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Back to Basics:
Hearing Science Concepts as a Foundation for Clinical Audiology

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Financial/Non-financial disclosure

- Financial:
  - Professor/Chairperson Towson University

- Non-financial
  - I ❤️ Hearing Science
So much to cover...so little time

- (a) characteristics of sound → TEOAE
- (b) vibration and resonance → MF tymp.
- (c) SDT → clinical decision making & patient responses

(a) Characteristics of sound

- From a strictly acoustics standpoint, the ear is a motion detector.

- But what this motion detector is anatomically wired to inside the head makes it amazing.
How amazing and beautiful and wonderful is the ear

Because even with eyes closed it is perfectly clear...
we can tell if a sound is from there or from here


And we can tell if a human or a rodent is near

We can tell if a sound comes from the right or the left.

From time and intensity cues at the cleft(s)

Cleft – opening or split created during embryonic development (usually abnormal, but I needed a rhyme)
We can tell if a singer sings in base or treble clef.

And we can tell if a message is from Sue or from Jeff.
‘cause vocal fold mass is transmitted high-def.

We can tell if a sound starts from outside or in

Photos: © 2013 Peter Emanuel. Used with permission
Because the free field’s where we ride on our Schwinn

We know if sound comes from cheap mic. or from skin
because frequency drops like the head of Boleyn

And we can tell if the muse delivers rock song or hymn.
We can tell if a crier is from far or from near

From intensity, and reflection, and absorption, my dear
We can tell if a sound is from joy or from fear

Because of some wiring to the amygdala, right here
How amazing and beautiful wonderful is the ear

Characteristics of sound

- **Acoustic**
  - Frequency: Number of cycles of vibration per second (20 to 20,000 Hz)
  - Intensity: "Strength" of the signal (0 – 120 dB SPL)
  - Duration
  - Phase
  - Complexity

- **Psychoacoustic**
  - Pitch
  - Loudness
  - Duration
  - Timbre/Sound Quality

Diagram showing intensity and frequency relationship with dB levels.
In hearing science, we examine the characteristics of sound in the:
- Time (temporal) domain &
- Frequency (spectral) domain

Looking at vibration in the time domain means examining the motion over time (x-axis)
Let’s begin in the time domain

- This should look familiar.

![Waveform Image]

**Sinusoidal waveform**

- What frequency is it?
  - 3000 Hz
- What type of sound is generated by a continuous sinusoidal waveform?
  - Pure tone
- What is one non-electronic way to create a pure tone?
  - Tuning fork
- What is the period?
  - Period = 1/frequency = 1/3000 Hz = .00033 seconds (or .33 ms)

\[ f = \# \text{cycles/time(s)} = 3/.001 = 3000 \text{ Hz} \]
• What is the amplitude of this waveform?
  4 cm

• What is the RMS magnitude (RMS amplitude)?
  $4 \text{ cm} \times .707 = 2.828 \text{ cm}$

Higher frequency? Larger amplitude?

Modified from Emanuel & Letowski (2009)
Simple sinusoidal vibration is rarely present in nature; vibration is usually complex.

The Fourier Theorem states that any complex vibration is the sum of various sinusoidal motions of varying amplitude, frequency, and phase.

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Aperiodic vibration ("noise")

Periodic vibration

Modified from Emanuel & Letowski (2009).
Time to frequency domain

Modified from Emanuel & Letowski (2009).

Breaking down complex signals

Fourier analysis
Light
Vibration (Sound)
Any waveform can be analyzed and shown in frequency domain

Picture modified from internet. Source unknown.

© 1993 Diana C. Wright (Diana C. Emanuel)
What’s in your sound?

In theory, a pure tone should appear as a single vertical line on a spectrum...in reality, it does not appear that way on our instrumentation.

The spectrum depends on the frequency and duration of the input signal (also instrumentation, gating, filtering).

A short stimulus will have a broader frequency spread.
A click is created by a brief electrical pulse (e.g., 80-100 μs) sent through a transducer. The acoustic waveform will be longer.

Polarity depends on polarity of pulse & earphone wiring.
½ ms = .0005 s
p = 1/f = 1/0.0005
2000 Hz pure tone?

