DSL for Bone-Anchored Hearing Devices: Prescriptive Targets and Verification Solutions

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Introduction

- Today we will talk about new methods for fitting bone-anchored hearing devices using DSL prescriptive targets, with verification on a coupler-like device called a *Skull Simulator.*
- The skull simulator shown in this course has been developed by Audioscan for integration into their verification systems. This presentation, therefore, is specific to Audioscan products.
- More information about the DSL targets we will discuss today is available in an open-source article (Hodgetts & Scollie, 2017) available at this link:
  - DSL prescriptive targets for bone conduction devices: adaptation and comparison to clinical fittings

Audioscan® Verifit®
Skull Simulator

Taylor & Francis
International Journal of Audiology 2017; Early Online: 1–10
International Journal of Audiology
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Technical Report

DSL prescriptive targets for bone conduction devices: adaptation and comparison to clinical fittings

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Learning Objectives

Participants will be able to…

- Describe the rationale for the DSL-BCD prescriptive targets, used with bone-anchored hearing devices.
- Describe the studies used to develop and revise the DSL-BCD prescriptive targets.
- Summarize the main steps of a fitting protocol designed for use with the Audioscan Verifit skull simulator

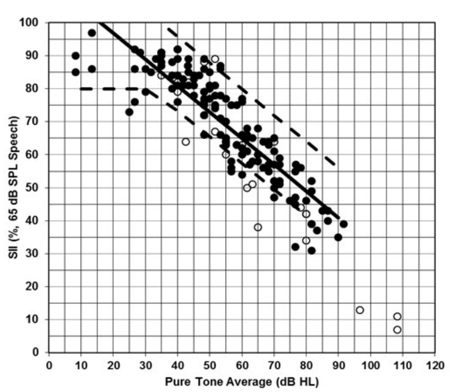
Agenda

0-5 Minutes	Introduction
5-15 Minutes	Prescriptive targets and their impact on the consistency and quality of fittings for air-conduction hearing aids.
15-25 Minutes	Bone-anchored hearing devices: types and terminology, and lessons on verification from the labs.
25-40 Minutes	DSL for Bone Conduction Devices (DSL-BCD): Development of version 1.1.
40-50 Minutes	The Audioscan Verifit Skull Simulator: What it is and how to use it.
50-55 Minutes	Case illustration and discussion of clinical uses beyond target matching.
55-60 Minutes	Summary

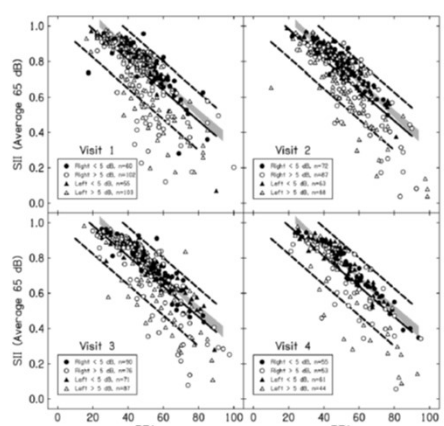
Air conduction prescription/verification is well understood. Do we need these tools for bone conduction hearing aids?

- Prescriptions promote *consistent and beneficial* levels of audibility across patients, (McCreery et al, 2013; McCreery et al, 2016; Stiles et al, 2012).
- Prescriptions are designed for use with *non-linear signal processing* because they are based on well-defined and realistic *speech signals* (Holube et al., 2010) and built with speech-based nonlinear input/output target functions (Scollie et al., 2005).
- It may be better to adjust & fit aided bone-conduction hearing with *aided speech* (rather than aided thresholds). (Hodgetts et al., 2010).
- Hearing aid analyzers support assessment of signal processing and accessories. Bone conduction devices now offer these sophisticated options, so having verification tools is more relevant than ever before.

Example 1: Prescription and verification improve the *consistency of fittings* across patients.



Moodie, et al, 2016



McCreery et al, 2015

Example 2: Prescription and verification impacts *audibility of specific speech sounds.*

Perceptual Implications of Level- and Frequency-Specific Deviations from Hearing Aid Prescription in Children

Authors: McCreery, Ryan W.; Brennan, Marc; Walker, Elizabeth A.; Spratford, Meredith
Source: Journal of the American Academy of Audiology, Volume 28, Number 9, October 2017,

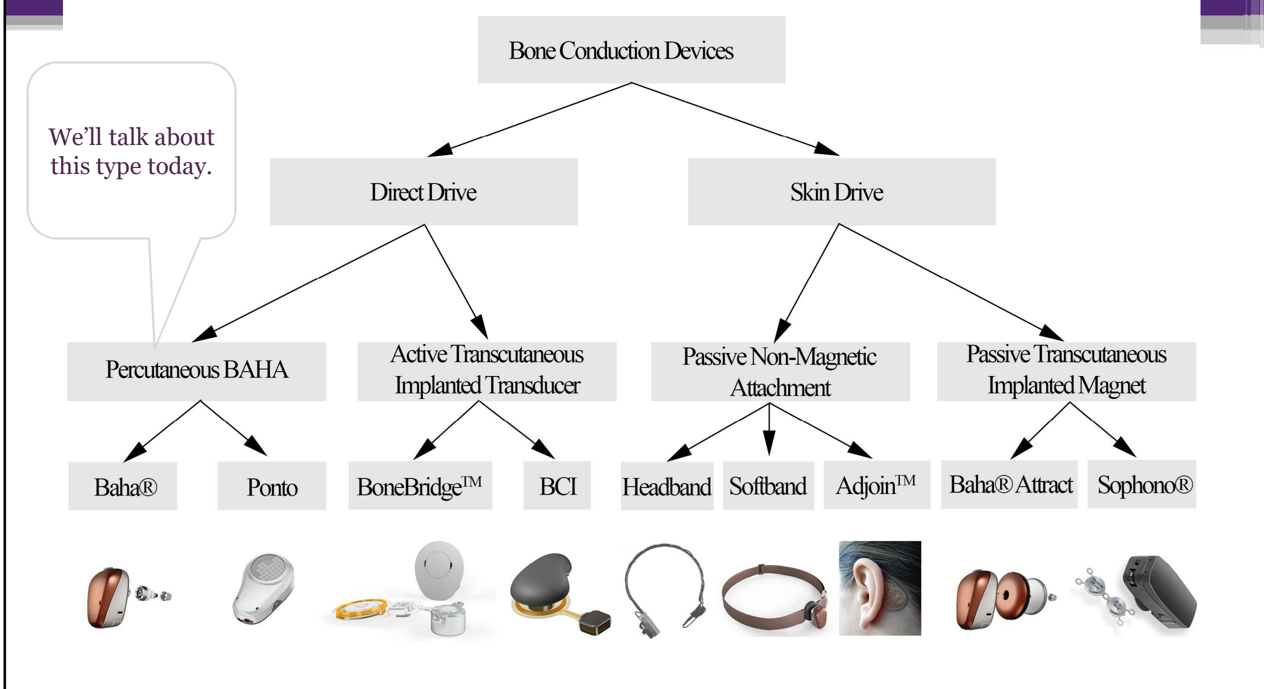
Results:

