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Comparison of Standard and Abbreviated Distortion Product Otoacoustic Emissions Procedures

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Abstract

Standard and abbreviated distortion product otoacoustic emissions (DPOAEs) procedures derived using the Grason Stadler Model 60 instrument were compared. The standard and abbreviated procedures were compared at frequencies of 1000, 1250, 1593, 2000, 2531, and 3187 Hz for 48 ears from 28 subjects. The subject pool included individuals with normal hearing and those with sensorineural hearing loss. The abbreviated procedure correlated well with the standard procedure for DPOAE amplitude across all frequencies tested. The two procedures were also highly similar in categorizing the subjects in regard to normal or abnormal hearing sensitivity. It appears that the shorter analysis time for the abbreviated procedure had little effect on its accuracy. Although the abbreviated procedure has an obvious frequency limitation, it may have some clinical advantages for hearing screening.

Key Words: Abbreviated test, distortion product otoacoustic emissions (DPOAEs), hearing screening, otoacoustic emissions abbreviated test

The advent of clinical instrumentation and procedures used to assess otoacoustic emissions (OAEs) has led to interest in developing an objective measure to evaluate cochlear function. To this end, several studies have examined the efficiency of either transient evoked otoacoustic emissions (TEOAEs) or distortion product otoacoustic emissions (DPOAEs) in predicting hearing loss (Bray and Kemp, 1987; Harris, 1990; Kemp et al, 1990; Martin et al, 1990; Smurzynski et al, 1990; Lonsbury-Martin et al, 1991; Gorga et al, 1993; Prieve et al, 1993). Although some variability exists among the findings, the collective results of these investigations suggest that both TEOAEs and DPOAEs can be used to predict the presence of hearing loss between 1000 and 4000 Hz, particularly if the hearing loss is greater than 30 to 40 dB HL, while the utility of both procedures for predicting hearing loss below 1000 Hz and above 4000 Hz is considerably less. Moreover, these investigations show that, although both procedures are relatively sensitive to the presence or absence of hearing loss, particularly in the 1000- to 4000-Hz range, neither procedure can be used to accurately predict a given subject's hearing threshold level at a specific frequency. Thus, both TEOAEs and DPOAEs hold considerable promise as screening procedures for predicting hearing loss but, presently, neither procedure can be used to accurately predict frequency-specific hearing thresholds.

The present study focused on evoked OAE results from the presentation of two tonal signals close in frequency. Although these types of signals result in distortion products in the cochlea, the most prominent response in the human ear occurs at a frequency that is equal to twice the frequency of the lower primary minus the frequency of the higher primary ($2f_1-f_2$). Typically, studies investigating DPOAEs have used procedures that elicit distortion product measurements over a three-octave range corresponding to the audiometric frequency range of 1000 to 8000 Hz. For example, Gorga et al (1993) derived three distortion products per octave for a total of 12 DPOAEs. In addition, some research and clinical applications of DPOAEs have specified the averaging of a large number (e.g., 200 to 300) of responses (Smurzynski et al, 1990; Gorga et al, 1993), regardless of

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the robustness of the response (in dB SPL [sound pressure level]), to achieve a favorable signal-to-noise ratio between the derived response and the noise floor.

Questions arise when considering these common approaches to measuring DPOAEs. First, if the efficiency of the DPOAEs derived at the lower and upper extremes of the commonly tested three-octave frequency range is poor to fair in predicting hearing loss at corresponding audiometric test frequencies, should routine clinical applications continue to include the derivation of these responses? Second, if a distinct measurable response is present and there is a favorable signal-to-noise ratio between the measured SPL of the distortion product and the SPL of the noise floor with fewer than 200 averaged responses, should routine clinical practice continue to include the derivation of 200 responses for each DPOAE measurement? These questions are especially pertinent since evidence indicates that DPOAEs are most useful for screening purposes, while the clinical utility of DPOAEs for threshold estimation awaits further determination. The derivation of 200 responses for 12 different distortion products is not overly time consuming; however, to increase the cost effectiveness of the procedure for screening purposes, it would be desirable to limit the procedure to only those frequencies that can be used to reliably predict hearing loss, and to as small a number of responses per DPOAE as needed to derive a reliable indicator of normal/abnormal hearing.

