Technologies and Techniques for Hearing Aid Fittings that Handle Bass to Treble

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Many thanks and kudos and acknowledgements:

- To all of my colleagues at the NCA
- For their work on these projects:
  - Paula Folkeard, Jonathan Vaisberg, Maaike van Eeckhoutte, Sumit Agrawal, Drew Dundas, Suzy Levy, Steve Beaulac, Danielle Glista, Robin O'Hagan, Parvaneh Abbasalipour, Jonathan Pietrobon, John Pumford, Vijay Parsa, Ewan Macpherson.
- For their technologies and support for these projects:
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Perspectives on routine verification and personalized fine tuning…

- These are essential for bass & treble… we can probably do fit the mid-frequencies fairly well regardless of how we do it. So will OTCs though!
- Why:
  - More high frequency variation in hearing loss configuration and ear canal acoustics.
  - More high frequency error in any assumed transfer function: from microphone location effects to RECDs.
  - More low frequency error if we don't personalize venting
- But: we have better tools than ever before!

How does broadband hearing aid fitting impact the wearer?

Preference and performance.

How does extended bandwidth fittings on speech recognition, preference and loudness.

- Current hearing aids offer broader bandwidth; recent lab studies with **simulators** indicate that bandwidth may be worthwhile (Alexander, 2017; McCreery et al., 2014; Jakien et al., 2016).
  - **Wearable devices** may facilitate provision of a period of real world use and **adaptation,** which may maximize bandwidth for new high frequency sound for some listeners.

Bandwidth perception arises from a synergistic combination of bass and treble, at least in normally hearing listeners.

- Moore & Tan studied sound quality for speech (shown here) and music in normally hearing listeners.
- High frequency audibility and low frequency audibility interact… *both together provide best sound quality*.

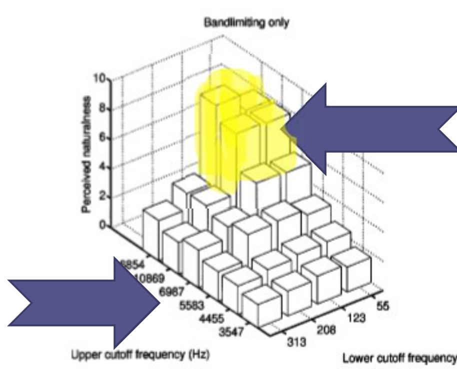


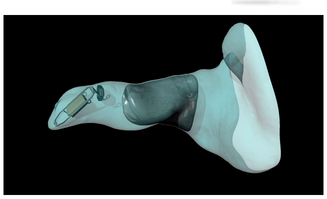
FIG. 8. Mean ratings for band-limited music (top) or speech (bottom) stimuli. The *x* axis shows the high-frequency cutoff, the *y* axis shows the low-frequency cutoff, and the *z* axis shows the mean rating.

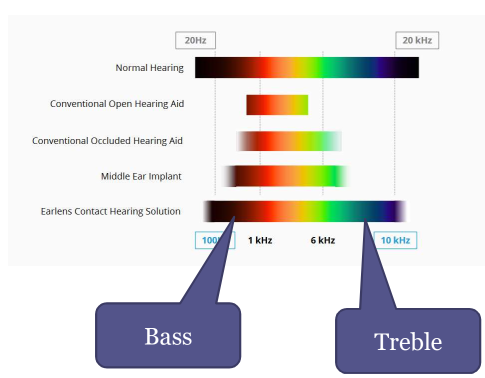
Moore & Tan, 2003

Extended bandwidth fittings in hearing aids that you can't buy in Canada.

Folkeard et al. (2021): speech, loudness, preference
Vaisberg et al., (2021): sound quality

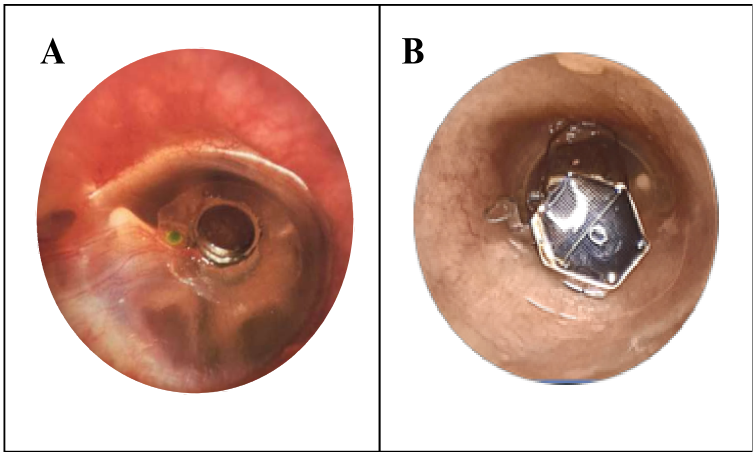
The Earlens system drives the TM directly, and claims a 100 to 10,000 Hz bandwidth:





http://earlens.wpengine.com/wp-content/uploads/2019/09/Dundas-AAA-2019.pdf

This is the device in place:

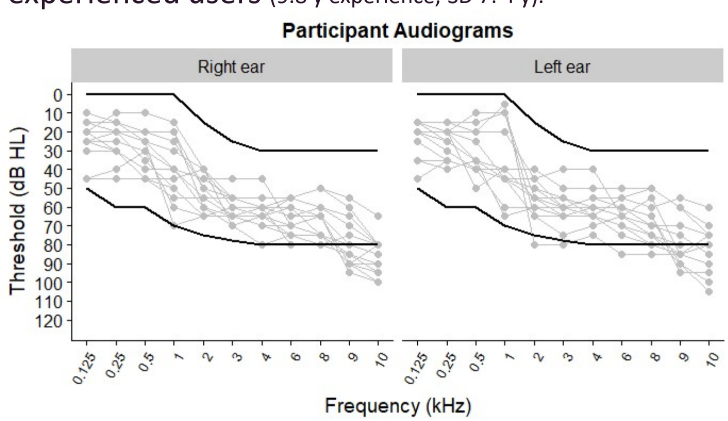


(yes you can run a tymp… open access article here).

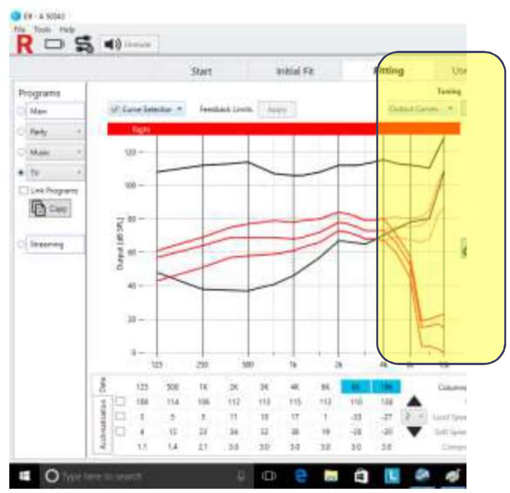
Lucas, Folkeard, Levy, Dundas, Scollie & Agrawal, 2022

Candidacy and participants:

- 28 passed screening for inclusion and consented
  - 13 excluded or withdrew (mostly ear size/condition)
- 15 completed the trial (mean age 72 y, 7 female).
- Mainly experienced users (9.8 y experience, SD 7. 4 y).

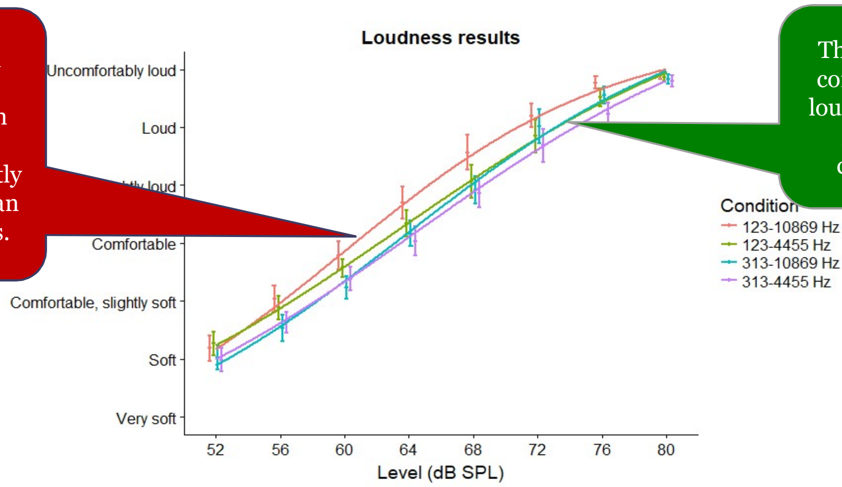


We used the programming software to “kill” high frequency output for the narrow condition:



Aided loudness ratings were louder for the fullband. Bass energy increased loudness too.

