 (5.7)	29.5 (4.3)	msec
Benefit	25.2 (19.1)	7.6 (10.3)	-1.8 (12.6)	rau

Standard deviations are given in parentheses. Rau, rationalized arcsine units (see text).

Cox and Alexander (1991) reported that, at least in the living room environment, there was a significant relationship between hearing loss and hearing aid benefit. To minimize the likelihood that this relationship would impact our examination of any relationship between hearing aid distortion and benefit, benefit was expressed in terms of delta scores as described by Ferguson (1966, p. 267). This transformation removed the effect of differences in unaided performance from the measure of benefit. All statistical tests were performed using delta scores as the benefit measure.

### Group Data Analyses

Linear correlations were computed to explore the relationship between benefit and each distortion considered separately. Table 2 gives the resulting correlation coefficients for each environment. For the living room environment, all except one of the correlations were negative, showing that the relationship between distortion and benefit was generally in the predicted direction (more distortion associated with less benefit). However, only one of the individual correlations (harmonic distortion, 500 Hz) was large enough to be statistically significant. Correlations for data obtained in the reverberant environment were uniformly negative, again suggesting that more distortion was associated

**Table 2 Linear Correlation Coefficients between Each of Seven Measures of Distortion and Corresponding Hearing Aid Benefit**

<i>Distortion</i>	<i>Living Room</i>	<i>Reverberant Room</i>	<i>Party</i>
Intermodulation (.5 kHz)	-.245	-.366*	.040
Intermodulation (1 kHz)	-.229	-.183	.232
Intermodulation (2 kHz)	-.088	-.228	.171
Harmonic (.5 kHz)	-.323*	-.243	-.018
Harmonic (.8 kHz)	-.064	-.404*	-.263
Harmonic (1.2 kHz)	.063	-.375*	.07†
Transient	-.067	-.385*	-.143

Data are given for three listening environments.

\* $p < .05$  (1-tailed test).

with lower benefit. In this environment, four of the seven coefficients were statistically significant, including exemplars of all three types of distortion measured. In contrast, the coefficients in the party environment were about evenly split between positive and negative, and none were statistically significant at the .05 level.

The overall impression gained from consideration of Table 2 is that hearing aid distortion was not related to the benefit obtained in the party environment, was perhaps weakly related to benefit in the living room environment, and was more strongly related to benefit in the reverberant environment. This analysis is useful, but it suffers from two drawbacks. First, because 21 correlations have been evaluated at the .05 level of significance, there is a high likelihood that at least one spuriously significant correlation will be found. Second, this type of approach ignores possible relationships between distortions. For example, Table 2 indicates that both harmonic distortion at 800 Hz and transient distortion are related to benefit obtained in a reverberant environment. However, these analyses cannot reveal whether each of these distortions had an independent influence on benefit. This factor is important when we consider the use of distortion data in predictions of hearing aid benefit.

To determine which (if any) distortion measures would make both significant and independent contributions to benefit prediction, multiple regression analyses were performed. However, because the probable relationships among the seven distortion measures could compromise these analyses, the number of distortion variables was first reduced using principal components analysis with varimax rotation (Norusis, 1988). This type of analysis can be used to identify a small number of underly-

**Table 3 Rotated Varimax Loadings of Distortion Variables on Each of Three Principal Components**

<i>Distortion</i>	<i>PC1</i>	<i>PC2</i>	<i>PC3</i>
Intermodulation (2 kHz)	.88		
Intermodulation (1 kHz)	.84		
Intermodulation (.5 kHz)	.79		
Harmonic (.8 kHz)		.90	
Harmonic (1.2 kHz)		.65	.55
Harmonic (.5 kHz)		.59	-.51
Transient			.79

ing dimensions that reveal the relationships among a set of variables. Each identified dimension, or principal component, is independent of the others. Three principal components explained 77 percent of the variance in the distortion data. Table 3 displays the loadings of the variables on each component after rotation. Only loadings greater than 0.5 (absolute value) are shown. The first and second principal components (PC1 and PC2) are readily interpretable, representing intermodulation and harmonic distortion, respectively. The third principal component (PC3) is most closely related to transient distortion but also has relationships to low-frequency and high-frequency harmonic distortion. Because the method of quantifying transient distortion is essentially a measure of "ringing" in the hearing aid, we postulate that this component is related to frequency response peakedness. In addition, the opposite signs of the loadings on the two harmonic distortion variables suggest that there is also an element of bandwidth involved in PC3.