The present study was undertaken to address these questions. DPOAEs were derived using two test protocols: (1) conventional DPOAE procedures similar to those outlined above and (2) a shortened screening procedure that involved both fewer DPOAEs and fewer averages per DPOAE.

The two procedures were then compared in terms of total test time and hit rates and false-alarm rates in predicting hearing loss. Finally, the DPOAEs derived during the screening procedure were compared to the same DPOAE results derived during the conventional procedure to determine if the actual measurements in dB SPL achieved with the two procedures were equivalent.

METHODS

Subjects

A total of 48 ears from 28 subjects were involved in this study. Patients were recruited from our audiology clinic and/or were subjects involved in ongoing research projects. The mean age of the subjects was 42.7 years (standard deviation 16.2 years), with the youngest being 9 and the oldest 75 years of age. This group of subjects included those with normal hearing (≤ 20 dB HL at 250 to 8000 Hz) and those with hearing loss. For the audiometric frequencies of interest in this study, 18, 11, and 20 ears demonstrated hearing loss (≥ 25 dB HL) at 1000, 2000, and 3000 Hz, respectively. All ears used in this study had normal tympanograms (compliance > 4.0 acoustic mmho and pressure ≤ 150 daPa). Some ears were omitted from the study due to potentially contaminating otologic/audiologic factors, such as otitis media and Meniere's disease.

PROCEDURES

All subjects were tested while seated in a sound room. The instrumentation used for the DPOAEs was the Grason Stadler, Inc. (GSI) 60. Two protocols available by the GSI 60 system were tested: the standard analysis routine and a screening version referred to as "Dartfast." A GSI 60 immittance cuff of the appropriate size was fitted to the end of the DPOAE instrument's probe assembly and placed securely in the ear canal of the subjects. The test program for this research included the following test parameters:

- A sampling rate of 16,000 Hz to analyze the acoustic emission.
- A minimum of 300 and a maximum of 380 frames* for the standard procedure, and a minimum of 10 and a maximum of

*A frame represents a collection of discrete amplitude measurements collected during a fixed time period, which is defined by the number of bins in a Fast Fourier Transfer (FFT) and the sampling rate. For example, if an FFT has 512 bins for the collection of data points and a sampling rate of 16,000 is selected, the period of time spent collecting a frame of data would be 512/16,000 or 32 msec. (An FFT is conducted on this frame of data to convert the incoming data at the microphone from amplitude versus time to amplitude versus frequency in the GSI 60. Multiple frames of data are collected and averaged, which causes noise of a random nature to be reduced in amplitude. During auditory brainstem response data collection, this measurement is referred to as a sweep. Therefore, it is possible to think of a frame of data as a sweep of data, and each sweep of data is evaluated with respect to the frame rejection criteria established within the configuration protocol.)

150 frames for the Dartfast procedure. The standard procedure required approximately 2 minutes and 15 seconds to complete (no rejections), while the Dartfast procedure required approximately 12 seconds to complete (no rejections).

- For acceptance of a DPOAE response, the absolute average noise level had to be ≤6 dB SPL.
- For acceptance of a DPOAE response, the DPOAEs had to be 10 dB or greater than the average noise floor, or the absolute average noise level had to be less than 12 dB SPL.
- For acceptance of a response, the primary tone had to be 40 dB greater than the noise floor.

The primary tones were maintained within 1 dB of 70 dB SPL (as measured in the ear canal) throughout each test for each subject.

Normal DPOAEs were those for which amplitude in SPL was equal to or greater than our "normal" 90th percentile criterion for the frequencies of interest. Normal audiometric hearing was considered as thresholds equal to or less than 20 dB HL for frequencies 250 to 8000 Hz.

Spearman correlation coefficients were computed for the standard and Dartfast procedures in reference to the amplitudes of the DPOAEs. An analysis was performed of the number of subjects classified correctly (normal hearing vs hearing loss) by each procedure.