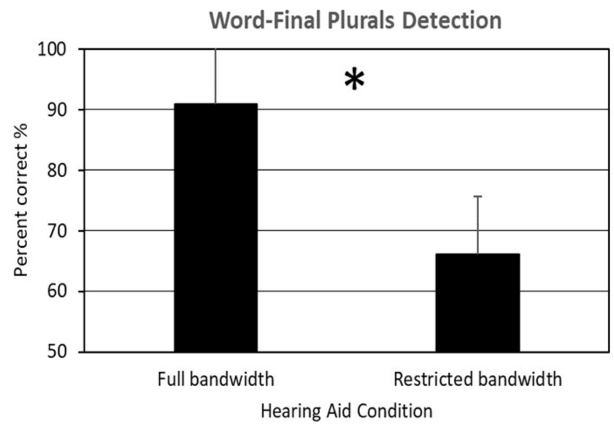
The Full band condition was significantly louder than all others.



The 123-4455 condition was louder than the 313-4455 condition.

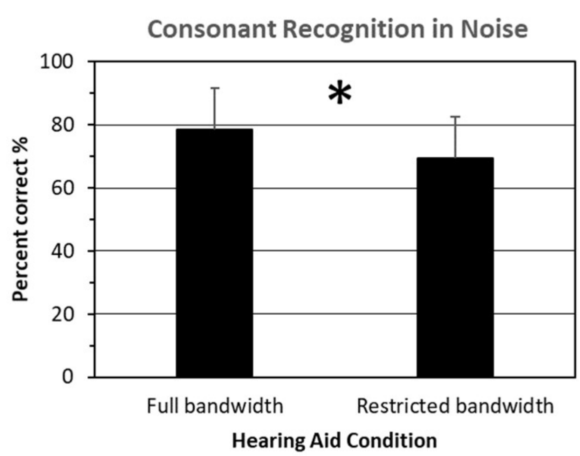
Folkeard et al., 2021

Word-final plurals were detected about 25% more often with full bandwidth.



Folkeard et al., 2021

Consonants were recognized 9% more often.

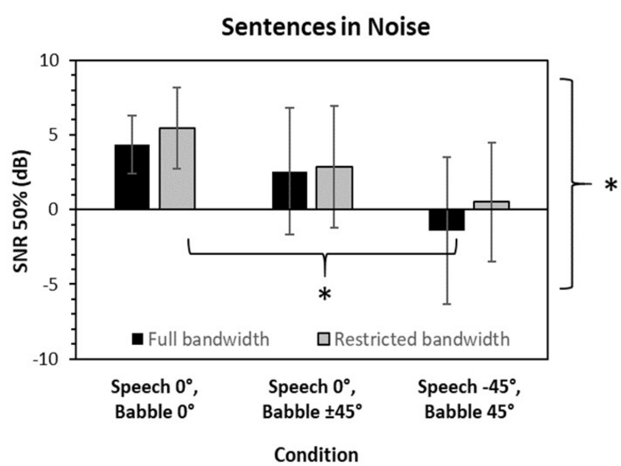


Folkeard et al., 2021

This 9% improvement was due to high frequency phoneme recognition.

Stimuli \ Response Differences	B	CH	D	F	G	H	J	K	L	M	N	P	R	SH	S	TH	T	V	W	Y	Z
B	-14	1	1	0	0	-1	0	0	0	0	0	0	1	0	0	1	0	12	0	-1	0
CH	0	-5	0	0	0	0	2	-1	1	1	0	0	1	0	1	0	0	0	0	0	0
D	-2	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	-1	0	0	0
F	0	-1	-1	2	1	-4	0	-1	0	0	0	-5	0	1	-1	6	-1	4	0	0	0
G	2	1	-5	-1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
H	0	0	-2	8	0	-2	0	-1	0	0	0	-1	0	0	0	0	0	-2	0	0	0
J	1	1	2	0	5	0	-4	-4	0	0	0	0	0	-1	0	0	-1	0	1	0	0
K	0	0	0	-1	-1	0	0	3	0	0	-1	2	0	0	0	0	-2	0	1	-1	0
L	-1	-1	0	0	0	-1	0	1	-13	2	-1	0	1	0	0	0	0	2	12	-1	0
M	0	0	0	0	0	0	1	0	2	-1	-3	0	0	0	0	0	0	0	1	0	0
N	0	0	0	0	0	0	0	0	-1	-2	1	0	0	0	0	0	1	0	0	1	0
P	-1	1	-1	-5	0	0	0	-4	-1	0	0	12	1	0	0	0	-1	-1	0	0	0
R	-1	0	0	0	-1	0	0	0	-1	0	0	1	-6	1	0	0	0	-2	9	0	0
SH	-1	-3	1	1	0	-1	-1	-1	0	0	0	2	1	6	-5	0	0	0	1	0	0
S	-1	0	-1	**-57**	S sounds like S not F →										78	-1	-1	0	1	-1	-1
TH	-7	-1	2	1	-1	1	0	0	-1	-1	0	-1	0	0	0	3	0	5	0	0	0
T	-1	2	1	0	0	0	-1	**-34**	T sounds like T not K →								37	0	0	0	0
V	1	0	-2	-2	-1	0	0	-1	0	1	0	0	0	0	0	6	0	-2	-1	0	1
W	0	0	0	0	-1	0	0	0	-1	1	0	0	-1	0	0	0	0	2	0	0	0
Y	0	-1	0	-1	1	-1	1	Z sounds like Z not V/B/D →										1	2	4	0
Z	-11	0	-15	-6	-1	-2	0	0	-1	-1	0	0	-1	0	6	0	0	**-37**	-1	0	**79**

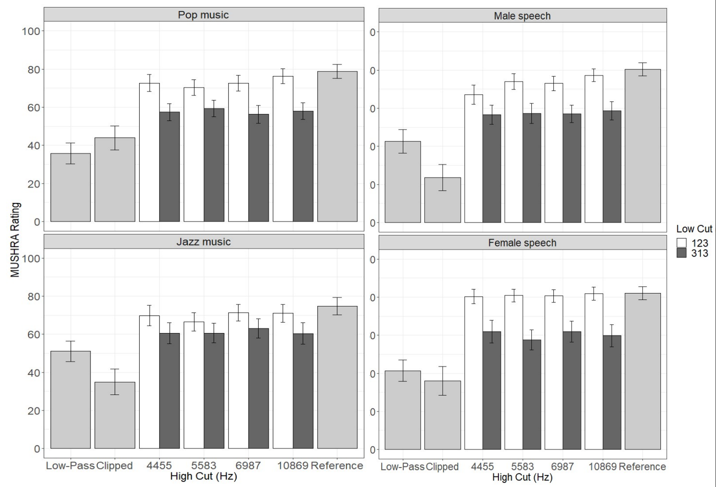
Listeners could hear at a lower SNR when the full bandwidth was provided.



