Viability of RECD in Fitting Vented and Open-Canal Hearing Aids

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Introduction

Real ear measurements of hearing aid output taken with a probe microphone are the most direct approach for quantifying aided audibility. Verifying aided audibility of speech and the proper maximum output is an essential part of the hearing aid fitting process. Real ear measurements often require multiple measurements, during which the patient must remain still for the duration of each measurement. Thus, real ear measurements may not be practical for infants, young children, and adults with some forms of developmental delay or impaired sensorimotor control.

The Real-Ear-to-Coupler-Difference (RECD) is a validated method for simulating the *in situ* response of a hearing aid, and generating appropriate prescriptive targets for gain and maximum output for a given individual[1]. In practice, the amount of occlusion provided by the earmold varies due to venting and the physical fit of the earmold, resulting in the ability for unamplified sound to enter the ear canal and amplified sound to leak out the ear canal[2]. A range of occluding fittings are selected for a range of losses; hearing aids with minimal occlusion are often recommended for individuals with normal or near-normal low-frequency hearing, while more occluding fittings are typically recommended for individuals with greater amounts of hearing loss.

The purpose of the present study was to examine the effects of non-occluded hearing aid fittings on the accuracy of RECD predictions of the real ear response. Our hypothesis was that both the variability in effective occlusion provided by the method of ear coupling and the impact of prescribed vents or open-fit hearing aid couplings are expected to have a negative impact on the accuracy of RECD-based predictions of ear canal SPL.

Methods

- 13 adults with healthy outer and middle ear status completed this study.
- Three ear coupling configurations were of interest:
  - Custom occluded earmold
  - Custom vented earmold (2mm vent)
  - Open-fit ear coupling

Two sets of bilateral earmolds (occluded and vented) were made for each participant. To represent an open fit configuration, #13 tubes were cut to approximately the bore length of the participant's earmold.

- Two simulated audiograms were selected to generate DSL v5 adult targets:
  - Flat 50 dB HL audiogram
    - This audiogram yields a prescription of measurable low-frequency output.
  - Sloping audiogram
    - This audiogram is a common loss configuration that yields greater prescribed output in high frequencies than low frequencies.

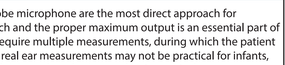
	Frequency (Hz)								
Configuration	250	500	750	1000	1500	2000	3000	4000	6000
Flat 50 dB Loss	50	50	50	50	50	50	50	50	50
Sloping Loss	25	30	40	45	50	55	60	65	65

Table 1. Audiometric thresholds (dB HL) for the simulated Flat 50 dB and Sloping audiograms.

Part I: Measurement of the RECD

The RECD was obtained for each participant under four different configurations of coupling to the ear:

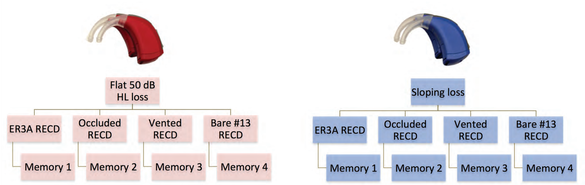
- ER3A foam tip
- Custom occluded earmold
- Custom vented earmold
- Bare #13 tube



- Configurations of ear coupling were chosen to:
  - Represent a range of coupling configurations that are encountered in the clinic
  - Represent a range of coupling configurations that varied in the amount of effective occlusion

Part II: Measurement of 2cc coupler response

- For each participant, the four RECD measures were used to generate four different output prescriptions.
- Using an HA2 coupler, each channel output was adjusted to approach its DSLv5 prescriptive output target.
- Devices used: two sets of Starkey 3 Series mini i110 BTE (bilateral; one set for each simulated audiogram)
  - Each of the four prescriptions occupied one of the four hearing aid memories.
  - This process was completed for each combination of bilateral RECDs and the two audiograms (flat 50 dB HL loss and sloping loss)



Methods, continued

Part III: Measurement of *in situ* real ear response

- Five *in situ* measurement conditions were determined to be of interest *a priori*:
  1. ER3A RECD + Occluded earmold HA coupling
  2. Occluded earmold RECD + Occluded earmold HA coupling
  3. ER3A RECD + Vented earmold HA coupling
  4. Vented earmold RECD + Vented earmold HA coupling
  5. ER3A RECD + Bare #13 tube HA coupling
- A sixth condition - Bare #13 tube RECD + Bare #13 tube HA coupling - was not measured due to insuppressible feedback.

- Rationale for conditions
  - Ideally, we want RECDs to be measured using the patient's earmold (Condition #2, Condition #4).
  - Clinically, it is often the case that RECDs are measured with ER3A foam tips when custom earmolds are not readily available (Condition #1, #3, and #5).

RECD value limits

- RECD values < -20 were limited to -20 during coupler and in situ measurements
  - Pilot testing revealed that extremely negative RECD values resulted in uncomfortably loud and feedback-prone output prescriptions.

