Utility of Standard DPOAEs in the Evaluation of the Normal-Hearing Tinnitus Patient

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Background

- Shiomi et al, 1997 (*Journal of the Association of Research In Otology*): “In comparison to normal-hearing and otologically normal subjects (including no tinnitus), DPOAE amplitudes were consistently reduced among tinnitus patients, even in those with audiometrically normal hearing.”

- Hall, 2000 (*Handbook of Otoacoustic Emissions*): “. . . a clear pattern has emerged. OAEs are abnormal, or not detectable, in the frequency region of the tinnitus, even among persons with clinically normal audiograms.”

- Onishi et al, 2004 (*International Tinnitus Journal*): “The authors conclude that DPOAEs constitute a useful audiological method for evaluation of patients complaining of tinnitus. [61.3% of normal-hearing tinnitus subjects demonstrated DPOAE amplitudes below the 5th percentile compared to only 3.6% in the control group.]”
• Granjeiro et al, 2008 (*Otolaryngology - Head and Neck Surgery*): “. . . DPOAE were abnormal in 68.4% of [tinnitus subjects] and in 50% of [non-tinnitus subjects].”

• Paglialonga et al, 2010 (*Auris Nasus Larynx*): “. . . abnormal OAEs, in particular at higher frequencies, [was observed] in tinnitus subjects with normal hearing sensitivity . . . outer hair cell dysfunction . . . might thus be assumed in normal-hearing tinnitus subjects.”

• Jastrebof & Hazell, 2004 (*Tinnitus Retraining Therapy: Implementing the Neurophysiological Model*): “Approximately 20% of patients with tinnitus have normal hearing. This is because changes too small to be detectable on a standard audiogram, if localized, can result in heterogeneity and trigger compensatory reactions of the auditory system, resulting in tinnitus.”
We were interested in evaluating the clinical utility of standard DPOAE measures during routine audiological evaluation of tinnitus patients with normal hearing through the standard audiometric test range of .25-8 kHz, so we asked:

- Can “standard” DPOAE measures differentiate between normal-hearing tinnitus patients and normal-hearing non-tinnitus patients?

**Data Collection**

- VA Computerized Patient Record System (CPRS) was reviewed for patients referred for primary complaint of tinnitus between 1 Jan 2011 - 31 Dec 2011 (12 months).
- All subjects had normal hearing thresholds (≤ 25 dB HL) at all frequencies .25-8 kHz.
- All subjects’ DPOAEs were measured using a standard clinical Bio Logic Scout DPOAE protocol.
Subject Characteristics

- Subjects identified: 28 (56 ears)
  - Female subjects excluded ($n = 2$)
  - Monaural tinnitus subjects excluded ($n = 1$)
  - Final $n = 25$ (50 ears)

- Mean Age: 42.1 years (SD = 9.28)
  - $\leq 30 = 6$ (24 %)
  - 31 - 40 = 4 (16 %)
  - 41 - 50 = 9 (36 %)
  - $> 51 = 6$ (24 %)

- Gender
  - Male = 25 (100 %)

- Tinnitus Description
  - Ring Only = 18 (72 %)
  - Other Only = 1 ( 4 %)
  - Ring + Other = 6 (24 %)

- SC for Tinnitus
  - Yes = 10 (36 %)
  - No = 15 (64 %)

- Tinnitus Ear
  - Both Ears = 25 (100 %)

- Tinnitus Awareness
  - 100% of the time = 15 (60 %)
  - 71 - 99% of the time = 7 (28 %)
  - 51 - 70% of the time = 2 ( 8 %)
  - 36 - 50% of the time = 1 ( 4 %)

- Mental Health Disorders
  - Yes = 17 (68 %)
    - 1 MH Diagnosis = 11 (65 %)
    - 2+ MH Diagnoses = 6 (35 %)
  - No = 8 (32 %)
**Acoustic Reflexes at 1 kHz**

<table>
<thead>
<tr>
<th></th>
<th>Right Contra</th>
<th>Right Ipsī</th>
<th>Left Contra</th>
<th>Left Ipsī</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>83.41</td>
<td>80.68</td>
<td>84.09</td>
<td>81.82</td>
</tr>
<tr>
<td>S.D.</td>
<td>7.30</td>
<td>5.83</td>
<td>5.49</td>
<td>5.68</td>
</tr>
</tbody>
</table>

**Speech Audiometry**

<table>
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<tr>
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<th>Right Ear</th>
<th>Left Ear</th>
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</thead>
<tbody>
<tr>
<td>SRT</td>
<td>WRS %</td>
<td>dB HL</td>
</tr>
<tr>
<td>Mean</td>
<td>9.63</td>
<td>94.50</td>
</tr>
<tr>
<td>S.D.</td>
<td>4.12</td>
<td>6.86</td>
</tr>
</tbody>
</table>
DPOAE Pass-Fail Criteria

- Most absolute DPOAE interpretation criteria have been published for hearing screening purposes rather than for determination of normal OHC status.
- Most judgments of abnormal DPOAE in normal hearing tinnitus patients have been based on *comparison* to normal-hearing non-tinnitus patients rather than absolute values.
- However, there are exceptions as denoted by * below.