Folkeard et al., 2021

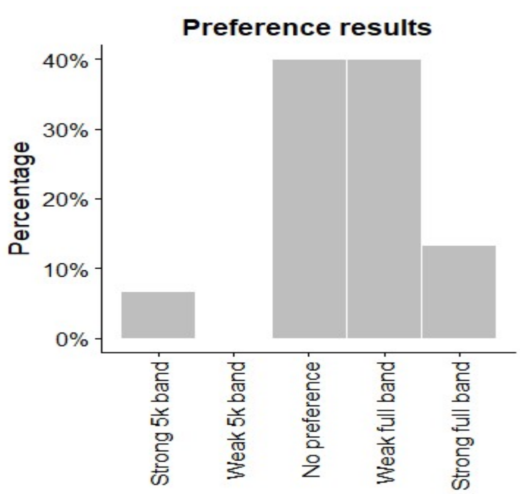
Sound quality ratings were best for speech & music when both low and high frequency energy was available:

- The **full band reference signal had significantly better sound quality** than all other conditions except 123-10,000 Hz, indicating that this is similar to the functional bandwidth of the system.
- When low frequencies are filtered out:
  - High frequency filtering does not change sound quality.
  - This is consistent with Moore & Tan's results: ***sound quality depends on full bandwidth, not just high frequency audibility.***



Vaisberg et al., 2021

Preference was mixed but does not favour the narrowband condition.



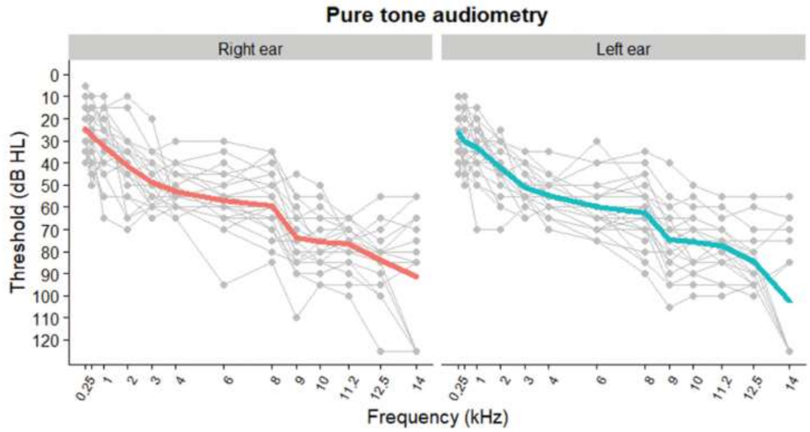
Folkeard et al., 2021

Extended bandwidth fittings in regular air conduction hearing aids

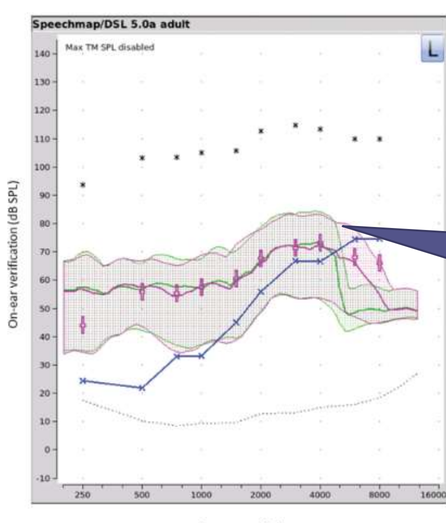
Van Eeckhoutte et al, (2020)
https://doi.org/10.1080/14992027.2020.1750718

Participants and hearing aid fitting:

- N = 26 adults (69 y average)
- Fitted with DSL v5 using 2017-2018 RIC devices
  - 4 week use period
- Measurement of actual hearing aid bandwidth as fitted.
- Outcomes measured post-acclimatization.

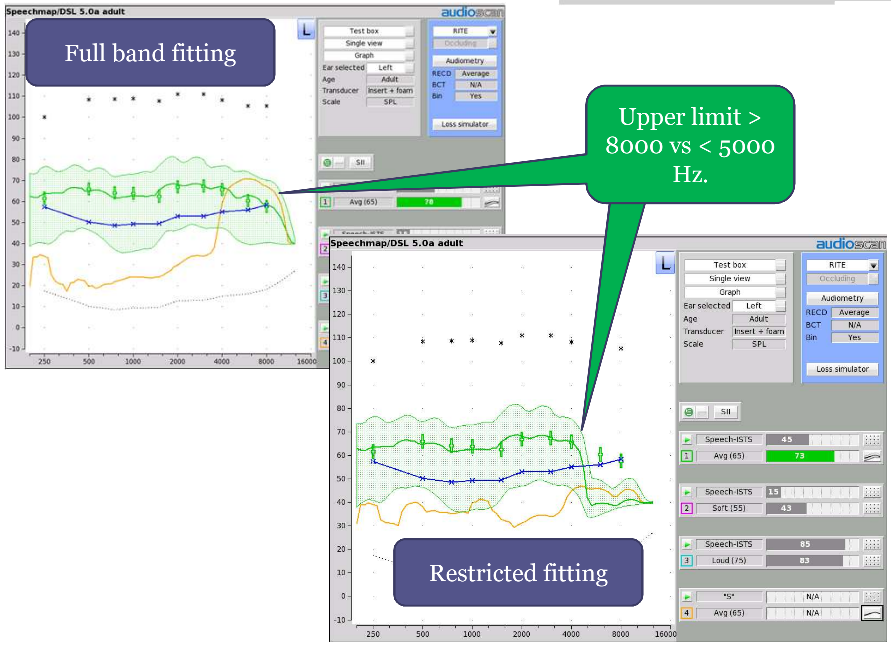


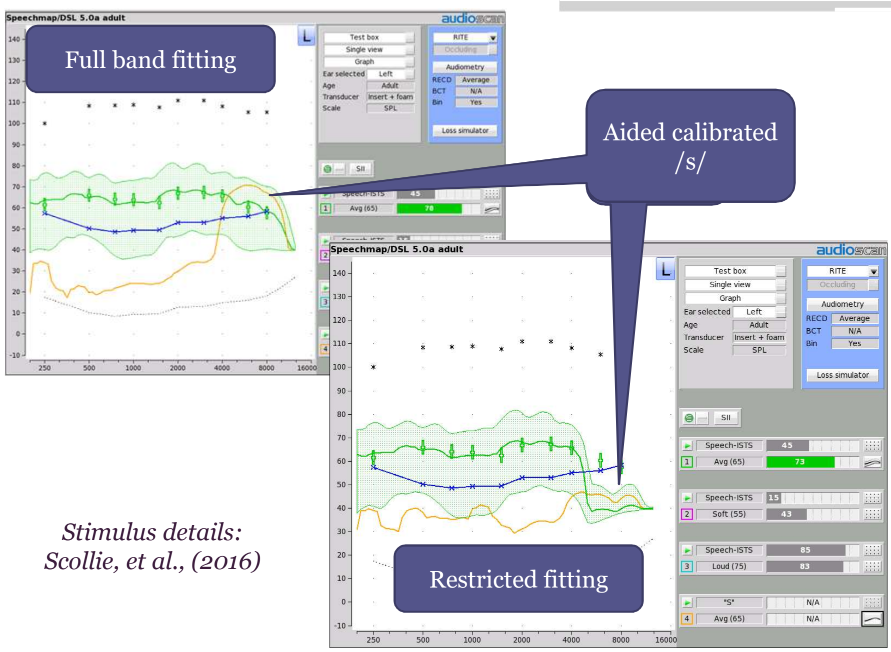
The aided output was manipulated with the hearing aid software to remove output >5 kHz. This setting was only used in lab.



Fullband condition was to about 6500 Hz on average.

Less than Earlens but still broader than older hearing aids.





Stimulus details: Scollie, et al., (2016)

Extended bandwidth increased loudness.

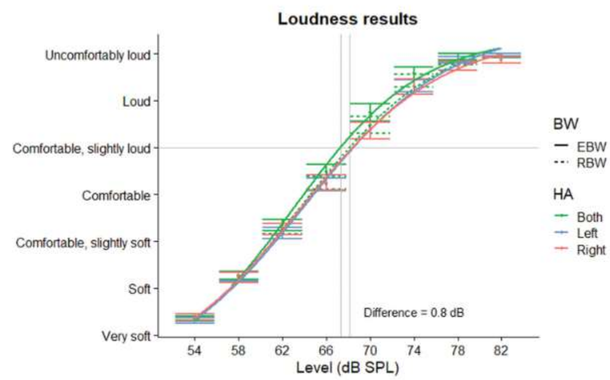


Figure 4. Mean loudness judgments from all participants for EBW, RBW, bilaterally and monaurally (only EBW) aided listening conditions. Error bars show one standard error of the mean. Sigmoidal fits for each condition are plotted in the form of thin lines in the same colour on top of the data. EBW = Extended Bandwidth, RBW = Restricted Bandwidth, HA = hearing aid (colour in the online version).