Results

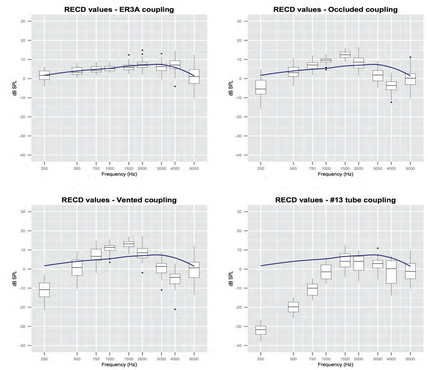


Figure 1. Boxplots of measured RECDs at audiometric frequencies for an ER3A foam tip (upper left panel), custom occluded earmold (upper right panel), custom vented earmold (lower left panel), and bare #13 tube (lower right panel). The **blue** line represents the **mean RECD obtained with an ER3A foam tip**, and is shown to contrast the RECD values obtained with ear coupling configurations of varying effective occlusion.

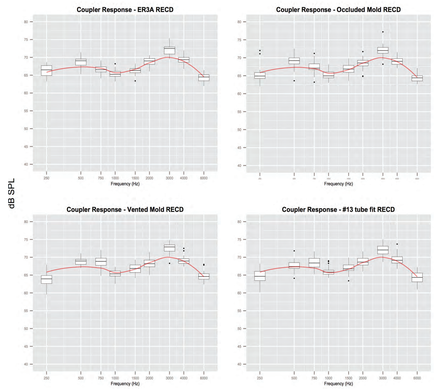


Figure 2a. Distribution of measured hearing aid coupler output responses as a function of frequency. The red line indicates the DSL v5 prescribed output targets for the simulated flat 50 dB hearing loss.

Results, continued

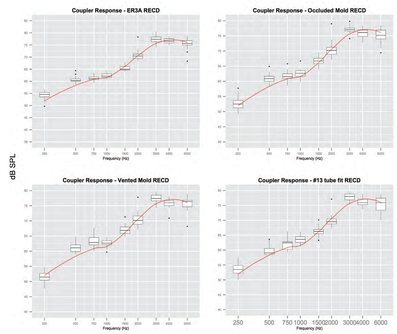


Figure 2b. Distribution of measured hearing aid coupler output responses as a function of frequency. The red line indicates the DSL v5 prescribed output targets for the simulated sloping hearing loss.

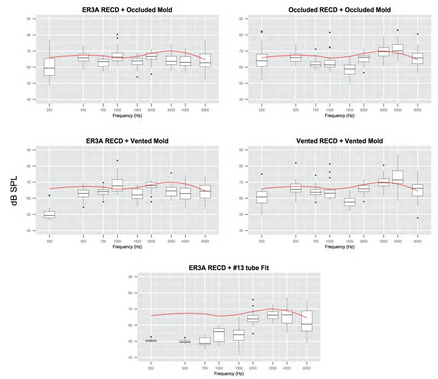


Figure 3a. Distribution of measured *in situ* hearing aid output response for each test condition. The red line indicates the DSL v5 prescribed output targets for the simulated flat 50 dB hearing loss.

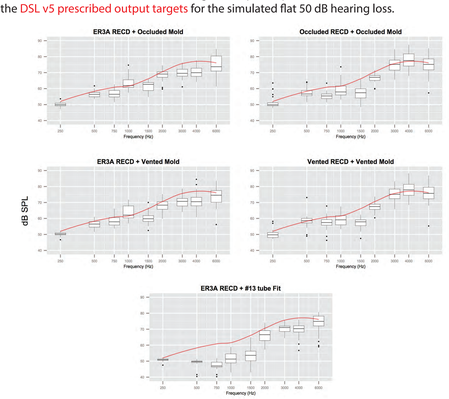


Figure 3b. Distribution of measured in situ hearing aid output responses (dB SPL) for each test condition. The red line indicates the DSL v5 prescribed output targets for the simulated sloping hearing loss.

Summary and Conclusions

Part I: Measurement of the RECD

- One-sample, two-sided paired t-tests were completed between left and right ears for the RECD value observed at each measured frequency. No comparisons were statistically significant ($\alpha = 0.001139$); thus, measurements were collapsed across ears for all subsequent analyses.

Part II: Measurement of the 2cc coupler response

- To ensure that hearing aid output matched the prescribed DSL v5 targets, one-sample, two-sided *t*-tests were completed for each audiometric frequency within each RECD condition and simulated audiogram. All analyses were appraised using a Bonferroni-corrected alpha of 0.001139.
- Clinically significant differences were identified by comparing the 95% confidence interval obtained for each comparison was evaluated against published acceptable fitting tolerances[3]: +/- 5 dB for frequencies < 3 kHz and +/- 8 dB for frequencies ≥ 3 kHz. All 95% confidence intervals for the 2cc coupler response fell within the acceptable fitting tolerances.