Children who had deviations from prescriptive target at all three input levels had poorer LNT word recognition in quiet than children who had fittings that matched prescriptive target within 5 dB RMS at all three input levels. Children with lower 4 kHz SLs through their HAs had poorer LNT recognition in quiet and CASPA phoneme recognition in noise than children with higher aided SLs.

Fitting Frequency-Lowering Signal Processing Applying the American Academy of Audiology Pediatric Amplification Guideline: Updates and Protocols

Example 3: Verification systems allow us to compare and document the impact of signal processing and the effectiveness of accessories.

- **Noise reduction** systems vary across brands and settings.
- **Feedback managers** are not all created equal – some will impact your frequency response while others don't.
- **Remote microphone & streaming devices** can have connection issues or breakdown – without measurements it can be challenging to diagnose or document these problems.
- **Hearing aid analyzers provide objective solutions** for assessing these technologies – but only for air conduction hearing aids until recently.



Is it possible to verify bone conduction hearing aids?

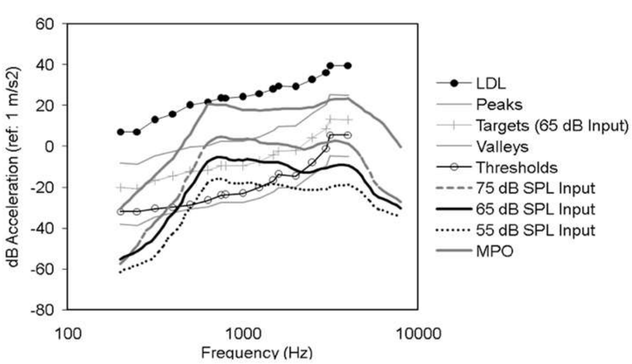
- Certainly! A skull simulator exists (TU-1000, Stenfelt & Hakansson, 1998). It is analogous to a coupler.
- An on-head microphone is in early development (Hodgetts et al., in press). It is analogous to a probe mic.
- It can be used to verify levels of aided speech from percutaneous bone conduction hearing aids.
- *Problem: this hardware has not been available for clinical use in fitting.*

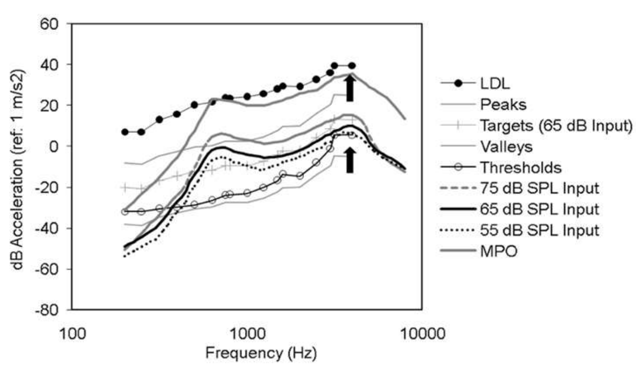
https://www.researchgate.net/publication/13645470_A_Miniaturized_Artificial_Mastoid_Using_a_Skull_Simulator

Lessons from the labs

These concepts help us understand if and how bone conduction hearing devices are different (for prescription and verification) than air conduction devices.

Just like with air conduction hearing aids, audibility and bandwidth matter. (Hodgetts et al., 2011)



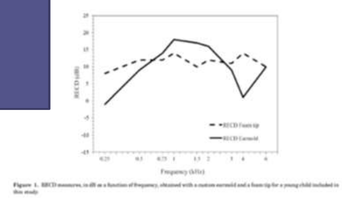


(Hodgetts et al., 2011)

Just like with air conduction hearing aids, the device has a different response in situ than on the coupler.

Real Ear to Coupler Difference

RECD



Real Head to Coupler Difference

RHCD

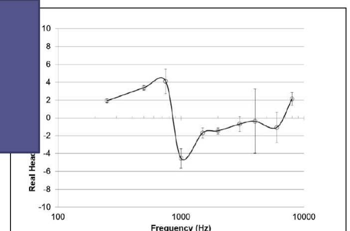


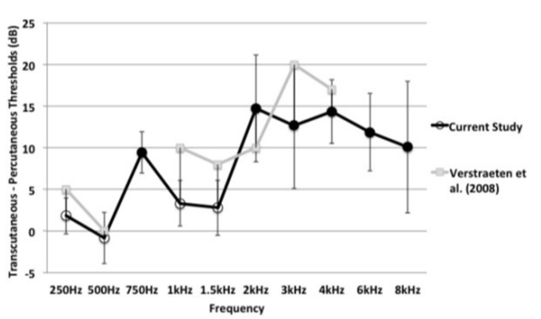
Fig. 6. Real Head to Coupler Difference (RHCD). Average values over all patients. Error bars indicate 1 SD.

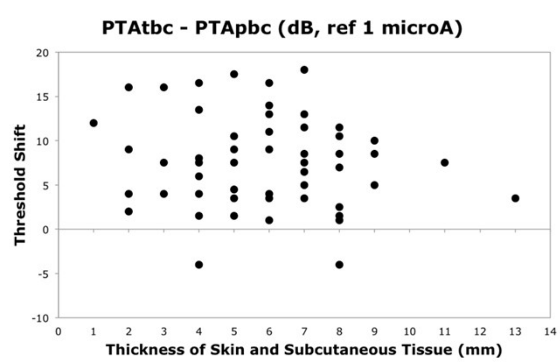
Moodie et al., (2016)

Hodgetts et al., (in press)

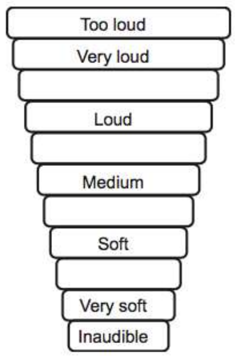
Just like with air conduction, we should define thresholds in the same units that we use for device verification.