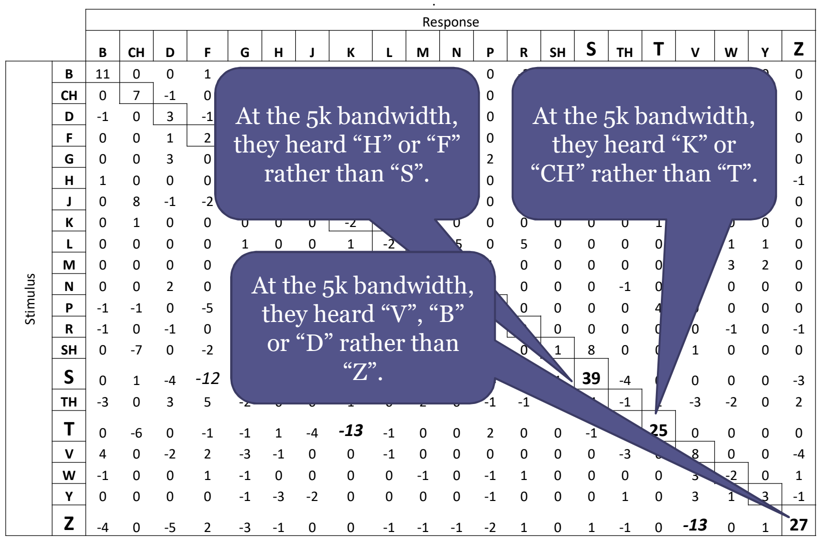
Extended bandwidth produced a small improvement in high frequency speech sound recognition.

Table 2. Differences in consonant confusions between the EBW and RBW conditions.

		Response differences																				
		B /b/	CH /tʃ/	D /d/	F /f/	G /g/	H /h/	J /dʒ/	K /k/	L /l/	M /m/	N /n/	P /p/	R /r/	SH /ʃ/	S /s/	TH /θ/	T /t/	V /v/	W /w/	Y /j/	Z /z/
Stimuli	B	6	0	0	1	−1	0	0	0	0	−3	0	0	−1	0	0	−1	0	−3	2	0	0
	CH	0	7	−1	0	0	0	1	0	−1	0	0	0	0	−3	−1	0	−2	0	0	0	0
	D	0	0	0	−1	2	−1	0	1	0	0	−1	0	0	0	0	0	0	0	0	0	0
	F	0	0	0	0	0	2	1	−1	0	0	0	1	0	0	−1	0	−1	−1	0	0	0
	G	1	0	−1	0	1	0	1	−1	−1	0	−1	1	0	0	0	0	0	0	0	0	0
	H	1	0	0	1	0	0	0	1	0	0	−1	0	0	−2	0	0	1	0	0	0	−1
	J	0	6	−1	−2	0	−1	−4	1	0	0	0	0	0	0	0	0	0	1	0	0	0
	K	0	0	0	0	0	0	0	−1	0	0	0	0	0	0	0	0	1	0	0	0	0
	L	0	0	0	0	1	0	0	1	−1	0	−5	0	5	0	0	0	0	−1	0	0	0
	M	0	0	0	0	0	0	0	0	−1	−6	3	1	0	0	0	0	0	0	2	1	0
	N	0	0	1	0	0	−1	0	0	0	0	−1	0	0	0	0	−1	0	2	0	0	0
	P	−1	−1	0	−1	0	0	0	6	0	0	0	−3	0	0	0	0	0	0	0	0	0
	R	−1	0	−1	0	0	0	0	0	0	2	−1	0	2	0	0	0	0	0	−1	1	−1
	SH	0	−4	0	−2	0	−1	0	0	0	0	−1	1	0	0	6	0	0	1	0	0	0
	S	0	1	−2	**−13**	0	−7	0	−2	−1	−2	−1	−3	0	1	**36**	−4	0	0	0	0	−3
	TH	−4	0	3	6	−1	0	0	1	0	0	0	−1	−1	0	−1	−1	1	−2	−1	0	1
	T	0	−6	0	0	−1	1	−1	**−13**	−1	0	0	0	0	0	0	−1	**22**	0	0	0	0
	V	3	0	−1	2	−3	−1	0	−1	−1	0	0	0	0	0	0	−2	0	6	2	0	−4
	W	−1	0	0	1	−1	0	0	0	0	−1	0	0	1	0	0	0	0	3	−3	0	1
	Y	0	0	0	0	−1	−3	−2	0	0	0	0	0	0	0	0	1	0	3	1	2	−1
	Z	−5	0	−3	1	−1	0	0	0	−1	−1	−1	−1	0	0	0	−1	0	**−10**	−1	0	**24**

Positive values on the diagonal indicate better performance in the EBW condition. Absolute values equal to or more than 10 are shown in bold font and underlined.

Similar performance as for Earlens: S, T, Z improved:



Similar to Alexander (2016); Consistent with Stelmachowicz et al. (2004); Dubno & Levitt (1981)

Preference results were skewed toward preference for extended bandwidth (but not for all listeners):

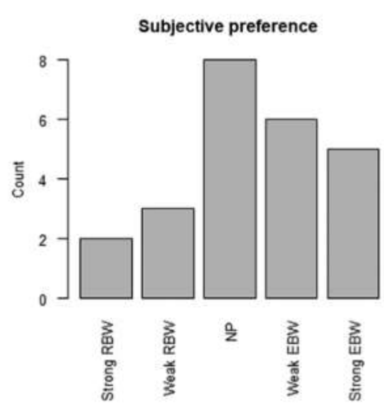


Figure 5. Subjective preference as measured by a paired comparison task. RBW = Restricted Bandwidth, NP = No Preference, EBW = Extended Bandwidth.

Let’s compare that to a recent similar study in children:
(adults) (kids)

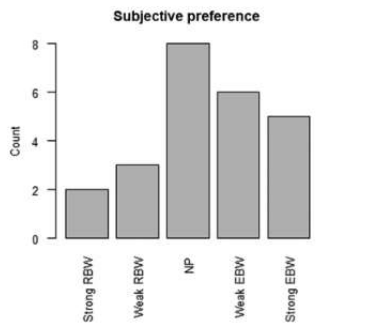
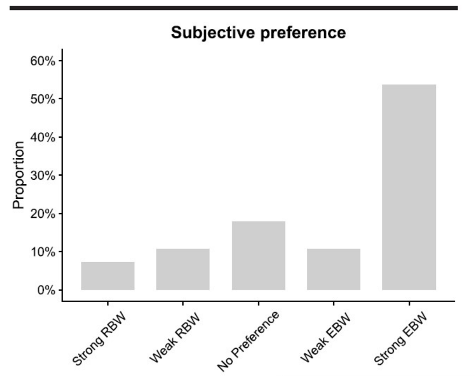


Figure 5. Subjective preference as measured by a paired comparison task. RBW = Restricted Bandwidth, NP = No Preference, EBW = Extended Bandwidth.

Van Eeckhoutte et al, (2020a)



Van Eeckhoutte et al, (2020b)

Bandwidth impacts:

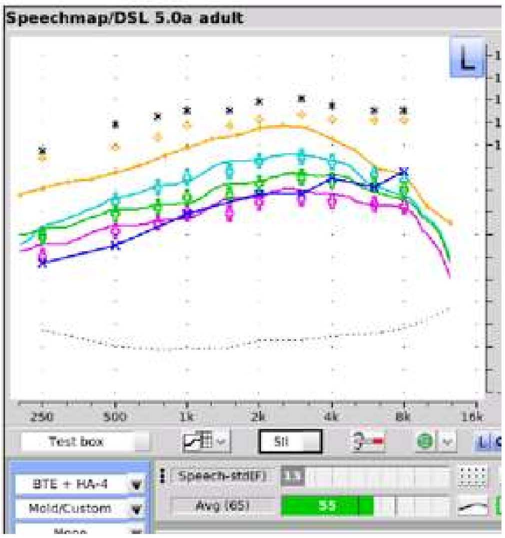
- What is the audible bandwidth that can be fitted?
  - Broadband fittings were feasible at the individual level.
    - **Adults:** 6 to 7kHz +/-2kHz, using DSLv5-Adult targets
    - **Children:** 7500 on average using DSLv5-Child with BTEs
    - As hearing loss increased, bandwidth decreased.
- Impacts:
  - **Adults:** Preference is either neutral or in favour of bandwidth for most of these listeners. Not highly predictable.
  - **Children**: Majority prefer extended bandwidth.
  - **Both:** Slight increase in loudness. Improved recognition of high frequency phonemes.