Part III: Measurement of the *in situ* real ear response

- Similar to methods described in Part II, goodness of fit was evaluated by comparing the real ear acoustic response with the prescribed DSL v5 targets via a series of one-sample, two-sided paired t-tests for each of the five test conditions. All analyses were appraised using a Bonferroni-corrected alpha of 0.001139.
- As in the analyses of Part II, the 95% confidence interval given for each comparison was evaluated against acceptable fitting tolerances. **Note that only the clinically significant comparisons are shown.**

Condition	Frequency	ΔM	*t*	*df*	*p**	95% CI - Lower	95% CI - Upper	Fit Tolerance - Low	Fit Tolerance - High
ER3A RECD + Occluded earmold	250	-5.408	-4.05	25	0.0004354	-8.158	-2.658	-5	5
	3000	-6.6	-8.317	25	1.148E-08	-8.234	-4.966	-8	8
Occluded RECD + Occluded earmold	750	-4.288	-6.861	25	3.432E-07	-5.576	-3.001	-5	5
	1500	-7.242	-8.73	25	4.61E-08	-8.951	-5.534	-5	5
ER3A RECD + Vented earmold	250	-14.608	-18.731	25	3.156E-17	-16.214	-13.002	-5	5
	500	-6.577	-8.15	25	1.673E-08	-8.239	-4.915	-5	5
	1500	-3.592	-4.8	25	0.0000626	-5.133	-2.051	-5	5
	3000	-6.627	-8.774	25	4.189E-09	-8.183	-5.071	-8	8
Vented RECD + Vented earmold	250	-4.446	-4.31	25	0.0002231	-6.571	-2.321	-5	5
	1500	-8.1	-12.725	25	2.023E-12	-9.411	-6.789	-5	5
ER3A RECD + #13 bare tube coupling	250	-14.639	-101.046	25	2.2E-16	-14.937	-14.34	-5	5
	500	-19.477	-108.707	25	2.2E-16	-19.846	-19.108	-5	5
	750	-16.515	-27.863	25	2.2E-16	-17.736	-15.295	-5	5
	1000	-10.904	-12.772	25	2.2E-16	-12.66	-9.146	-5	5
	1500	-12.323	-11.482	25	2.2E-16	-14.534	-10.113	-5	5

*Bonferroni - adjusted *p*: 0.001139

Table 2. *In situ* responses that were clinically significantly different from the DSL v5 target; flat 50 dB HL loss.

Condition	Frequency	ΔM	*t*	*df*	*p**	95% CI - Lower	95% CI - Upper	Fit Tolerance - Low	Fit Tolerance - High
ER3A RECD + Occluded earmold	500	-4.685	-11.469	25	1.885E-11	-5.529	-3.843	-5	5
	1500	-3.946	-5.791	25	4.895E-06	-5.35	-2.543	-5	5
	3000	-7.646	-11.59	25	1.509E-11	-9.005	-6.287	-8	8
Occluded RECD + Occluded earmold	500	-3.835	-6.19	25	0.00001793	-5.111	-2.559	-5	5
	750	-3.969	-7.904	25	2.929E-08	-5.004	-2.935	-5	5
	1500	-8.065	-9.844	25	4.402E-10	-9.753	-6.378	-5	5
	2000	-3.942	-7.154	25	1.693E-07	-5.077	-2.807	-5	5
ER3A RECD + Vented earmold	500	-4.862	-9.551	25	8.034E-10	-5.91	-3.813	-5	5
	1500	-4.9	-6.371	25	1.142E-06	-6.484	-3.316	-5	5
	1500	-7.892	-11.892	25	8.725E-12	-9.256	-6.525	-5	5
	500	-12.119	-24.954	25	2.2E-16	-13.12	-11.12	-5	5
Vented RECD + Vented earmold	750	-12.058	-23.022	25	2.2E-16	-13.14	-10.98	-5	5
ER3A RECD + #13 bare tube coupling	1000	-10.612	-12.744	25	2.2E-16	-12.327	-8.897	-5	5
	1500	-11.714	-9.841	25	2.2E-16	-14.167	-9.264	-5	5
	2000	-4.619	-5.289	25	0.00001769	-6.418	-2.82	-5	5
	3000	-6.973	-11.615	25	2.2E-16	-8.21	-5.737	-8	8
	4000	-6.8	-7.886	25	2.2E-16	-8.576	-5.024	-8	8

*Bonferroni - adjusted *p*: 0.001139

Table 3. *In situ* responses that were clinically significantly different from the DSL v5 target; sloping loss.

Conclusions:

- RECDs measured with each of the four configurations of ear coupling were statistically significantly different from each other.
- As openness of fit increased, match to target became increasingly difficult. Still, 2cc coupler match to target within bounds of clinical error tolerance was achieved.
- The utility of the RECD in achieving *in situ* DSL v5 targets diminishes for minimally occluding ear-coupling configurations.
- For conditions in which the RECD is obtained using a custom earmold, real ear matches to prescribed targets are better than conditions in which the RECD is obtained with the ER3A standard foam tip.

References

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2. Hoover, B. M., Stelmachowicz, P. G., & Lewis, D. E. (2000, August). Effect of Earmold Fit on Predicted Real Ear SPL Using a Real Ear to Coupler Difference Procedure. *Ear & Hearing*, 21(4), 310-317.

3. British Society of Audiology and British Academy of Audiology. (2007, July). Guidance on the use of real ear measurement to verify the fitting of digital signal processing hearing aids. In British Society of Audiology. Retrieved January 18, 2014, from http://www.thebsa.org.uk/docs/RecPro/REM.pdf