Nope, too short to be a pure tone

Spectrum shows broad frequency stimulus
Here’s where things get ugly

\( P_0 = 20 \, \mu Pa \)

\( \mu = 1 \text{ millionth} \times 10^6 \)

To convert \( \mu Pa \) to \( Pa \), move the decimal 6 places to the left

\( 20 \, \mu Pa = 0.00002 \, Pa \)

Notice we used the peak here (not RMS magnitude) to estimate because that is the value used for dB pk.

Sometimes, the unit for clicks is pe dB SPL, peak equivalent dB sound pressure level, which is based on the RMS value of a sine wave that has the same amplitude or peak to peak amplitude as the click.

The spectrum level is the intensity level of bands 1 Hz wide.

The overall intensity level is the intensity of the entire sound.

About 3300 Hz wide

Imagine 3300 pieces of noise each 1 Hz wide and 44 dB. What would the total level be?

\[ x = 44 + 10 \times \log(3300) = 79 \, \text{dB} \]
Why is the stimulus so much shorter in time than the response?

This is the response in the time-domain.

This is the response in the frequency-domain.
(b) Vibration & Resonance

- Vibration
  - Back and forth motion due to elasticity
  - Oscillation - back and forth motion due to gravity.
- Resonance frequency
  - frequency at which a system will vibrate in free vibration or
  - frequency at which a system in forced vibration will vibrate at greatest amplitude.

Resonance frequency

- Resonance frequency depends on three things: mass, spring, friction.

Modified from Emanuel & Letowski (2009)
Resonance curves

- Increased mass ↔ Increased stiffness
- Increased friction

Magnitude of vibration vs. Frequency (Hz)

Van Camp et al. (1986)

- **Springs**
  - Mechanic: Eardrum, ligaments, tendons.
    (Things that act “springy”)
  - Acoustic: air mass on either side of the eardrum
    (Air that “springs back”)

- **Masses**
  - Mechanic: Ossicles, pars flacida, perilymph
  - Acoustic: Air in additus ad antrum
    (Air that moves back and forth)

- **Friction**
  - Mechanic & acoustic

Modified from Emanuel & Letowski (2009)
Nickel tour of impedance

- When a system is forced to vibrate at a frequency below resonance frequency, stiffness reactance (opposition by the spring element) is dominant.
- When a system is driven to vibrate at a frequency above the resonance frequency, mass reactance is dominant.

Conventional tympanometry

- Tympanometry is usually assessed with a low frequency probe tone (~226 Hz)

- With a low frequency tone, we are essentially looking at the stiffness reactance of the middle ear
Multi-frequency (MF) Tympanometry

- MF tympanometry indicates if the system has added mass (e.g. disarticulation) or added stiffness (e.g. ossicular fixation).
- So, we don’t we tend to use it?
  - Lack of equipment & training (Emanuel et al., 2011)
  - Because it is freakishly difficult to understand most of the literature.
    - Try starting with Hunter & Margolis (1992)

![Tympanogram (2-D)](image)

- Admittance (mmho, ml, cc)
- Pressure (mmH2O or daPa)

continued
Admittance as a function of frequency (Lilly, 1984 based on model developed by Berg, 1980).

Middle ear system (multiple mass, spring & friction elements)


Mean frequency response of human cadaver ears (Homma, et al., 2009)

Figure created with data from Homma et al. (2009).
Multi-frequency (MF) tympanometry

- Normal multi-frequency progression
  - As probe frequency increases, amplitude increases
  - Notching begins above about 900 Hz but may begin earlier due to artifact.
    - Resonance frequency of ME for AC is 800-1200 Hz; for BC sound, closer to 2k Hz.
    - Change in shape is due to interaction of the probe frequency, middle ear resonance, and ear canal pressure.

MF Tympanometry

- Increased stiffness in ME
  - Resonance frequency increases
  - Notching occurs at an abnormally high frequency
    - Higher than usually assessed, even with MF testing
- Increased mass in ME
  - Resonance frequency decreases
  - Notching occurs at an abnormally low frequency
    - May be picked up w/ 660 Hz probe tone
(c) Signal Detection Theory & Audiometric Testing

- Moving on...you know how to test threshold, so...let’s talk about thresholds as they relate to signal detection theory and bias

Signal Detection Theory (SDT)

- SDT examines the ability of respondents to distinguish between a signal and noise.
- It explores what happens under conditions of uncertainty and how response criterion (response bias) affects responses.
Signal detection theory