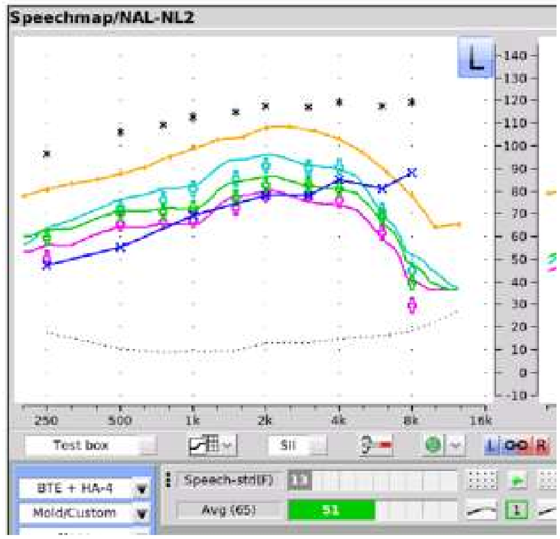
Clinical strategies for maximizing bandwidth

1. Routine verification while fine tuning, aiming for a broadband fitting.

→On ear whenever possible.
→Consider bass response per program.

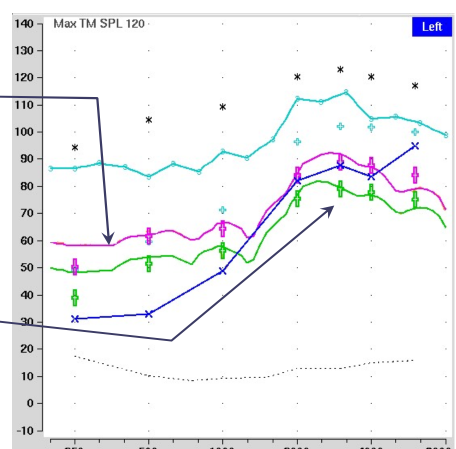
Be aware that some prescriptive targets roll off high frequencies, limiting our use of extended bandwidth.





On ear measurement of a vented or open fittings shows the combined effects of both the vent and the aid:

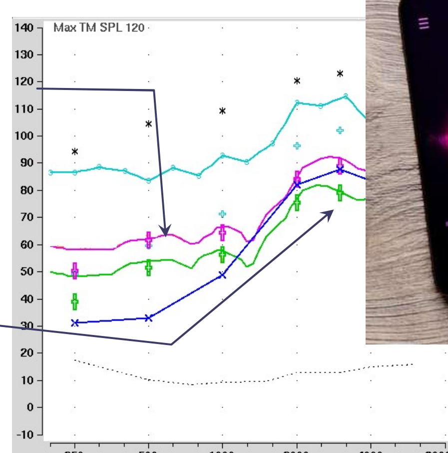
- In the low frequencies:
  - Normal pitch cues, binaural cues for localization (interaural time differences) from the normal acoustic path.
- In the high frequencies:
  - Electroacoustic gain to provide access to consonants.

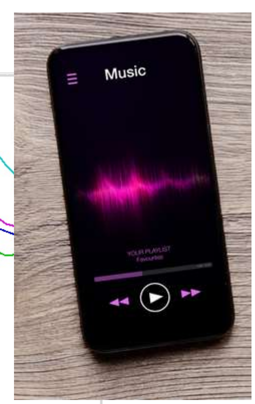


For programs that will receive sound through the vent, we can roll off the low frequencies.

For programs that do not include vent-transmitted sound, consider the role of 'bass compensation':

- In the low frequencies:
  - This audibility will be missing from a _______________ program.
- In that program, I can verify the low frequency response by:
  - Using _______________ as my test signal.
- One practical challenge I will have in doing this is: __________.

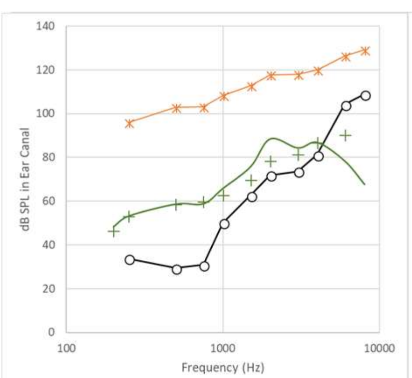


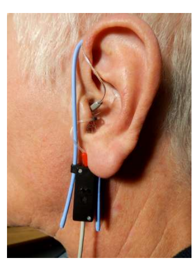


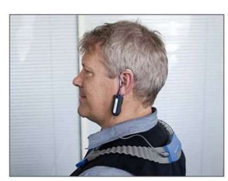
2. Measure and match the RECD for a more accurate SPLogram.

This helps you define foamtip versus earmold in a more accurate way.

Most of us who verify will map the auditory area in dB SPL. *(terms: speechmapping, SPLogram, REAR, in situ)*



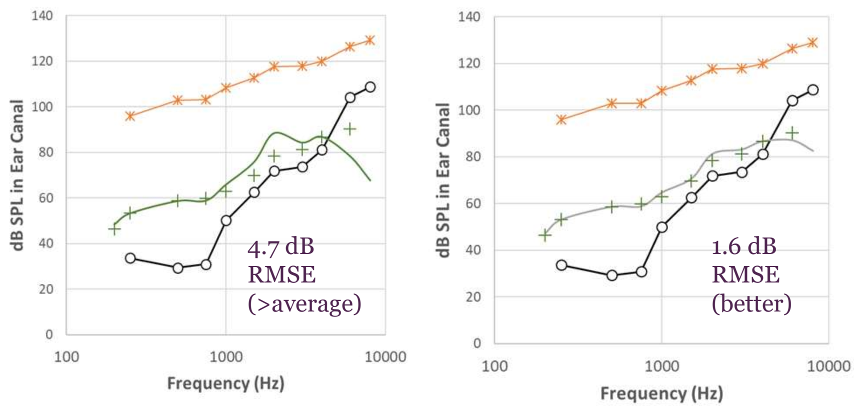




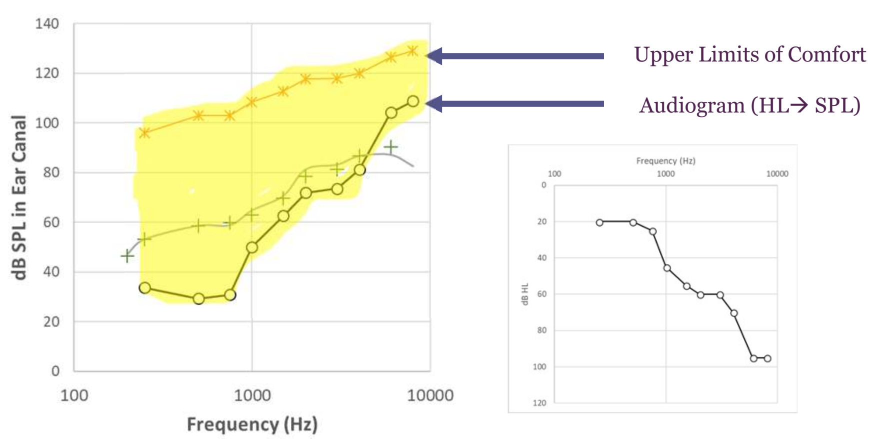
https://en.wikipedia.org/wiki/Real_ear_measurement
https://www.audiologyonline.com/articles/verification-counseling-digital-hearing-instruments-13085

ANSI S3.46, 2013

When we do this, we view the fitting against the auditory area.