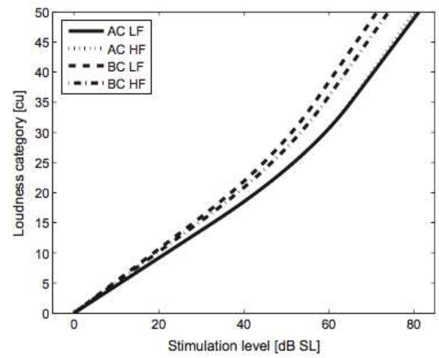
Conduction through an abutment is more "direct" than through tissue, so audiometric bone thresholds don't equal abutment-based bone thresholds.





Loudness growth in bone conduction hearing is different than in air conduction (Stenfelt & Zeitooni, 2013)





The biggest limiting factor in bone conduction hearing is the *output limiting of the device*, not the user's loudness discomfort levels.

- New developments in transducers have contributing to higher maximum output in recent devices (Håkansson, 2003; Jansson et al., 2014).
- Implication for DSL-BCD: Targets change when I change the device type!

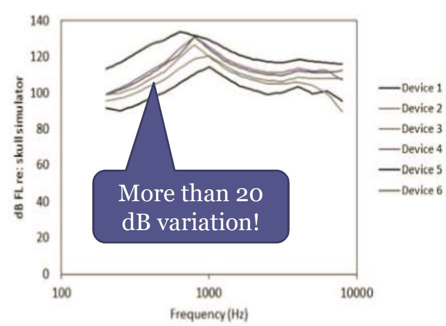
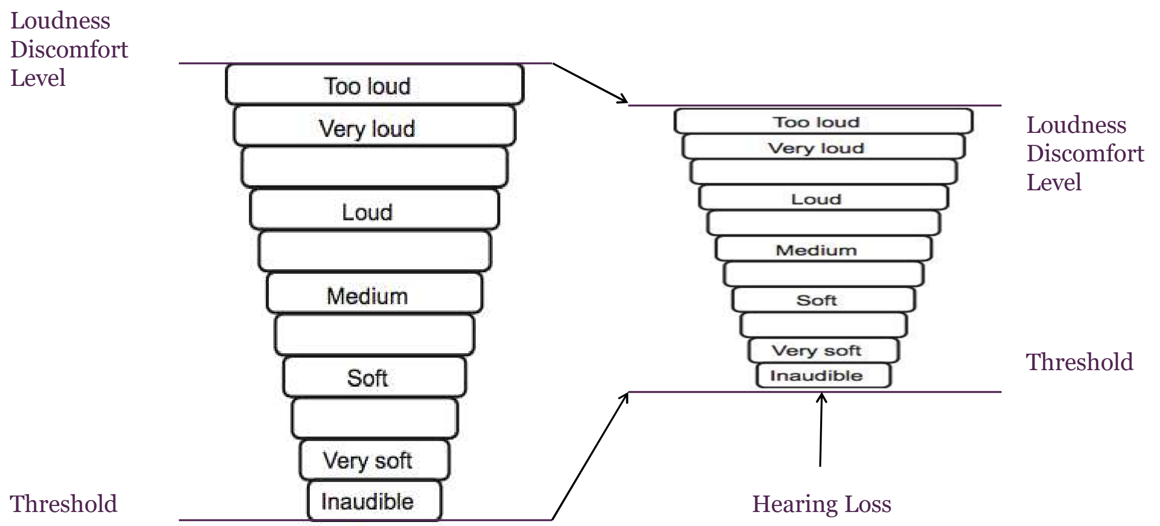


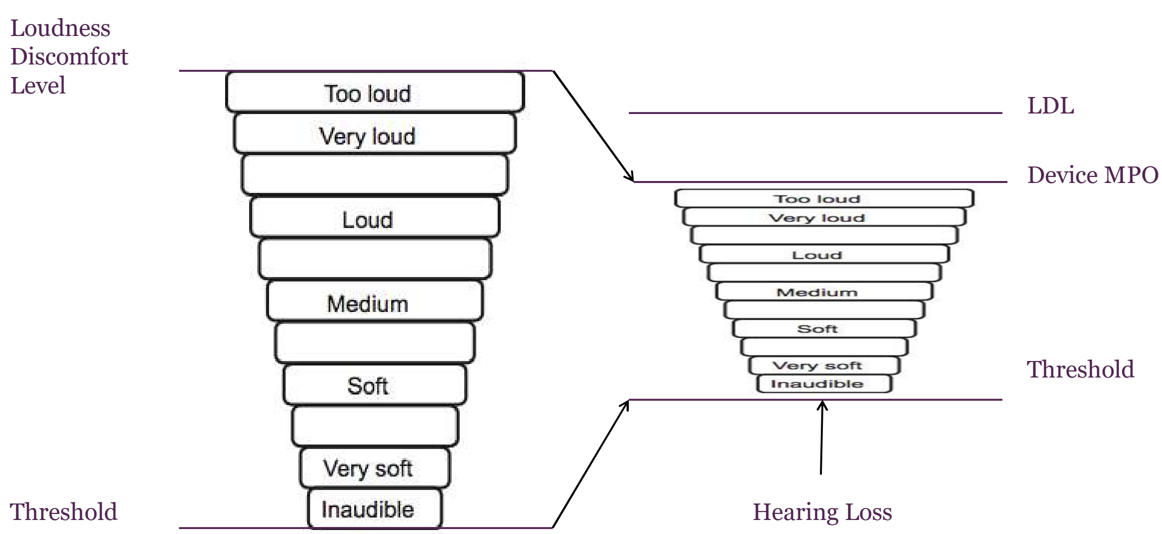
Figure 2. Device-specific maximum output curves for six bone-anchored hearing instruments of varying makes, models and fitting ranges. All curves were measured with a 90 dB pure tone sweep, with output force levels (dB) measured on a TU-1000 skull simulator.