- **SNR ≥ 13 dB**
- **SNR ≥ 6 dB**
  - Granjeiro et al (2007)*
  - Iowa State Newborn Screening Protocol
  - Gorga et al (2005)*
- **5th Percentile**
  - Onishi Et al (2004)*
- **SNR ≥ 3 dB**
  - Washington State Newborn Screening Protocol
- **SNR ≥ 3-6 dB above 2 SD above the noise floor**
  - Gorga et al (2000)*
- **Christensen (2007)**
  - Various DPOAE screeners
    - SNR ≥ 5
    - SNR ≥ 6
    - SNR ≥ 10
- **Hall & Muller (1997)**
  - Response replicability within ± 3-5 dB
Bio-Logic Scout Available Protocols and Norms

Select Protocol

Reference Data

- Vanderbilt 65/55, 95-5th %ile
- Boys Town 65/55
- Expanded Boys Town Data
- NONE
- Vanderbilt 65/55, 2 St. Dev.
- Vanderbilt 65/65, 2 St.Dev.
- Vanderbilt 65/65, 95-5th %ile

Protocol

- 750-8000 Hz Diagnostic Test
- 1.5-10 kHz Ototoxic Test
- 1.5-10 kHz Ototoxic Test - High Noise
- 2.5 kHz Screen, 3/4 for Pass
- 2.5 kHz Screen, 3/5 for Pass
- 2.5 kHz Screen, 4/6 for Pass
- 2.5 kHz Screen, 3/5 for Pass
- 2.5 kHz Screen, 4/6 for Pass
- 2.6 kHz Screen, 3/5 for Pass
- 2.6 kHz Screen, 4/6 for Pass
- 2.8 kHz Diagnostic Test
- 2.8 kHz Diagnostic Test - High Noise
- 750-8000 Hz Diagnostic Test
- Spontaneous QAE Test
- TE Screen, 70% at 3/3 freq. for Pass
- TE Screen, 70% at 3/4 freq. for Pass
- TE Screen, 70% for Pass, 1.2-3.5 kHz
- TE test

OK  Cancel
Selected Bio-Logic Scout DPOAE Protocol

Frequency range: 750-8000 Hz (8 data points)

\[ \frac{f_2}{f_1} = 1.22 \]

\[ DP = 2(f_1) - (f_2) \]

L1 = 65 dB
L2 = 55 dB
Sample Size = 1024 (each, 2 runs)
The Vanderbilt Data Set vs. Current Protocol

About the Vanderbilt Data Set

- 15 male and 15 female subjects
- Ages ranged from 21-28 years
- All thresholds 500-8000 Hz for both ears < 15 dB HL
- No gender differences observed for DPOAE amplitudes
- Data were collected in quiet (not sound-treated) room