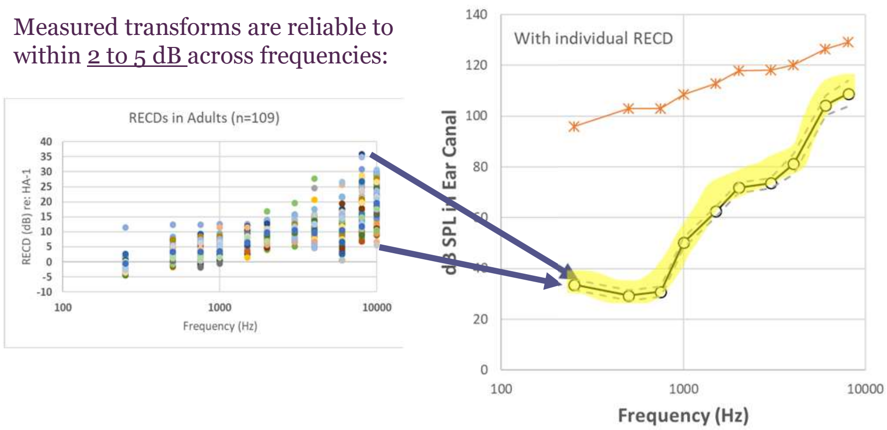
When we do this, we view the fitting against the auditory area.



Seewald et al., 2005, influenced by earlier work the 1980's by Skinner & Pascoe

RECD variability affects accuracy of the displayed thresholds. Measuring it should optimize this transform. *(if we choose insert phones)*

Measured transforms are reliable to within 2 to 5 dB across frequencies:

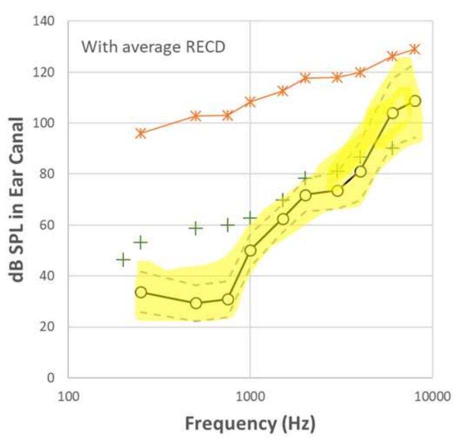


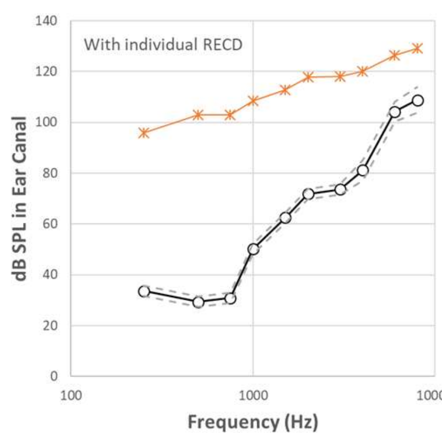
Munro & Davis, 2003; Munro & Howlin, 2005; O'Brien, et al, 2010; Sinclair et al., 1996; Vaisberg et al., 2016

If we use average RECDs, the prediction is less accurate:

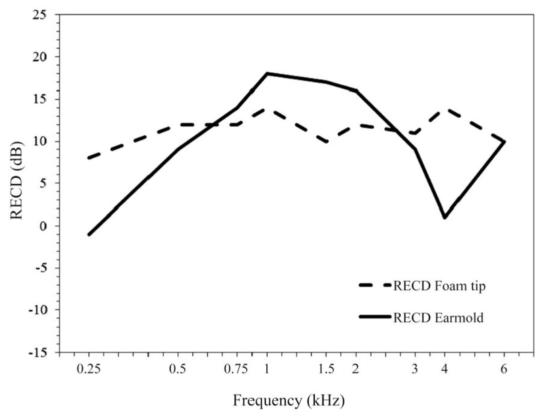
Average corrections

Individual corrections





Because RECDs Measured with Foam Tips vs Earmolds are not the same, a new correction has been developed to predict one from the other. This illustrates the average differences between the two:



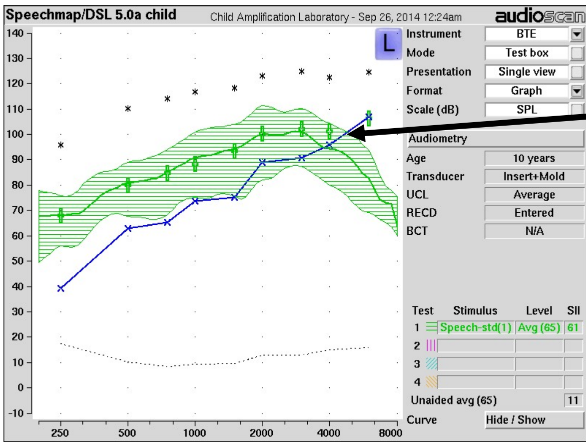
Moodie et al, 2016

3. Use phonemes to crosscheck the treble end of your fitting.

With calibrated /s/ and /sh/

https://www.uwo.ca/nca/pdfs/clinical_protocols/IHP_Amplification%20Protocol_2019.01.pdf

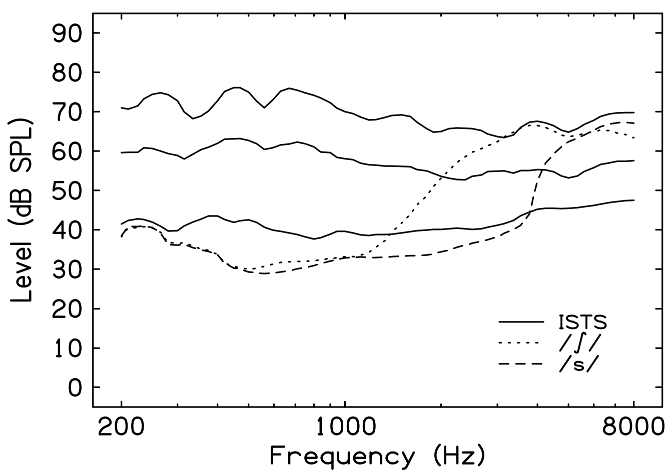
Major concept 1: Maximum audible output frequency



Where peaks cross threshold is the upper limit of the MAOF range.

Acknowledgement to Boystown group for MAOF concept

Major concept 2: Calibrated /s/



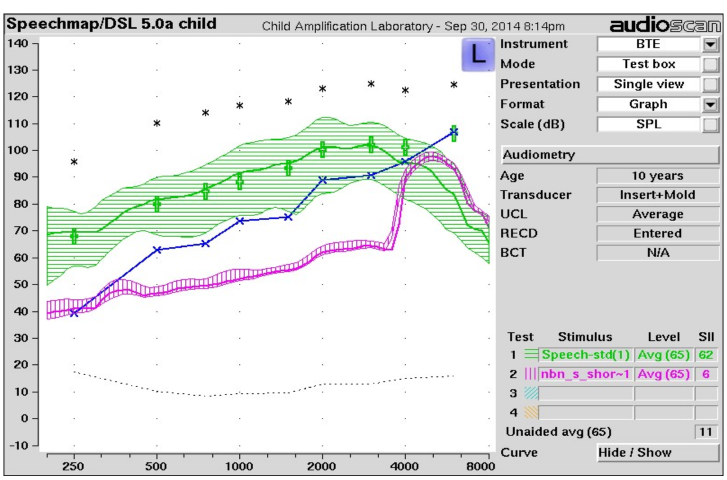
- Implemented in Audioscan Verifit, Otometric Aurical, and Interacoustics Affinity hearing aid analyzers.
- Measures if upper limit of audible bandwidth delivers an /s/ or not.