Hodgetts & Scollie (2017)

Dynamic Range



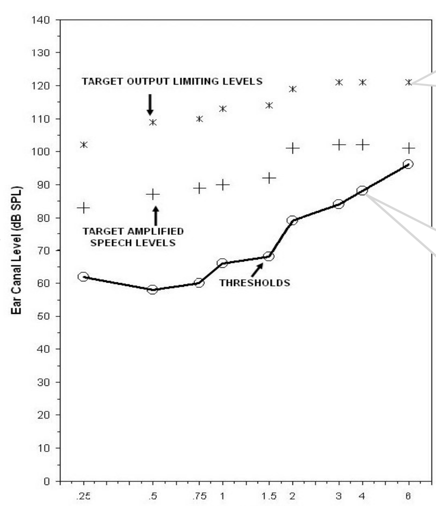
Dynamic Range



DSL for Bone Conduction Devices (DSL-BCD): Development of version 1.1

We imagined a fitting screen… like the SPLogram but for force levels from bone conduction devices.

What if we could measure something like dB SPL output for bone conduction aids?

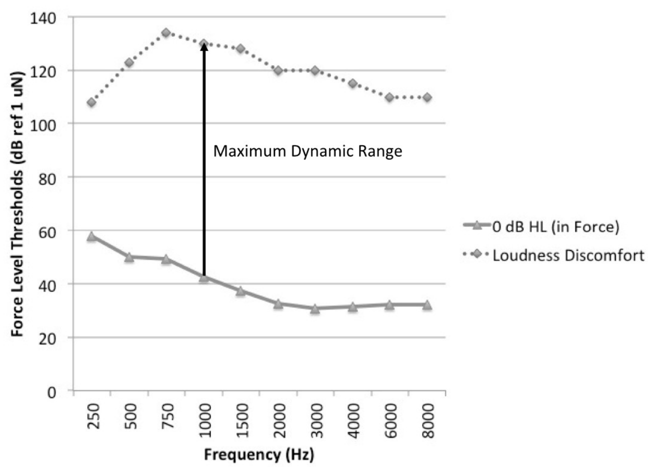


We knew that bone conduction aids had limited max output. Would we even reach the listener's upper limits of comfort?

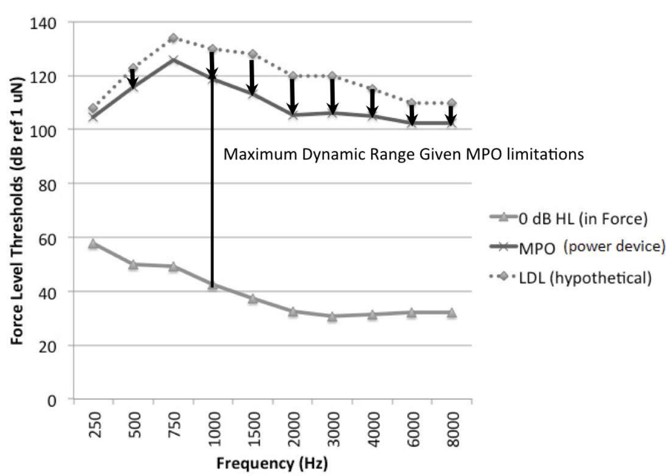
Define thresholds for "in situ" listening for percutaneous devices.

Figure from Seewald et al., (2005)

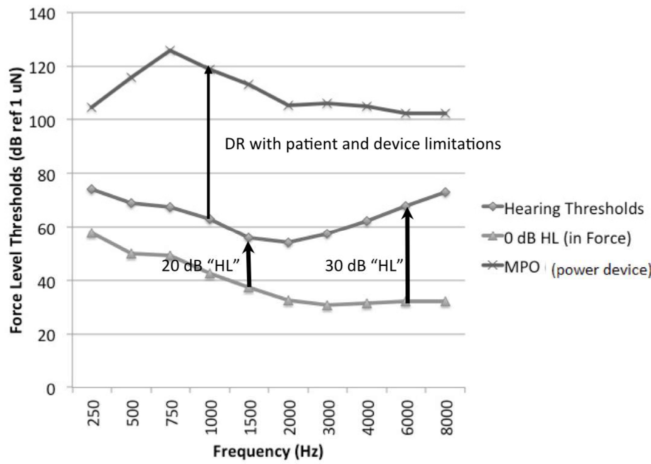
We call this the force level-o-gram or FLogram.



The output fitting range is limited by patient upper limit of comfort, or device maximum output, whichever is lower.



If the patient has a mixed hearing loss, the dynamic range will be further reduced because the threshold line is elevated.



We (and others) ironed out a few details.

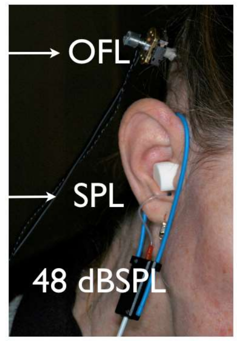
- We measured microphone location effects for BCD.
- We defined several *transforms* & selected published *norms*:
  - RHCD: Real head to coupler difference (transforms head to skull simulator)
  - RETFLdbc: Force levels at normal threshold (Carlson & Håkansson, 1997)
- Bill's lab explored a wide range of different methods for measuring the output of percutaneous devices, eventually settling on the *skull simulator* as a good solution (Hodgetts et al, 2010).

Bone Conduction Devices can be measured in dB output force level (dB FL), which we use much like real ear or coupler SPL are used for air conduction.

"HL" → + RETFL → + RHCD → OFL

HL → + RETSPL → + RECD → SPL

40 HL +3 +5 = 48 dBSPL



Example
2000 Hz

We defined a clinical workflow:

Assess hearing for direct bone conduction via the abutment.
- Use the patient's own device to re-measure thresholds. These are called "in situ" or "dial level targets".

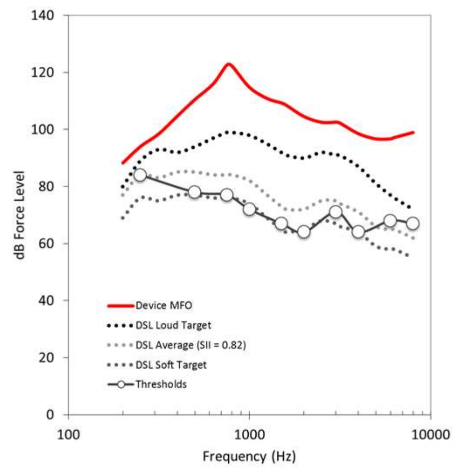
Prescribe listening levels
- Shaped across frequencies
- Compressed across input levels
- Limited to device-specific MFO

Verify device output
- Fit to targets using speech inputs, measure output on a skull simulator on the FLogram.