RESULTS

Spearman rank order correlation coefficients for comparing the standard and Dartfast procedures were consistently high across all frequencies analyzed (1000 Hz = 0.949, 1250 Hz = 0.955, 1593 Hz = 0.950, 2000 Hz = 0.974, 2531 Hz = 0.961, 3187 Hz = 0.975). This high correlation is also reflected in the regression analysis graphs shown in Figure 1 (A–F) and Table 1.

In addition to computing the correlation between the results of the two DPOAE procedures, we analyzed the number of ears categorized correctly as to the presence of hearing loss. Of the 18 ears demonstrating hearing loss at 1000 Hz, 12 and 11 were categorized correctly by the standard and Dartfast procedures, respectively. Thirty ears had normal hearing at 1000 Hz, and 24 and 25 ears were classified as normal by their DPOAEs using the standard and Dartfast procedures, respectively. Of the 48 ears tested at 1000 Hz, 44 ears were classified similarly by both procedures.

Table 1 Percentage of Subjects Identified Correctly as Normal or Hearing Impaired by the Standard and Dartfast DPOAE Procedures

Frequency (kHz)	*Hearing*	*Standard (%)*	*Dartfast (%)*
1	Impaired	67	61
	Normal	80	83
2	Impaired	55	64
	Normal	97	100
3.1	Impaired	75	75
	Normal	68	68

At 2000 Hz, of 11 ears with hearing loss audiometrically, 6 and 7 ears demonstrated hearing loss on the standard and Dartfast procedures, respectively. Of the 37 normal-hearing ears, 36 and 37 were classified as normal by the standard and Dartfast procedures, respectively. The two DPOAE procedures classified similarly 45 of 48 subjects.

At 3187 Hz, the standard and Dartfast procedures each detected 15 of the 20 ears with hearing loss. Both procedures classified correctly 17 of 25 normal-hearing ears, and all 45 ears were classified similarly by both procedures.

DISCUSSION

There is considerable interest in the potential use of OAEs as a hearing screening procedure. A key component of a screening procedure is its brevity, since the less time a test requires the more useable it becomes, as long as its validity is retained. This study shows that, for a variety of analyses, the Dartfast procedure compares well with the longer standard procedure. Our findings in comparing the two DPOAE procedures indicate that they have a high correlation of results, similar sensitivity and specificity, and similar amplitudes. In the group of subjects tested, the standard and Dartfast procedures were similar in identifying correctly subjects with normal or abnormal hearing. Performing the Dartfast procedure, however, takes less than one-tenth of the time of the standard procedure. Brass and Kemp (1994) reported favorable results from their abbreviated OAE procedure that was only 40 percent shorter than their standard procedure. Together, the OAE data support the use of such compressed procedures, especially for screening purposes.

