Physiological Responses to Sound

Time Domain
- Click OAE
- DPOAE
- Click ABR
- Tone ABR
- Click SSR
- AM SSR

Frequency Domain

Understanding the Stimulus

- Carrier Frequency
- Amplitude Modulation Depth
- Frequency Modulation
- Modulation Rate
• Mixed Modulation stimuli have less spectral splatter; therefore, more **Frequency Specific**.

• **Higher Intensities** allow for increased information with patients with severe and profound losses.

• MASTER Tones can be **calibrated** to ANSI Standard.
ASSR Response
• The cochlea is stimulated at the frequency of the carrier tone
• The brain perceives the modulation of the tone
• It is assumed that the part of the cochlea that is being stimulated by the carrier frequency (i.e. 1000 Hz) must be intact for the brain to respond to the modulation rate (i.e. 80 Hz) producing an ASSR response.
**Modulated Stimuli Produce Steady-State Responses at the Modulation Frequency**

- Carrier at 1 kHz, 100% AM, 8 Hz modulation frequency
- Activation at 1 kHz region of basilar membrane
- Steady-State response at the modulation frequency

![Sound Cochlea Brain](image)

**Four Stimuli Presented Simultaneously to One Ear**

- Carrier Hz
- Activation at the carrier frequency regions of the basilar membrane
- Steady-State response at the modulation frequencies

![Sound Cochlea Brain](image)

**Four stimuli to the Right ear**

<table>
<thead>
<tr>
<th>Carrier Hz</th>
<th>Mod Hz Right</th>
<th>Mod Hz Left</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>77</td>
<td>81</td>
</tr>
<tr>
<td>1000</td>
<td>85</td>
<td>89</td>
</tr>
<tr>
<td>2000</td>
<td>93</td>
<td>97</td>
</tr>
<tr>
<td>4000</td>
<td>101</td>
<td>108</td>
</tr>
</tbody>
</table>

- Activation at the carrier frequency regions of the basilar membrane
- Steady-State response at the modulation frequencies

![Sound Cochlea Brain](image)
What is Exponential Modulation?

AM² - Enhances the Amplitude of the Response for lows and highs so that you can obtain responses closer to threshold.

e.g. 500 Hz and 4000 Hz

Typical Stimulus Components

• Carrier Tone Frequency – 250, 500, 750, 1000, 1500, 2000, 3000, 4000, 6000, 8000 Hz

• Amplitude Modulation Depth – set at 100%
  - Exponential is the default (AM²)

• Frequency Modulation – a percentage change in frequency – set at 20% (10% on each side)

• Modulation Rate – rate of stimulus change (e.g. 80 Hz = 80 times per second)
  - varies by frequency, per ear
How do you know that a response is truly present?

**ASSR Response**
- The cochlear neurons in the region of the carrier tone are stimulated.
- The activity in those neurons is turned on and off with the modulation frequency and this can be detected in the EEG.
- It is assumed that the region of the cochlea that responds to the carrier frequency (i.e. 1000 Hz) must be intact for the neurons to respond to the modulation rate (i.e. 80 Hz) producing an ASSR response.

**ASSR Recording**
- The scalp-recorded activity is converted into the frequency domain using a Fast Fourier transform (FFT).
- The amplitude of the response to each stimulus can be measured at the specific frequency at which the tone was modulated (yellow spikes).
Signal Detection Options for ASSR

• Phase Coherence
• Fourier Linear Combiner
• F-test

When stimuli are presented at or above threshold:

• Phases of the vectors calculated for the EEG samples are “clustered”
• Brain’s EEG response becomes “phase-locked” or “coherent”
• Calculated Phase Coherence statistical values are significantly different from those calculated for “no response” samples.

When stimuli are presented below threshold:

• Phases of the EEG samples are randomly distributed relative to the stimulus modulation frequency (MF).
• Phase-coherence values for randomly distributed phases are low, which is the same as occurs when no stimulus is presented.
Determining that a Response is Present

RapidASSR™ Detection - Fourier Linear Combiner

- Fourier Linear Combiner (FLC) generates estimates of ASSR amplitude and phase.
- FLC algorithm mimics the brain’s responses to the 8 ASSR stimuli so that the resulting “estimated EP” is the best match for the EEG signal.
- Statistical analysis estimates amplitude and phase. When the patient’s response is similar to the algorithm with a high confidence level (95%) then a “positive ASSR” is marked on the audiogram.