<table>
<thead>
<tr>
<th>Vanderbilt f2 (Hz)</th>
<th>Current Protocol f2 (Hz)</th>
<th>Difference (Hz)</th>
<th>% Octave Difference</th>
<th>Equivalent Pts/Octave</th>
<th>Vandy Mean Amplitude (dB SPL)</th>
<th>Vandy SD</th>
<th>Vandy Mean minus 2 SD</th>
<th>Vandy Mean minus 1 SD</th>
<th>Vandy 5th %ile</th>
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<tr>
<td>634</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>9.25</td>
<td>5.97</td>
<td>- 2.69</td>
<td>3.28</td>
<td>7.34</td>
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<tr>
<td>805</td>
<td>750</td>
<td>+ 55</td>
<td>7.33 %</td>
<td>14</td>
<td>9.05</td>
<td>6.39</td>
<td>- 3.77</td>
<td>2.62</td>
<td>6.96</td>
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<tr>
<td>1001</td>
<td>1031</td>
<td>- 30</td>
<td>3.00 %</td>
<td>30</td>
<td>10.18</td>
<td>6.56</td>
<td>- 2.94</td>
<td>3.62</td>
<td>8.09</td>
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<tr>
<td>1586</td>
<td>1453</td>
<td>+ 133</td>
<td>9.15 %</td>
<td>11</td>
<td>10.65</td>
<td>6.63</td>
<td>- 2.61</td>
<td>4.02</td>
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<tr>
<td>2002</td>
<td>2016</td>
<td>- 14</td>
<td>0.07 %</td>
<td>1428</td>
<td>6.85</td>
<td>6.40</td>
<td>- 5.95</td>
<td>0.45</td>
<td>4.81</td>
</tr>
<tr>
<td>3174</td>
<td>2859</td>
<td>+ 315</td>
<td>11.02 %</td>
<td>9</td>
<td>6.10</td>
<td>5.18</td>
<td>- 4.26</td>
<td>0.92</td>
<td>4.44</td>
</tr>
<tr>
<td>4003</td>
<td>3984</td>
<td>+ 19</td>
<td>0.05 %</td>
<td>2000</td>
<td>6.10</td>
<td>5.68</td>
<td>- 5.26</td>
<td>0.42</td>
<td>4.28</td>
</tr>
<tr>
<td>6347</td>
<td>5672</td>
<td>+ 575</td>
<td>10.01 %</td>
<td>10</td>
<td>1.22</td>
<td>8.51</td>
<td>-15.80</td>
<td>-7.29</td>
<td>-1.5</td>
</tr>
<tr>
<td>--</td>
<td>8016</td>
<td>--</td>
<td>--</td>
<td>--</td>
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</table>
Mean DPOAE SNRs for the right and left ears of 25 subjects. No significant differences were found between the two runs or between both ears at any frequency ($p > .05$). Gray lines are the 25th and 75th percentiles. Two separate runs are shown.
Signal-to-Noise Ratios (SNRs)

Mean DPOAE SNRs for the right and left ears of 25 subjects. No significant differences were found between the two runs or between both ears at any frequency ($p > .05$). Gray lines are the 25$^{th}$ and 75$^{th}$ percentiles. Two separate runs are shown.
Mean DPOAE SNRs for the right and left ears for two combined runs of 25 subjects. No significant differences were found between the two runs or between both ears at any frequency ($p > .05$). Gray lines are the 25th and 75th percentiles.
Mean DPOAE SNRs for the right and left ears for two combined runs of 22 subjects. No significant differences were found between the two runs or between both ears at any frequency \((p > .05)\). Gray lines are the 25th and 75th percentiles. SNR criteria are shown.
Criterion: DP Amplitude

-1 SD from mean
DPOAE amplitude is lower than 64.2% of normals

-2 SD from mean:
DPOAE amplitude is lower than 95.6% of normals

5th Percentile:
DPOAE amplitude is lower than 95% of normals
Mean DPOAE amplitudes and noise floors for the right and left ears of 22 subjects. No significant differences were found between the two runs or between both ears at any frequency ($p > .05$). Gray lines are the 25th and 75th percentiles. Two separate runs are shown.
Mean DPOAE amplitudes and noise floors for the right and left ears of 25 subjects. No significant differences were found between the two runs or between both ears at any frequency ($p > .05$). Gray lines are the 25th and 75th percentiles. Two separate runs are shown.
Mean DPOAE amplitudes for the combined right and left ears for two combined runs of 25 subjects. No significant differences were found between the two runs or between both ears at any frequency ($p > .05$). Gray lines are the 25th and 75th percentiles.
Mean DPOAE amplitudes for the combined right and left ears for two combined runs of 25 subjects. No significant differences were found between the two runs or between both ears at any frequency \((p > .05)\). Gray lines are the 25th and 75th percentiles. Amplitude criteria also are shown.
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Response Abnormality: Results per Criterion

- **Signal-to-Noise Ratio (SNR) Criteria**
  - $> 3$ dB
  - $> 6$ dB
  - $> 6$ dB above 2 SD above the noise floor

- **Amplitude Criteria**
  - $> -1$ SD
  - $> -2$ SD
  - $\geq$ Vandy 5th Percentile

- **Replicability Criterion**
  - $+ 3$ dB

- **High-Frequency Responses Criterion**
  - 2, 3 and 4 out of 4 abnormal responses
  - 2 and 3 out of 3 abnormal responses
% Abnormal DPOAES per Criterion: 3 dB SNR

All Subjects per Frequency

Right          Left           Both

- 750: 6% 0% 0%
- 1031: 12% 0% 5%
- 1453: 5% 4% 6%
- 2016: 1% 2% 0%
- 2859: 0% 0% 0%
- 3984: 7% 6% 8%
- 5672: 16% 14% 18%
- 8016: 14% 19% 24%