Scollie et al, 2016, JAAA

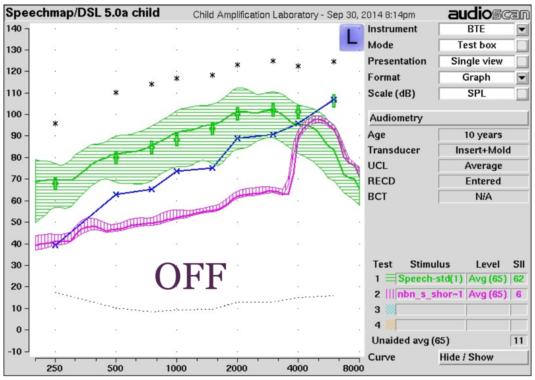
Steps

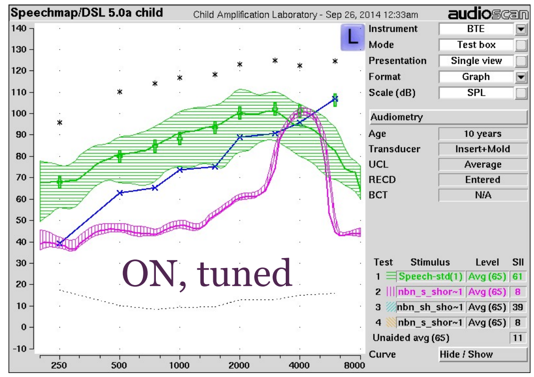
1. Verify and tune the hearing aid to DSL (FL off):
   - Mark the lower & upper limits of the Maximum Audible Output Frequency (MAOF) range.
2. Assess candidacy:
   - Measure aided /s/ at 65 dB SPL. Does the upper corner fall within the MAOF and/or passband? If not, frequency lowering candidacy may be a factor.
3. Fit frequency lowering if indicated:
   - Tune to the *weakest possible setting* that moves the upper corner of /s/ into the audible passband of the device.

This fitting has an MAOF of about 6000 Hz and does not make /s/ audible:



Frequency lowering can improve /s/ audibility, if fine tuned:

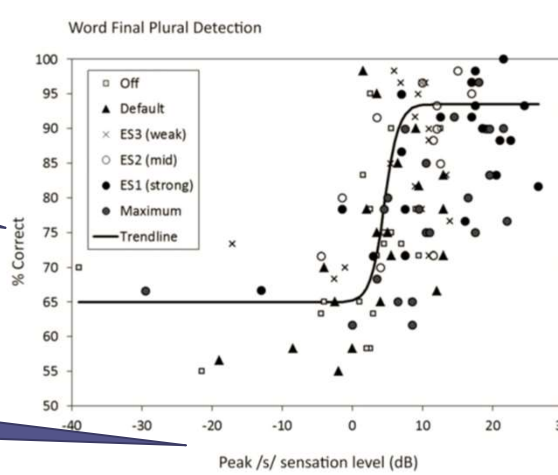




Aided /s/ at 10 dB SL provided best outcomes in this study:

% correct

Audibility as measured with REM



Scollie et al, 2016, JAAA

4. Use new tools for simulated real ear measurement and vented fititngs

Improve bass accuracy with test box (aka S-REM) verification

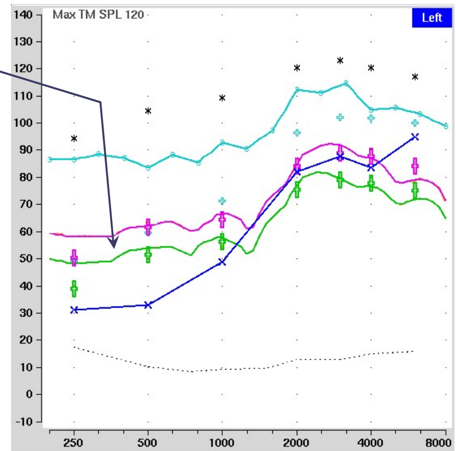
https://www.audiologyonline.com/articles/audioscan-vent-corrections-27884

Recall that S-REM was originally developed for a fully closed fitting.

In on-ear measurement, sound can both enter a vent and exit from a vent.

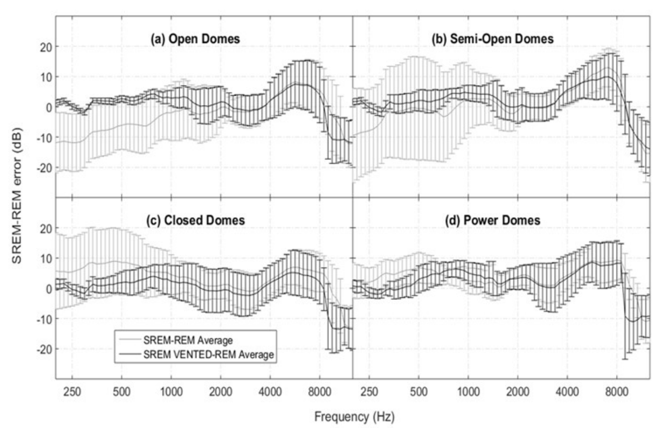
This is a real ear measurement of an open fitting.

- In the low frequencies:
  - What part of this signal would be measured on a **sealed** test box (coupler) measurement?
  - Would this fitting look over or under targets?



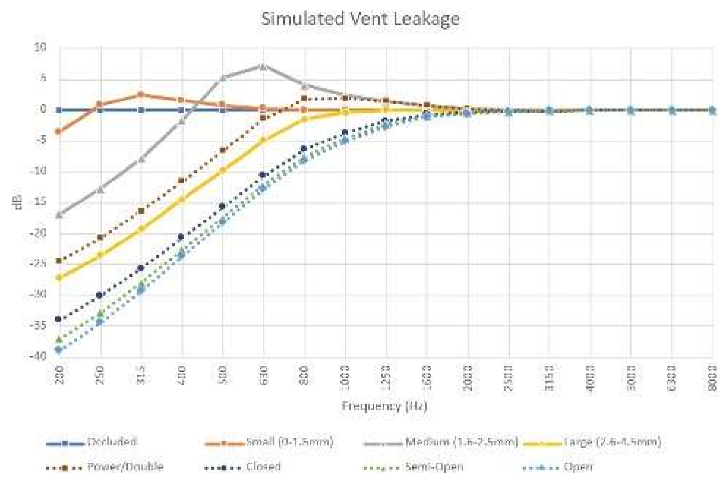
Actual fittings may look either over or under targets when measured on a sealed coupler.

- Fittings without low frequency gain will look under.
- Fittings with low frequency gain will look over.
- If you "fix" that in the coupler, it will be wrong in the ear.



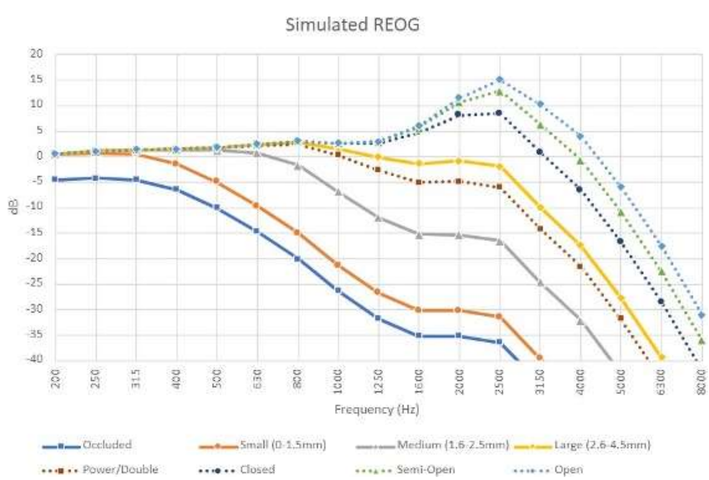
Scollie, Folkeard, Pumford, Abbasalipour, & Pietrobon (2022)

Some aided sound exits the ear through the vent:

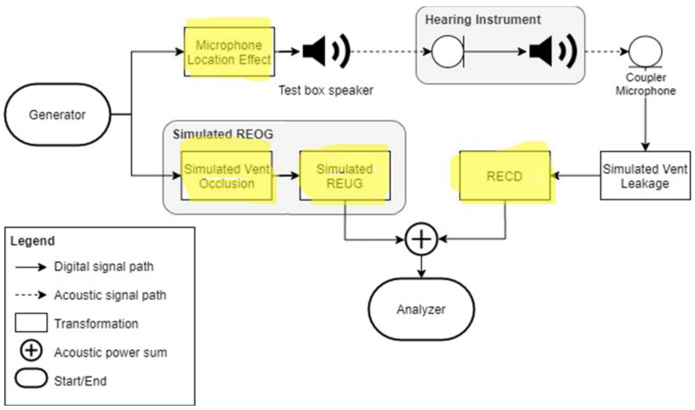


https://www.audiologyonline.com/articles/audioscan-vent-corrections-27884

Some unaided sound enters through the vent, and there may be a residual open ear resonance as well.