Hodgetts & Scollie (2017)

Our first version of DSL-BCD targets was based on DSL v5, converted from dB SPL to dB FL.

- The targets used wide dynamic range compression, mainly to overcome the limited output dynamic range of the devices.
- Similar to DSL v5:
  - More gain/output for children.
  - Frequency shaping for audibility.
  - Slight reduction for binaural fittings in adults.
  - Targets fall below threshold for very low input levels, especially if they are below compression threshold.



We compared our targets to the fittings of a group of successful percutaneous device users.

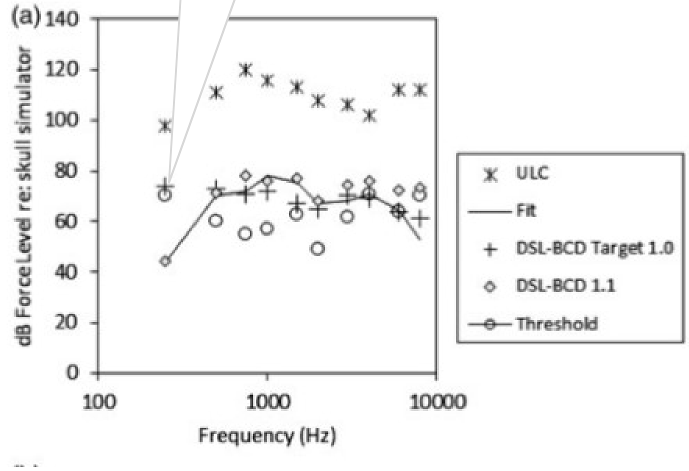
- 39 successful BCD users (24 male) from iRSM clinic
  - Mean age of 57.3; range 23–72
  - All had received follow-up visits to fine tune
  - All wore devices at least 8 hours per day for at least two months
  - Wide range of force level thresholds, ranging from 44 to 81 dB FL (4fPTA)
- Devices were measured at user settings
  - 65 dB SPL running speech input, shaped to ISTS + MLE (Cox & Moore, 1988, Holube et al., 2010).
  - Measured on a skull simulator (TU-1000) in a desktop anechoic chamber, 1/3 octave band analysis.

Hodgetts & Scollie (2017)

Results

- Low frequency targets were 19 dB higher than typically worn, attributed to need for fine tuning.
- Mid frequency targets were about 4 dB high, attributed to unwanted device resonances.
- High frequencies targets and fittings were not significantly different.

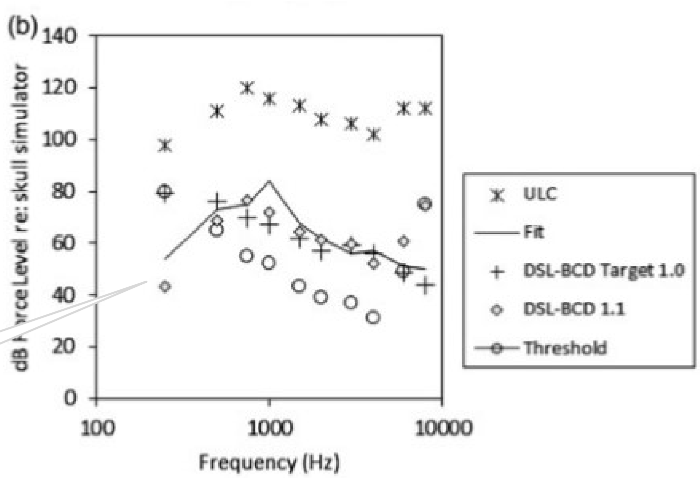
Version 1 target is too high here.



Hodgetts & Scollie (2017)

We incorporated a low cut, and the revised targets are used in Version 1.1.

- The revised target (v1.1) agrees with the 39 patient fittings to within 1.9 dB from 500 to 4000 Hz.

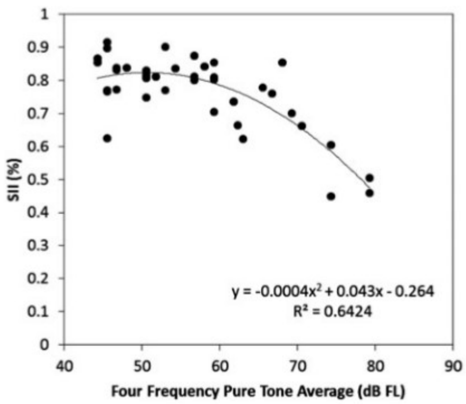


Impact of the low cut can be seen here.

Hodgetts & Scollie (2017)

One benefit of verifying aided speech is that the system can calculate Aided Speech Intelligibility Index values. These are useful for counselling.

- In our patients, the Aided Speech Intelligibility Index (SII) values were consistent and high when fitted to DSL v1.1.
- As with air conduction fittings, the SII values are lower when the degree of hearing loss is higher.
- *Clinical implementation requires a skull simulator.*



Hodgetts & Scollie (2017)

The Audioscan Verifit Skull Simulator: What it is and how to use it.

The Verifit Skull Simulator works with Verifit2 and Verifit1 if software-updateable (check serial number).

This is the abutment. Connect the hearing aid to this.

Note the blue/red markings for left/right setups.

You will need to update software to get the associated targets.

Unplug the air conduction coupler(s) and plug the skull simulator into the test box.

Tip: Remember to calibrate the air conduction mics first! This needs to happen before you move to the skull simulator if not already done/stored.

VF-2

VF-1

Position the skull simulator sideways to the speaker.

This points the directional mic on the hearing aid to the speaker.

Tip: *If you are testing right you should see red. If left, you should see blue.*

2a VSS PLACEMENT FOR VERIFIT (VF-1)

LEFT DEVICE

RIGHT DEVICE

Tip: Extender for VF-1 placement.