Using the loadings shown in Table 3, scores for each principal component were computed for each subject. The ensuing three distortion variables were then entered as predictors into multiple regression analyses with hearing aid benefit as the dependent variable. A separate multiple regression analysis was completed for each of the three listening environments. Results were negative for both the living room and party environments: none of the distortion components made a significant contribution to benefit prediction for these group data. For the reverberant room environment, all three of the distortion components were modestly but significantly correlated with benefit (correlations ranged from .32 to .41). However, only PC2 (harmonic distortion) was entered into the regression equation. This variable explained 17 percent of the variance in benefit in the rever-

berant room. The two other components did not make significant additional contributions.

In summary, the analysis of group data for each environment suggested that simulated in-situ hearing aid distortion produced by properly fitted, well-functioning instruments was related to hearing aid benefit only when subjects were listening to speech in a reverberant environment. Furthermore, harmonic distortion was the best predictor of benefit, and additional data on other types of distortion did not improve the predictions.

**Intrasubject Data Analyses**

Because each subject in the study wore three different hearing aids, it was also possible to analyze the data through a consideration of each individual's results. This analysis asked whether the hearing aid with the lowest distortion produced the most benefit for each individual subject. To explore this question, intermodulation distortion data were summed across frequencies and the same procedure was followed for harmonic distortion data so that each hearing aid had one value for each type of distortion.

Contingency tables showing distortion ranking cross tabulated with benefit ranking were constructed for each type of distortion in each listening environment. A chi square was computed for each contingency table. This statistic reflected the extent of the systematic relationship between distortion and benefit when subjects were considered individually. The results are given in Table 4. The analysis revealed a significant relationship between harmonic distortion and benefit in the party environment. In this environment, the instrument with the highest overall distortion tended to produce the least benefit and the one with the smallest distortion tended to produce the most benefit.

**Table 4 Chi Square Values and Benefit Rankings for Three Hearing Aids Tested with Each Subject**

<i>Environment</i>	<i>Distortion</i>		
	<i>Inter-modulation</i>	<i>Harmonic</i>	<i>Transient</i>
Living Room	6.00	2.39	4.19
Reverberant Room	2.17	3.81	4.35
Party	8.17	12.53*	4.34

Values derived from a cross tabulation of distortion rankings.

\*p < .05 (1-tailed test).

## DISCUSSION

The primary goal of this study was to explore whether in-situ hearing aid distortion might be associated with hearing aid benefit even in properly fitted, well-functioning hearing aids that were not being operated under saturation conditions. This matter was addressed in two ways. First, all hearing aid fittings in a given environment were grouped and relationships between distortion and benefit were examined. This is equivalent to asking whether subjects who were fitted with lower distortion hearing aids tended to obtain more benefit. This group type of analysis is most successful in revealing important effects when subjects are fairly equivalent on influential variables other than those under investigation. Second, considering the three fittings for each subject, we determined whether the lowest distortion instrument tended to produce the most benefit for that individual. This type of analysis is not very powerful, but it has the advantage of using each subject as his/her own control so that between-subject differences on other influential variables do not obscure the outcome as they might in a group analysis.

Results obtained in the living room environment did not clearly indicate that in-situ distortion was an important factor influencing benefit. When subjects were considered as a group, the only significant relationship between benefit and distortion occurred for harmonic distortion at 500 Hz (Table 2). When results for individual subjects were considered, no significant relationships were seen (Table 4). Given the large number of correlations computed for Table 2 and the absence of other corroborating evidence, it is possible that the single significant outcome might have been a spurious observation.