Detecting the signal using F test

- Compares the response amplitude at the modulation rate to the variability of the noise around it
- A response must have a p<.05 to be considered significant
- Response color plot
  - Red = >.101
  - Yellow = .051 - .101
  - Green = <.050

Why is Residual Noise Important?
For a Response to be measurable, it must be Larger than the Residual Noise.

Key to Obtaining Good Data is Reduction of Noise

- **Techniques**: Averaging multiple sweeps together or increasing the duration of the sweep analysed with Fourier Transform.
- **Principle**: The level of noise decreases with the square root of the duration of the recording.
- **Example**: If the patient state stays the same, it takes four times as many sweeps will be required to reduce the noise by half.
Noise Level on the Collection Screen

- Noise level is displayed per frequency and per ear.
- If the noise level is <10nV (5 nV for newborn infants) and there is no response, move-on.
- If the noise level is above 10nV (5 nV for newborn infants) and there is still no response, continue averaging to reduce the noise floor.

Monitoring Noise Levels

- Is the Residual Noise decreasing?
- Is the F-Value decreasing?
- Monitor actual response amplitude relative to residual noise
  - E.g. If response amplitude is less than 10 nV, it isn’t likely to become significant, even when residual noise is low, move on to save time.

Reducing Residual Noise is Critical

- For Severe to Profound Hearing Losses, you have the benefit of Recruitment – the responses are larger at threshold.
- For Mild to Moderate Hearing Losses and Normal Hearing – the responses are smaller at threshold.
- Published Data shows that a longer averaging time is needed for obtaining true thresholds for patients with mild to moderate hearing loss and normal hearing.
Patient Preparation

- Impedance must be low and even
  - Below 5 kOhms
  - Within 2-3 kOhms
- Transducer – insert earphones, headphones, HALO Ear Muffin, bone oscillator, or soundfield
- Preferable if patient is asleep.

ABR Montage Options

- Two-channel ABR- Ipsi/Contra
  - Vertex to Ipsi and Contra Mastoid (earlobe)
  - Nape as ground
- Two-channel ABR- Ipsi/Nape
  - Vertex to Ipsi Mastoid (earlobe) and Vertex to Nape
  - Contra Mastoid (earlobe) as ground
- Single-channel
  - Vertex to Ipsi Mastoid (earlobe)
  - Nape or Contra as ground
Electrode Locations

- Fz/Cz versus posterior neck gives largest response
- Inion reference may give less noise
- Neck electrode may be difficult in babies
- Mastoid may provide ear-asymmetries
Choose Initial Stimulus Level

- Default stimulus level is 60 dB
- Choose level based on Click threshold.
  - E.g. if click threshold is 70, start at 80 for MASTER
- For patients in Natural Sleep this can be critical.
  - If Click threshold is 25, start at 40 or 50
  - Starting at 60 dB can be unsettling for normal hearing patients and noise could be a problem
- If click threshold is <25 dB, consider starting at 30 dB and ascending, if needed.

Do I always have to decrease in 10 dB steps?

- No, you need to look at the amplitude of the response in relation to the background noise and also the F-value.

- If the F-value is very low (0.000) and amplitude is larger than background noise then you could drop in 20 dB step.
Bio-logic Systems Corp.:

Make note of cardiac response. Notice the amplitude of the responses on the spectogram – 4000 Hz for the left ear has a huge yellow spike and the f-ratio is .000, 500 Hz for the right ear is not as large and the f-ratio is .040. The amplitudes of the responses are larger if you are above threshold and become smaller as you get closer to threshold.

Do I have to collect the maximum # sweeps set in the protocol?