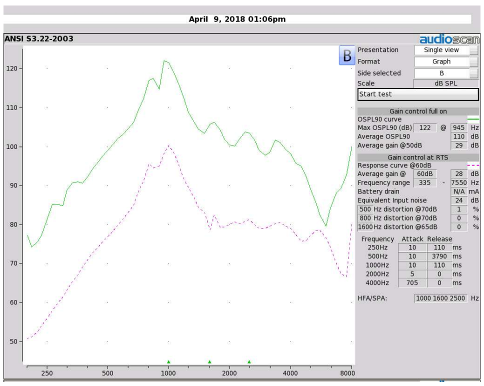
2b VSS PLACEMENT FOR VERIFIT2 (VF-2)

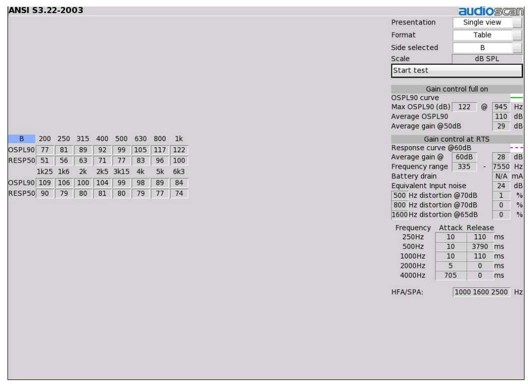
LEFT DEVICE

RIGHT DEVICE

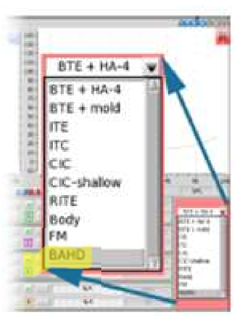
Snap on the hearing aid. Place reference microphone to the hearing aid microphone. Select “BAHD” to move into this mode.

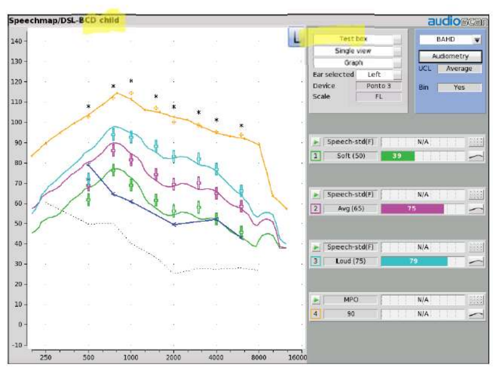
Running quality control tests, such as ANSI sequences, is possible.





Fitting to targets is possible. Select "BAHD" and choose DSL-BCD child or adult. You'll enter direct bone thresholds next (not shown).





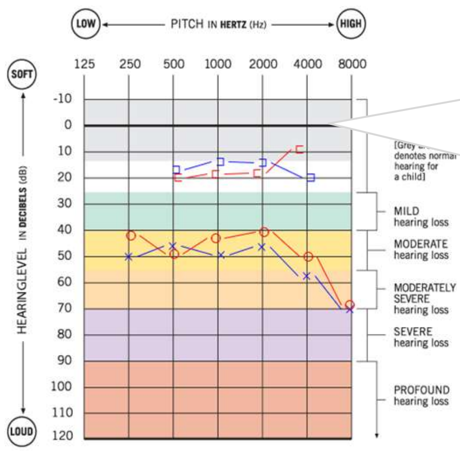
Behind the scenes, transforms are applied to create the FLogram:

dB Dial Level at threshold + RETFLdbc + RHCD
= dB FL threshold on abutment

dB FL on skull simulator + microphone location effects
+ RHCD = dB FL on abutment

Clinical cases using the DSL-BCD targets with the Verifit skull simulator.

Case 1: 65 year old male, history of bilateral chronic ear disease and multiple tubes. Bilateral mastoidectomies. Implanted in 2013.

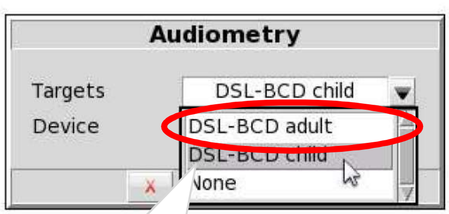


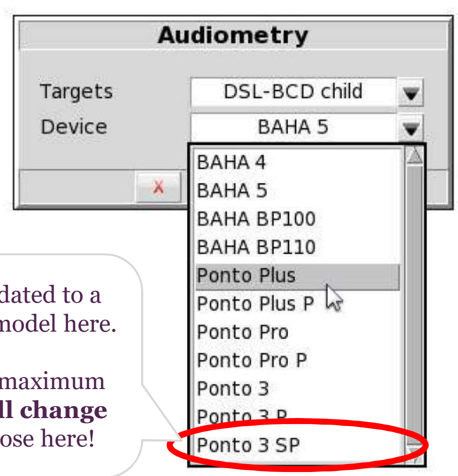
Although this is his clinical audiogram, we retested his hearing by direct bone conduction using the hearing aid fitting software (in situ).

Why? This tests through the abutment so any effects of conduction through skin and other tissue are removed.

dBC thresholds were 10-15 dB dial level across frequencies.

We customized the DSL targets for this case.



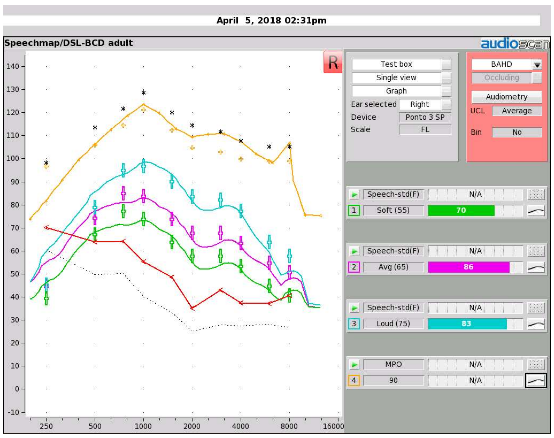


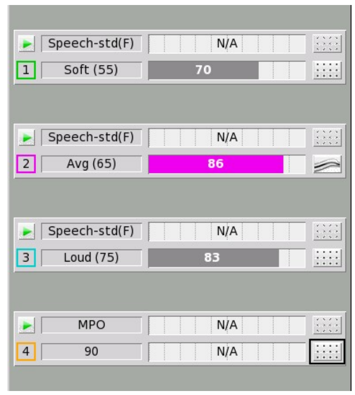
Adult targets for this adult patient.

This patient has recently updated to a new device. Enter make and model here.

Remember: this defines the maximum output target **so targets will change** depending on what you choose here!

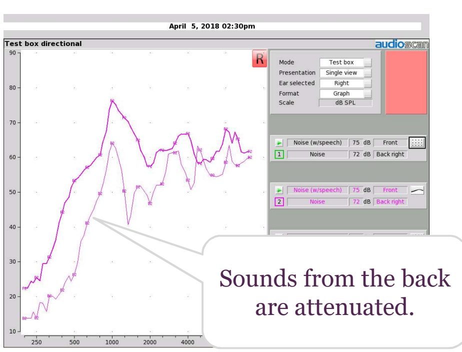
Fitting results: We were able to meet targets, and the aided SII values are high and similar to the published norms (>70% would be expected).