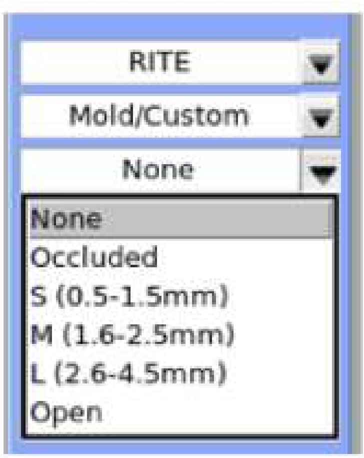
New "vent models" in the VF2 create a simulated "vent" in the test box. This is a **software correction**, not a real vent.

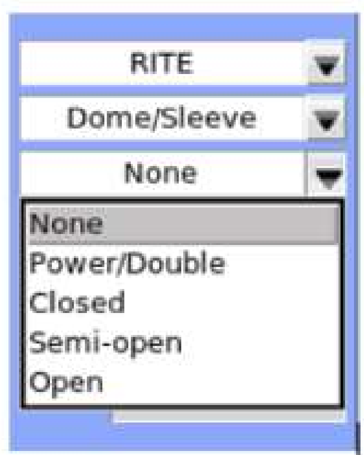


Click here for how to do this.

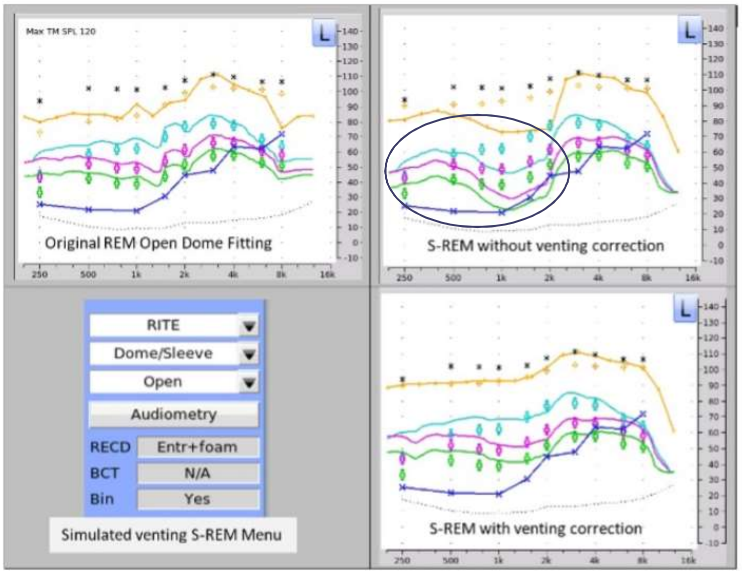
Click here for validation study.

Here are the menu items for this feature:

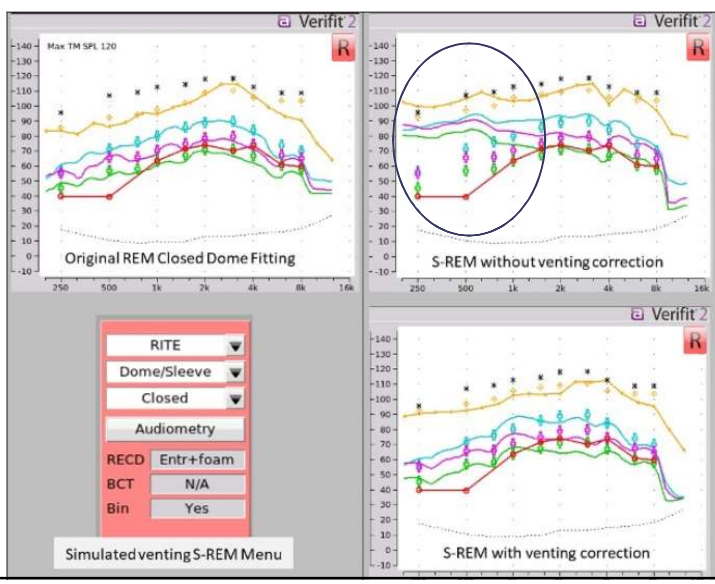




This case has little low frequency gain:



This case has some low frequency gain:



5. Personalize bone conduction fittings with new skull simulation and prescription strategies.

Hodgetts & Scollie, (2017)

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

Implementations to date:
Oticon Medical, Audioscan

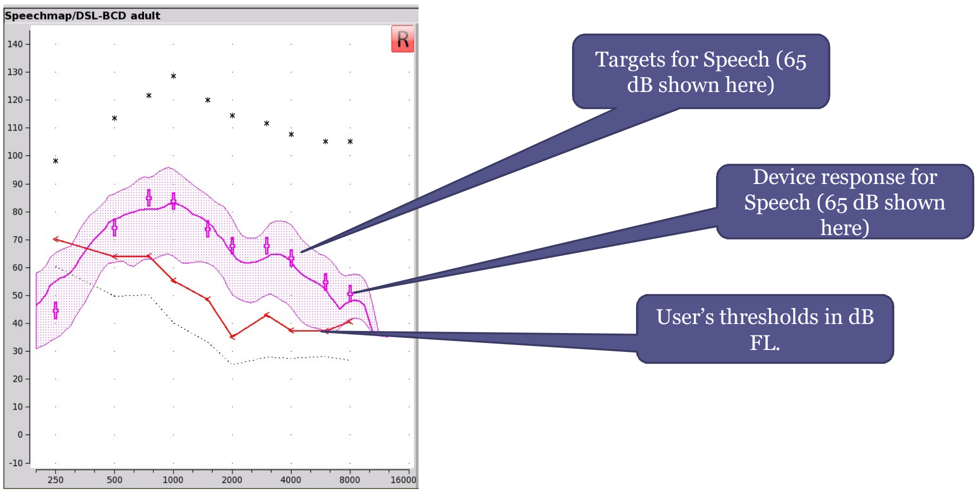
DSL targets can be used for test box verification in VF1 (check serial number) or VF2.

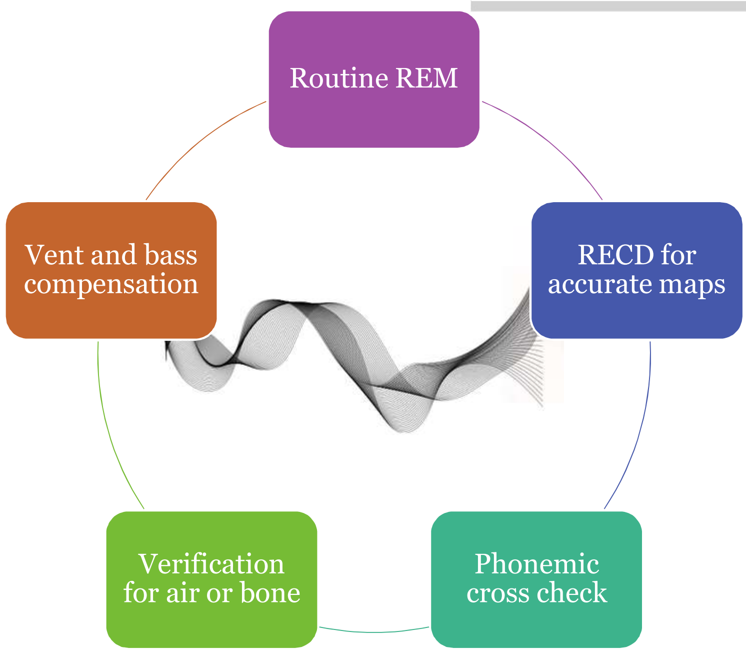
This is the abutment. Connect the hearing aid to this.

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

Updated software provides targets.

Verify and fine-tune to targets to fit a full audible bandwidth (note low frequency differences).





Thanks for coming back to CAA.

Thanks for caring about making hearing aid fittings full and clear and the best they can be.

Thanks for coming to this talk today.