- No!!!!
- If a response is present and remains for 2 to 3 consecutive sweeps, move on.
- Choose either “Accept Results” or “Change Intensity” to move on.
- Remember, if the noise level is <10nV (5 nV for newborn infants) and there is no response, move-on.
- If you find that you are collecting to the maximum in every case, contact technical support for assistance.

MASTER – Estimating the Audiogram

- ASSR thresholds are converted to estimated audiometric behavioral thresholds.
- Based on Dr. Picton’s research, we currently subtract 10dB from the ASSR threshold to estimate behavioral threshold (15 dB at 500 Hz).
### Threshold Differences

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>17 dB</td>
<td>14 dB</td>
<td>13 dB</td>
<td>13 dB</td>
<td>6-9</td>
</tr>
<tr>
<td>1000</td>
<td>4 dB</td>
<td>8 dB</td>
<td>5 dB</td>
<td>7 dB</td>
<td>1-4</td>
</tr>
<tr>
<td>2000</td>
<td>4 dB</td>
<td>8 dB</td>
<td>5 dB</td>
<td>5 dB</td>
<td>0-6</td>
</tr>
<tr>
<td>4000</td>
<td>11 dB</td>
<td>9 dB</td>
<td>8 dB</td>
<td>5 dB</td>
<td>5-8</td>
</tr>
</tbody>
</table>

### Estimating Behavioral Thresholds

- **500 Hz**
- **1000 Hz**
- **2000 Hz**
- **4000 Hz**

### Ahn et al 2007

Slide courtesy of Dr. Terry Picton
UCLA Comparison Study

Data collected by Ali Strocker, MD

UCLA Study Methods

• Infants/toddlers studied at time of scheduled diagnostic testing after informed consent.
• Diagnostic ABR performed for both ears
• ASSR tested in one ear
  – Randomized in cases of bilateral failed screen
  – Failed ear in cases of unilateral failed screen
  – Non-atretic ear in cases of atresia or canal stenosis

Instrumentation

• Biologic Navigator Pro
  – Master
  – AEP
  – ER3 insert earphones
  – ABR evaluation using two recording channels
    • Vertex to nape
    • Vertex to ipsilateral mastoid
  – ASSR evaluation single channel
    • Vertex to nape
Methods – ABR set-up
- 27 ms recording window
- Filters 50-1000 Hz
- Stimulation rate 27.7 Hz
- Fsp stop 2.9 (minimum 1280 sweeps) P <0.01
- Fsp numerator utilized 20 sampled points (4 2/3 ms)
- Max averages 6144
- 20 dB steps at high levels, 10 dB near threshold
- Tone bursts of 500, 2000 and 4000 Hz

Methods – ASSR set-up
- Epoch 16 sweeps
- Artifact Rejection 40 μV
- 100% Amplitude Modulation:
  • 500 (91 Hz)
  • 2k (96 Hz)
  • 4k (99 Hz)
- 3 Frequency Simultaneous Recording
- Above 80 dB each frequency tested individually
- 20% FM with Exponential Modulation
- Response P <0.05 for each frequency
- Noise below 5 nV for no response
- 10 dB steps

Subjects
- Twenty five infants
  - 17 male
  - 8 female
  - Median age – 2.5 months
    • Range: 1 month to 23 months
  - Tested ear:
    • 17 left
    • 8 right
  - 23 infants tested in natural sleep, 2 under sedation
Results

• Threshold Comparisons for ABR versus ASSR
  – 2000 Hz
    • No Difference (P = 0.92)
  – 500 Hz
    • ASSR 14.8 dB higher than ABR  (P <0.0001)
  – 4000 Hz
    • ASSR 10.5 dB higher than ABR  (P = 0.0002)
• Average test time for ASSR 23.5 minutes,
  ABR 46.5 minutes
  – Difference 20.3 minutes (P = 0.0003)

500 Hz

Comparison of ABR and ASSR Threshold

2000 Hz

Comparison of ABR and ASSR Threshold
ASSR in Auditory Neuropathy
In patients with auditory neuropathy or neural dys-synchrony….