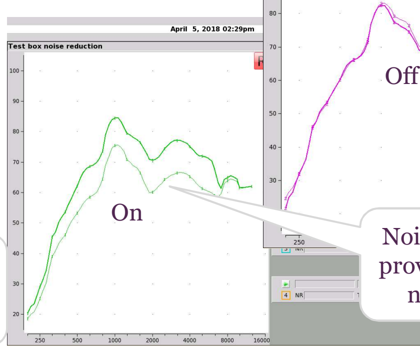


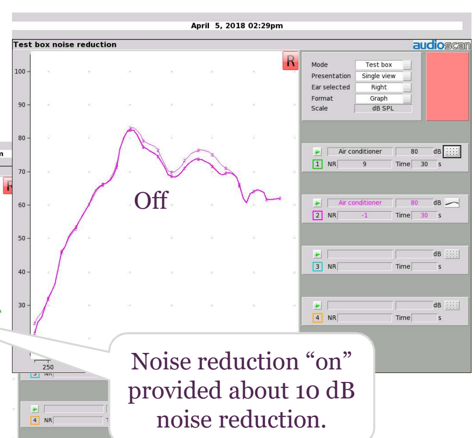
Beyond fitting to target… we can assess the noise reduction and directionality of the hearing aid.

Directional test in full band mode:

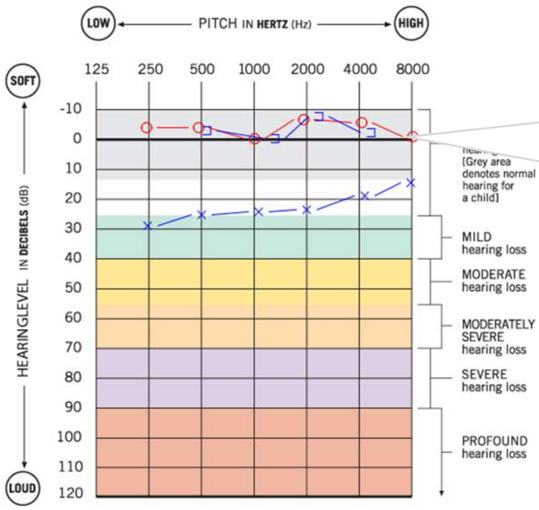


Noise reduction test with off vs on:





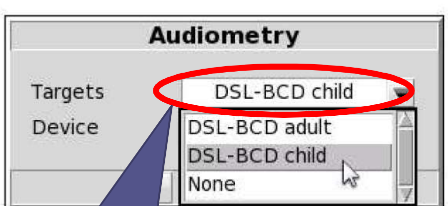
Case 2: 8 year old girl, unilateral atresia and microtia. Successful softband user, recently received implant/device.



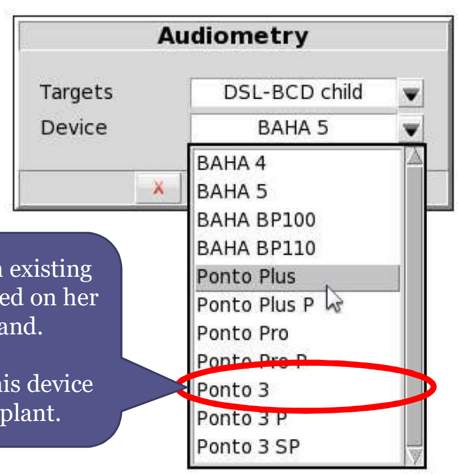
Retested thresholds by direct bone conduction.

Thresholds of -5 to +5 dB dial level across frequencies.

We customized the DSL targets for this case.



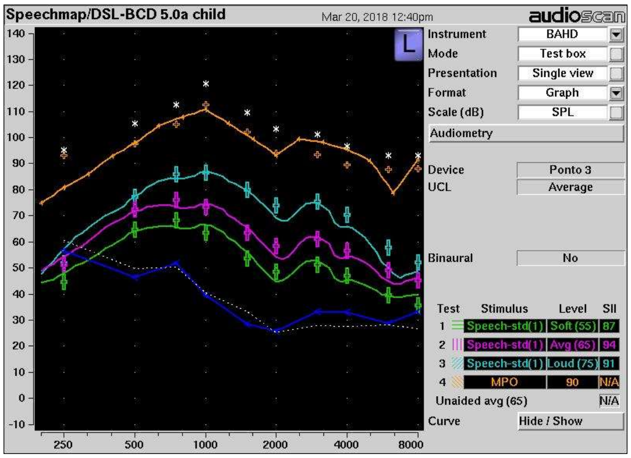
Child targets for this pediatric patient.

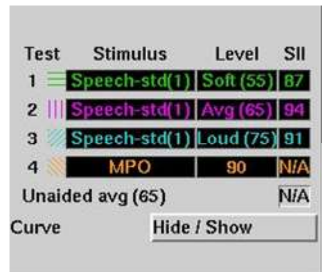


This patient had an existing Ponto 3 that was used on her previous softband.

She will be using this device with the new implant.

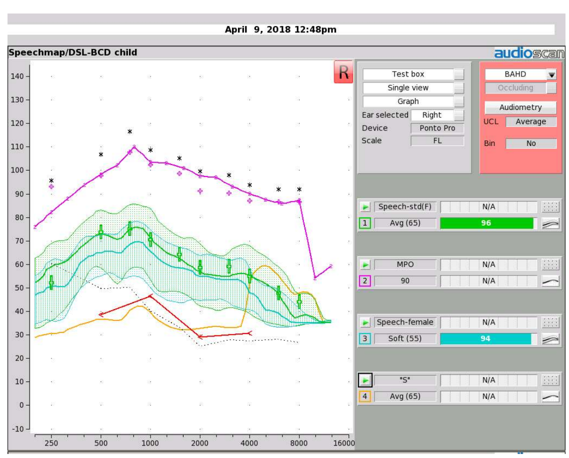
Fitting results: We were able to meet targets. Note the somewhat higher listening levels and aided SII values compared to the adult case. This is expected and consistent with DSL adult versus child targets.





What about softband fittings?