All Frequencies per Subject

- 1: 0% 0% 0%
- 2: 4% 0% 2%
- 3: 0% 1% 2%
- 4: 14% 8% 2%
- 5: 12% 0% 0%
- 6: 18% 0% 0%
- 7: 0% 0% 0%
- 8: 8% 0% 0%
- 9: 0% 0% 0%
- 10: 14% 6% 2%
- 11: 0% 0% 0%
- 12: 18% 4% 0%
- 13: 1% 2% 0%
- 14: 0% 0% 0%
- 15: 0% 0% 0%
- 16: 0% 0% 0%
- 17: 6% 14% 2%
- 18: 2% 0% 0%
- 19: 0% 0% 0%
- 20: 6% 14% 2%
- 21: 14% 2% 2%
- 22: 14% 2% 2%
- 23: 1% 4% 12%
- 24: 6% 14% 2%
- 25: 2% 2% 0%
## % Abnormal DPOAES per Criterion: 6 dB SNR

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Right</th>
<th>Left</th>
<th>Both</th>
</tr>
</thead>
<tbody>
<tr>
<td>750</td>
<td>9%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>1031</td>
<td>4%</td>
<td>4%</td>
<td>4%</td>
</tr>
<tr>
<td>1453</td>
<td>3%</td>
<td>2%</td>
<td>4%</td>
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<tr>
<td>2016</td>
<td>6%</td>
<td>8%</td>
<td>4%</td>
</tr>
<tr>
<td>2859</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>3984</td>
<td>16%</td>
<td>10%</td>
<td>0%</td>
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<tr>
<td>5672</td>
<td>22%</td>
<td>8%</td>
<td>4%</td>
</tr>
<tr>
<td>8016</td>
<td>29%</td>
<td>23%</td>
<td>26%</td>
</tr>
</tbody>
</table>

### All Subjects per Frequency

- **Right**
- **Left**
- **Both**

### All Frequencies per Subject

- **Frequency 1**: 6%
- **Frequency 2**: 6%
- **Frequency 3**: 4%
- **Frequency 4**: 4%
- **Frequency 5**: 4%
- **Frequency 6**: 0%
- **Frequency 7**: 4%
- **Frequency 8**: 0%
- **Frequency 9**: 0%
- **Frequency 10**: 6%
- **Frequency 11**: 0%
- **Frequency 12**: 6%
- **Frequency 13**: 0%
- **Frequency 14**: 0%
- **Frequency 15**: 0%
- **Frequency 16**: 0%
- **Frequency 17**: 0%
- **Frequency 18**: 6%
- **Frequency 19**: 4%
- **Frequency 20**: 2%
- **Frequency 21**: 4%
- **Frequency 22**: 2%
- **Frequency 23**: 6%
- **Frequency 24**: 0%
- **Frequency 25**: 0%
% Abnormal DPOAEs: Amplitude Vanderbilt -2 SD

All Subjects per Frequency

All Frequencies per Subject
% Abnormal DPOAEs: Amplitude Vanderbilt -1 SD

All Subjects per Frequency

All Frequencies per Subject
% Abnormal DPOAEs: Amplitude Vanderbilt 5th %ile

All Subjects per Frequency

Right    Left    Both

750  62%  60%  64%
1031  47%  44%  50%
1453  36%  36%  36%
2016  37%  38%  36%
2859  61%  56%  66%
3984  47%  54%  40%
5672  61%  54%  68%
8016  0%   10%  20%

All Frequencies per Subject

1  75%  29%  21%
2  21%  36%  25%
3  29%  21%  21%
4  64%  36%  0%
5  100% 64%  36%
6  100% 64%  36%
7  57%  54%  43%
8  43%  54%  43%
9  29%  36%  21%
10  36%  36%  21%
11  54%  43%  36%
12  68%  68%  68%
13  89%  89%  89%
14  64%  64%  64%
15  75%  75%  75%
16  86%  86%  86%
17  86%  86%  86%
18  86%  86%  86%
19  86%  86%  86%
20  86%  86%  86%
21  86%  86%  86%
22  86%  86%  86%
23  86%  86%  86%
24  86%  86%  86%
25  86%  86%  86%
Amplitude Criterion: 6 dB above the NF + 2 SD

Right          Left           Both

68% 72% 32%
40% 44% 26%
95% 80% 66%
59% 60% 42%
26% 36% 36%
19% 26% 26%
56% 92% 80%
67% 66% 68%
0% 10% 20%

All Frequencies per Subject

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25
56% 50% 31% 9% 19% 25% 50% 53% 31% 22% 47% 44% 47% 38% 34%
Amplitude replicability should be within ± 3-5 dB (Hall & Muller, 1997). We chose ± 3 dB as the more stringent criterion.
Criterion Comparison: % Abnormal Responses

Percentage of all responses that were abnormal at each test frequency per criterion (2 ears, 2 runs combined)

Percentage of all responses that were abnormal for all test frequencies combined per criterion (2 ears, 2 runs combined).