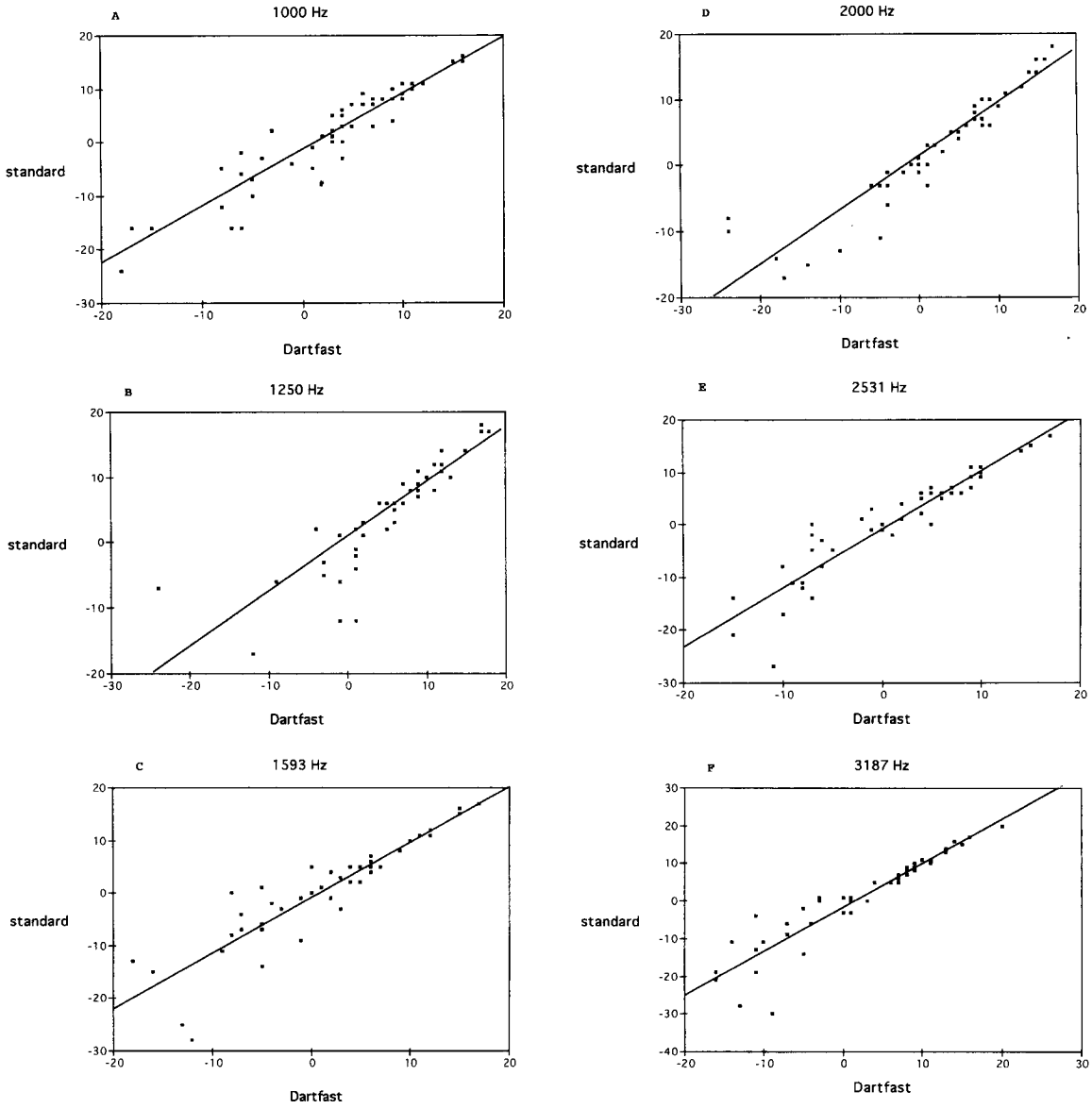

Figure 1 Simple regression analysis of amplitudes in SPL for the standard and Dartfast procedures for six frequencies.

The major disadvantage of the Dartfast program is its restricted frequency range. The inability to test at low or very high frequencies suggests that hearing losses in these regions will be missed by the Dartfast procedure but may be picked up by the standard procedure. However, it is well known that OAEs are not test efficient at the low frequencies (Gorga et al, 1993) and, in some clinics and laboratories, OAE testing is not conducted at 500 Hz because of its poor accuracy. In fact, a recent report by Brass and Kemp (1994) demonstrates the utility of analyzing a narrow response band of 1.6 to 2.8 kHz. Hence, although the Dartfast procedure does not measure DPOAEs at the low frequencies, it is unlikely that a great deal of information is lost; however, this may not be true for the high frequencies. It is clear that 4000 Hz and even 8000 Hz are frequencies for which DPOAEs have good sensitivity and specificity (Gorga et al, 1993). Moreover, there are populations with auditory dysfunction related to noise exposure and ototoxicity who require screening at these higher frequencies. Therefore, the Dartfast procedure, with its mid-frequency range testing ability, has limitations. For a particular use, the benefits of time savings with the Dartfast version of the GSI 60 must be offset by its inability to test the high-frequency portion of the frequency-response range of DPOAEs.

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