- Softband devices have been measured on research skull simulators (Hodgetts et al., 2006).
- A full clinical method is currently under development – not done yet.
- Bear in mind that:
  - Threshold norms and transfer functions are now only available for percutaneous. Entered audiometric bone thresholds will vary – best to remeasure with the softband device in situ.
  - Recommended listening levels may not be exactly correct – regard these as approximate.



Summary

- Clinical skull simulators are now available for several types of hearing aid analyzers. The Verifit skull simulator supports ANSI, DSL targets, and analysis of signal processing.
- The steps are pretty similar to fitting air conduction aids. You've got this!
- You can check for the free software update on the Audioscan website.
  - VF2: yes VF1: yes for newer units (check serial number)
- You can transfer the skull simulator between units.
- Remember to calibrate the regular air conduction mics first (weekly).
- Remember to learn the left/right positioning & put the ref mic low, near the hearing aid mics. Check the help for photos of setups.

Happy fitting and…

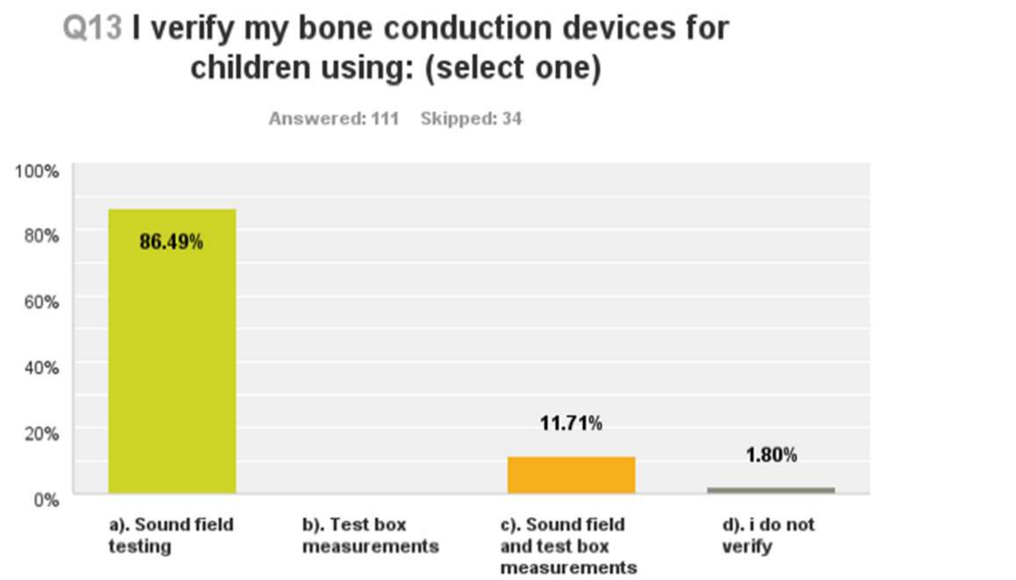
(I'm sorry Audioscan. I just had to.)

Selected references – mostly on bone-related topics.

- Carlsson P. & Håkansson B. (1997). The bone-anchored hearing aid: Reference quantities and functional gain. Ear & Hearing. 18(1):34–41.
- Håkansson, B. (2003). The balanced electromagnetic separation transducer- A new bone conduction transducer. J. Acoust. Soc. Am. 113 (2)
- Hodgetts, W. E., Scollie, S. D., and Swain, R. (2006). Effects of applied contact force and volume control setting on output force levels of the BAHA® Softband. *International Journal of Audiology, 45:* 301-308
- Hodgetts, B., and Scollie, S. (2017). DSL prescriptive targets for bone conduction devices: Adaptation and comparison to clinical fittings. *International Journal of Audiology*, 1-10. http://dx.doi.org/10.1080/14992027.2017.1302605
- Hodgetts, W. E., Hagler, P., Hakansson, B.E.V., & Soli, S. D. (2010). A comparison of three approaches to verifying aided BCD output. International Journal of Audiology 49(4): 286-295.
- Hodgetts, W. E., Hagler, P., Hakansson, B.E.V., & Soli, S. D. (2011). Technology-Limited and Patient-Derived Versus Audibility-Derived Fittings in Bone-Anchored Hearing Aid Users: A Validation Study, Ear & Hearing, 32(1): 31-39.
- Stenfelt, S., and Håkansson, B. (1998). A miniaturized Artificial Mastoid Using a Skull Simlulator. Scand. Audiol. 27 (2), 67-76.
- Stenfelt, S. and Zeitooni, M. (2013). Loudness functions with air and bone conduction stimulation in normal-hearing subjects using a categorical loudness scaling procedure. Hearing Research 301 · April 2013.

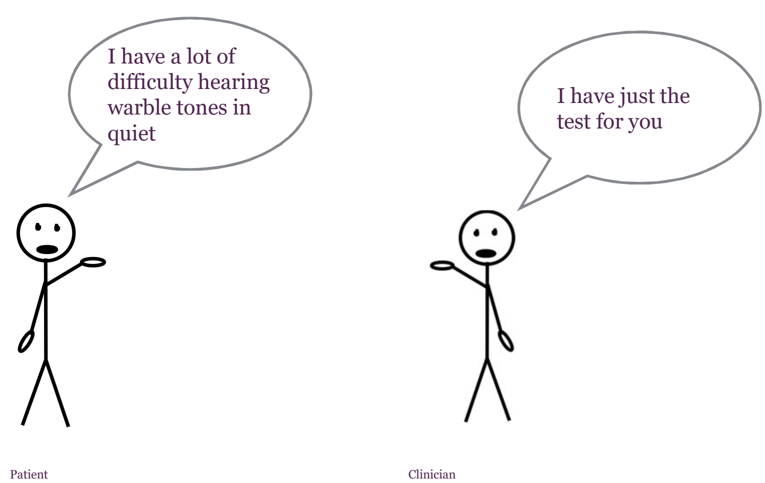
Other questions

- What are the advantages of this over using an aided audiogram?
  - Verification is a better way to assess the details of frequency response shaping for realistic inputs such as speech (Hodgett et al., 2010). We still can measure **aided audiograms as a measure of outcome**, but wouldn't need them for setting devices to recommended programmed settings.



Gordey and Bagatto, 2015

Measures of Audibility?



Are individual measures of Upper Limit of Comfort recommended?

- No, because the device maximum output is likely to be lower than the patient’s UCL. You may not be able to reach UCL.