* < 1% of all responses for all test frequencies combined were < 3 dB above 2SD above the noise floor
Percentage of all responses that were abnormal at each test frequency per criterion (2 ears, 2 runs combined)

Percentage of all responses that were abnormal for all test frequencies combined per criterion (2 ears, 2 runs combined).
Criterion: % Abnormal High-Frequency DPOAEs

Criterion: Abnormal high-frequency DPOAEs


Criterion Comparison:
% of Subjects Whose DPOAEs All were WNL

<table>
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<tr>
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<th>Left</th>
<th>Both</th>
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<tbody>
<tr>
<td>2SD</td>
<td>60%</td>
<td>52%</td>
<td>28%</td>
</tr>
<tr>
<td>&lt;3 SNR</td>
<td>56%</td>
<td>48%</td>
<td>28%</td>
</tr>
<tr>
<td>&lt;6 SNR</td>
<td>52%</td>
<td>44%</td>
<td>28%</td>
</tr>
<tr>
<td>1SD</td>
<td>24%</td>
<td>28%</td>
<td>24%</td>
</tr>
<tr>
<td>5th %ile</td>
<td>4%</td>
<td>8%</td>
<td>4%</td>
</tr>
<tr>
<td>6&gt;(2SD&gt;NF)</td>
<td>0%</td>
<td>4%</td>
<td>4%</td>
</tr>
</tbody>
</table>
The current data suggest that the criteria which result in the largest number of identified DPOAE abnormalities are:

- Amplitudes less than 6 dB above 2 SD above the noise floor
  - Criterion can be calculated easily by each facility for its own specific protocol.
  - Criterion is therefore appropriate for the specific VA population and protocol being used.

- Amplitudes below the Vanderbilt Data Set 5th percentile.
  - Criterion optimally should be applied only when the facility uses the identical protocol.
  - Criterion may not be appropriate for VA population.

**CAVEAT**: Neither criterion has been applied to a normal-hearing, age-matched, non-tinnitus VA population for determination of its specificity.
Criteria Specificity: Examples

Granjeiro et al, 2008 (Otolaryngology - Head & Neck Surgery): abnormal in 68.4% of WNL tinnitus subjects and in 50% of WNL non-tinnitus subjects.

Onishi et al, 2004 (International Tinnitus Journal): abnormal in 61.3% of WNL tinnitus subjects and in 3.6% of WNL non-tinnitus subjects.

Criterion: 6 dB > (2SD > NF)
Criteria Specificity: Examples

Granjeiro et al, 2008 (Otolaryngology - Head & Neck Surgery): abnormal in 68.4% of WNL tinnitus subjects and in 50% of WNL non-tinnitus subjects.

Onishi et al, 2004 (International Tinnitus Journal): abnormal in 61.3% of WNL tinnitus subjects and in 3.6% of WNL non-tinnitus subjects.

Criterion: Vanderbilt 5th %ile
Discussion and Conclusions

- Most DPOAE interpretation criteria have been published for hearing screening purposes rather than for determination of OHC status although exceptions exist.

- Most studies that have explored DPOAEs in normal-hearing tinnitus patients provide comparisons to normal-hearing non-tinnitus subjects rather than absolute norms for determination of normal or abnormal OHC motility.

- Although DPOAE equipment may overlay normative criteria on DP-grams for reference, the specific population and protocol comprising those norms may differ significantly from actual patients and the clinical protocol being utilized.

- Obtaining and utilizing normative data obtained for specific DPOAE device(s) in specific facilities is optimal but difficult to achieve in the VA system.
Various criteria result in substantial differences in the identification of DPOAE abnormalities.

Although abnormal DPOAEs were identified at various frequencies for most of these normal-hearing tinnitus subjects, the inconsistency of those abnormalities among subjects, combined with the fact that abnormal DPOAEs among normal-hearing non-tinnitus are regularly observed, renders DPOAEs minimally useful, if at all, in the routine evaluation of normal-hearing tinnitus patients.

In fact, if abnormal DPOAEs may be observed in 50% of normal-hearing non-tinnitus subjects and 68% of age-matched normal-hearing tinnitus subjects (Granjeiro et al, 2008), standard DPOAEs may be unsuitable for routine use in the differentiation of normal-hearing tinnitus patients from normal-hearing non-tinnitus patients.
Questions or Comments?

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Handouts may be requested via email:
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