– We might expect absent, sporadic, or elevated response pattern

– The response may actually be the cochlear microphonic

ASSR vs. Behavioral Thresholds in Patients with Auditory Neuropathy No Relationship!

~70-100 dB threshold for All Patients– Could be detection of Cochlear Microphonic or stimulus artifact.

Rance et al.
UCLA Cases with TBABR and ASSR

AP 30 Months Old

- Dx of Downs Syndrome and Hx of heart surgery
- Sedated ABR requested for baseline pre-chemo Tx for Acute Myelocytic Leukemia
- Bilateral Refer at birth Screening ABR
- No DX ABR due to insurance issues
- Tested under sedation
- OAEs absent bilaterally
AP- Bilateral CHL

Recommended Otologic consult and repeat ABR or behavioral assessment.
LM 5 Months Old

- C-section due to fetal distress
- Multiple blood transfusions
- 10 days in NICU
- Bilateral Refer at birth Screening ABR
- Tested in natural sleep (4 test sessions)
The document contains a table and a graph illustrating hearing test results for a patient named LM with Bilateral AN.

### LM- Bilateral AN

<table>
<thead>
<tr>
<th>Thresholds</th>
<th>CM</th>
<th>5kHz</th>
<th>2kHz</th>
<th>4kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>LE</td>
<td>Present</td>
<td>70 dB</td>
<td>&gt;105 dB</td>
<td>&gt;105 dB</td>
</tr>
<tr>
<td>RE</td>
<td>Absent</td>
<td>80 dB</td>
<td>70 dB</td>
<td>75 dB</td>
</tr>
</tbody>
</table>

Results from initial test session.
Normal tymps and OAEs were present at that time.
Fit with mild gain amplification. Discontinued use at 9 months.
Making good progress with AVT therapy.
MH  25 Months Old

• Term birth, no complications
• Pass birth Screening ABR bilaterally
• ABR requested for baseline pre-chemo Tx
  s/p left eye retinoblastoma enucleation
• Tested under sedation
• Shallow tympanograms bilaterally
MH - Normal

<table>
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<tr>
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<tr>
<td>LE</td>
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<td>20 dB</td>
<td>20 dB</td>
<td></td>
<td></td>
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Fit with bilateral BTEs at 5 months of age.

MH - Normal

CK  4 Months Old

- Hx of soft Cleft Palate
- Pass AS, Refer AD at birth Screening ABR
- Tested under sedation (2 previous sessions)
- Immediately following PE tube placement
- No OAE or Tymps due to drainage s/p tube placement
CK- Bilateral Moderate SNHL

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<tr>
<td>LE</td>
<td>70 dB</td>
<td>60 dB</td>
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<td>70 dB</td>
<td>80 dB</td>
<td>50 dB</td>
<td>40 dB</td>
</tr>
<tr>
<td>UMB</td>
<td>40 dB</td>
<td>50 dB</td>
<td>50 dB</td>
<td>50 dB</td>
</tr>
</tbody>
</table>

Fit with bilateral BTEs at 5 months of age.
SZ 32 Months Old

- Dx of Goldenhar Syndrome
- Profound HL
- Ear canal stenosis AD
- ABR requested to confirm type of HL as SNHL as part of Cochlear Implant Pre-evaluation
- Tested under sedation
- OAEs absent bilaterally
- Shallow tympanograms bilaterally
SZ- Bilateral Profound SNHL

<table>
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<tr>
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<th>2kHz</th>
<th>4kHz</th>
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<td></td>
<td></td>
</tr>
<tr>
<td>UMB</td>
<td>&gt;60 dB</td>
<td>&gt;70 dB</td>
<td></td>
<td></td>
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</tbody>
</table>

Wears power BTE in LE. CI pre-evaluation in process.

SZ Profound

BM 15 Months Old

- 2 months in NICU
- Hx of ventilator support
- Daily Dialysis for congenital kidney condition
- No Birth Hearing Screening
- Several behavioral attempts yielded responses to speech stimuli in the mild hearing loss range
- ABR under sedation
- OAEs present and robust bilaterally
BM- Bilateral AN

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Referred to outside provider for behavioral assessment and amplification.