- SDT is examined in MANY different fields.
- Very commonly, it is applied to diagnostic decisions compared with the actual status of pathology or patient/research subject responses

SDT examples

- A radiologist looks at a scan for the presence of a tumor.
  - 2 possible decisions: Yes (abnormal) or No (normal)
  - 2 possible statuses: Yes (tumor present) or No (no tumor)
- A patient taking a hearing test has to indicate if he/she heard a tone
  - 2 possible decisions: Yes (heard it) or No (did not hear)
  - 2 possible statuses: Yes (tone present) or No (no tone)
2x2 table (radiologist)

<table>
<thead>
<tr>
<th>Radiologist decision (abnormal?)</th>
<th>Tumor actually present</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Hit</td>
<td>False alarm</td>
</tr>
<tr>
<td>No</td>
<td>Miss</td>
<td>Correct rejection</td>
</tr>
</tbody>
</table>

2x2 table (hearing test)

<table>
<thead>
<tr>
<th>Patient response</th>
<th>Signal presented by audiologist</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>Hit</td>
<td>False alarm</td>
</tr>
<tr>
<td>No</td>
<td>Miss</td>
<td>Correct rejection</td>
</tr>
</tbody>
</table>
Decisions...decisions

"Is that really abnormal...maybe it is just a smudge...are my eyes getting tired..."

“I am sure there is NO tumor”

uncertainty

“I am sure there IS a tumor”

Decisions...decisions

“Did I hear a tone...I'm not sure...was it that ringing in my ears...Maybe it was my breathing?”

“I am sure there is NO tone”

uncertainty

“I am sure there IS a tone”
“Did I hear a tone…I’m not sure…was it that ringing in my ears?…Maybe it was my breathing?”

“I am sure there is NO tone”

“I am sure there IS a tone”

Decisions...decisions

“Internal response

Probability

Noise

Signal + Noise

Uncertainty

Internal response

CONTINUED
Decisions...decisions

Response criterion (β) or bias

Negative ("no") response

Positive ("yes") response

Probability

Internal response

Noise

Signal + Noise

uncertainty

Decisions...decisions

Response criterion (β) or bias

Negative ("no") response

Positive ("yes") response

Probability

Internal response

Noise

Signal + Noise

continu​ed
Effect of response criterion (bias)

\[ \beta \rightarrow \]

- I will say yes only if I am really sure (strict)
  - False alarm rate ↓ 😊
  - Hit rate ↓ 😊

\[ \beta \leftarrow \]

- I will say yes even if I am not sure (lax)
  - False alarm rate ↑ 😊
  - Hit rate ↑ 😊

Reasons for response criterion (bias)

<table>
<thead>
<tr>
<th>STRICT CRITERION</th>
<th>LAX CRITERION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiologist</td>
<td>Radiologist</td>
</tr>
<tr>
<td>- Cost containment 😊</td>
<td>- Early dx 😊</td>
</tr>
<tr>
<td>- Limit panic 😊</td>
<td>- High cost 😊</td>
</tr>
<tr>
<td>- Later dx 😊</td>
<td>- HCP loses credibility 😊</td>
</tr>
<tr>
<td>Audiology patient</td>
<td>- Audiology patient</td>
</tr>
<tr>
<td>- Elevated threshold measures compared with true 😊</td>
<td>- “Button happy”; may increase test time 😊</td>
</tr>
<tr>
<td>- Less “button happy”; may decrease test time 😊</td>
<td>- Thresholds may be closer to accurate 😊 or farther away, if audiologist is uncertain 😊</td>
</tr>
</tbody>
</table>
Can we eliminate uncertainty?

- Usually, no, but the separation between the $N$ and $S + N$ distributions may be improved
  - Discriminability index ($d'$)

How can $d'$ be increased?

- Radiologist:
  - Improved training
  - Improved scanning technologies
- Audiology patient
  - Use different stimuli
  - Re-instruct
  - Use different test technique
The relationship between the hit rate and the false response rate as a function of $d'$ is shown via a receiver operating characteristic (ROC) curve.

References

Back to Basics Webinar Series

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Hearing Science Concepts as a Foundation for Clinical Audiology  
*Diana C. Emanuel, PhD*

[www.audiologyonline.com/backtobasics](http://www.audiologyonline.com/backtobasics)