A note of caution should be sounded about generalizing these results to all hearing aid fittings. It should be kept in mind that these data were obtained using relatively wide dynamic range hearing aids that were not operating in saturation. Peak-clipping instruments with narrow dynamic ranges (similar to many popular in-the-ear types) would probably generate more in-situ distortion (due to saturation), even in the living room type of environment. Under these conditions, we would be more likely to see a relationship between in-situ distortion and benefit even in a relatively quiet setting.

When subjects listened to speech in a reverberant room similar to a classroom, there were

several significant relationships between hearing aid distortion and benefit (Table 2). Furthermore, the multiple regression analysis revealed that a composite harmonic distortion variable weighted towards the mid-frequencies explained a sizable proportion of the variance in benefit. However, this relationship was not seen when data were considered individually (Table 4), perhaps because the aggregate distortion variables for the within-subjects analysis were equally weighted at each frequency.

Listening in a cocktail party type of setting is notoriously difficult and unsuccessful for hearing aid wearers, and we were especially interested in the results for this environment. Here again, when subjects were analyzed as a group, no relationship was seen between hearing aid distortion and benefit. However, the within-subjects analysis was indicative of a substantial relationship between overall harmonic distortion and benefit (Table 4). These apparently contrary outcomes might be explained by the large variability that exists across hearing-impaired listeners in the extent to which background noise interferes with speech intelligibility. Since the party environment incorporated relatively high background noise levels, we hypothesize that the strong and variable effects of background noise overshadowed the weaker effects of hearing aid distortion when subjects were considered as a group. When each subject was considered alone, thus controlling for the effect of background noise, the negative effects of hearing aid distortion were more obvious.

Overall, these analyses suggested that distortion generated by contemporary behind-the-ear hearing aids is related to hearing aid benefit in both reverberant and noisy (party) listening environments but not in the relatively quiet setting of a typical home living room. This outcome was somewhat unexpected, because the data of Jirsa and Norris (1982) suggested that distortion would be more detrimental in a quiet listening situation than in a noisy one. Perhaps the redundant speech cues found in the quieter environment allowed intelligibility to resist the effects of these relatively small amounts of distortion. In the more degraded listening situations, however, redundant cues would be less available, possibly resulting in a loss of intelligibility for even small amounts of additional degradation. Based on these results, it would be reasonable to include a measure of in-situ distortion for noisy and/or reverberant settings during hearing aid evaluations. Such measures may yield data that are predictive of the amount

of benefit that can be obtained in these problematic listening environments.

A secondary goal of this study was to determine whether several different types of distortion seemed to make independent contributions to the prediction of benefit. In other words, were several different measures of distortion needed to obtain the best prediction of benefit, or did a single measure yield all the available information? The results suggested that (1) of the distortion measures explored, harmonic distortion was most strongly related to benefit; and (2) data describing additional types of distortion would not improve benefit predictions in any of the tested listening environments. It should be noted that these conclusions are limited to the measurement procedures used in this study. Other approaches to quantifying intermodulation and/or transient distortion or perhaps other distortion metrics such as coherence analysis (Preves, 1990) might yield different conclusions.

The results of this investigation suggested that measurement of simulated in-situ distortion under life-like listening conditions might produce data that are valuable in refining models that predict benefit to be obtained from a hearing aid fitting. Future research should explore the relationship between benefit and in-situ distortion measured in the ear canal of the hearing aid wearer. Although ear-like couplers yield acoustic results that are very similar to those seen on typical real ears, some variations from coupler values would be expected in individual ears. These variations might affect the results of group analyses such as those reported in this study but would not be expected to influence the outcome of intrasubject analyses based on rankings for several hearing aids worn by the same person. The results of the current preliminary study encourage us to pursue the goal of defining clinically practical methods for measuring in-situ distortion and using these data in hearing aid fittings.

Finally, it is also worth noting that even though unsaturated contemporary hearing aids were seen to produce relatively low distortion levels, the differences between instruments were related to speech intelligibility benefit under certain conditions. This points to the conclusion that manufacturers and clinicians should continue to strive for hearing aid fittings that minimize distortion in everyday hearing aid use.

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