Relationship of Head Circumference and Age in the Prediction of the Real-Ear-to-Coupler Difference (RECD)

Kelli M. Watts[1] Marlene Bagatto[2] Sandra Clark-Lewis[1] Samantha Henderson[1] Susan Scollie[2] Judith Blumsack[1]

[1] Auburn University, Auburn, AL
[2] Western University, Ontario, Canada

Address for correspondence Kelli M. Watts, Auburn University, Auburn, AL 36849 (e-mail: mcdowkm@auburn.edu).

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Abstract

Background Pediatric hearing instrument fitting is optimally performed with individually obtained real-ear-to-coupler difference (RECD) measurements. If these measurements cannot be obtained, predicted values based on age are used. Recent evidence obtained from children aged 3–11 years suggests that head circumference (HC) may be a viable alternative or addition to age for use in RECD prediction.

Purpose The purpose of the present study was to determine if HC can be used to predict RECDs in infants, children, and adults.

Research Design A correlational design was used. HC and RECD values were measured in all participants.

Study Sample Participants were 278 North American infants and children (136 males and 142 females) aged 1.6 months to 11 years and 109 adults (42 males and 67 females) aged 18 years to 83 years.

Data Collection and Analysis After otoscopic inspection and immittance measurements were performed to assess candidacy for inclusion in the study, HC was measured twice for all participants and a single RECD measure was obtained for each participant at twelve frequencies (250 through 12500 Hz). The reliability of HC measurements was assessed with an intraclass correlation analysis. Linear regression analyses were performed with age and HC as predictor variables and RECDs as the dependent variable.

Results Analysis indicated good reliability of the HC measurement. The relationships between RECD and HC were comparable with the relationships between RECD and age. Combining HC and age did not improve predictive accuracy.

Conclusions HC can be used in children and adults as an alternative metric in the prediction of RECDs when individual RECDs cannot be obtained.

Key words
- head circumference
- hearing aids
- hearing instrument fitting
- RECD

Introduction

Real-ear-to-coupler difference (RECD) values play a critical role in hearing aid fitting to infants and young children. The RECD is simply the difference in decibels between the level of a broadband signal recorded in an individual's ear canal and the same sound measured in a 2 cc coupler. The RECD accounts for the differences in acoustics between the metal coupler (which was designed to mimic the size of an adult ear canal) and an individual's ear. RECDs are used to calculate the sound pressure level in the ear canal for the purpose of calculating amplification targets. They also are used for hearing aid verification to ensure safe and accurate output

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levels that provide appropriate access to auditory input. Specifically, the RECD is used to support coupler-based, or simulated, real-ear verification methods. Variability of RECD values among infants and children of the same age is high, and RECD values change with ear canal growth (Feigin et al[14]; Bagatto et al[4]; Bingham et al[7]). Accordingly, the American Academy of Audiology's clinical practice guidelines recommend the use of individual RECD measurements in the pediatric hearing aid fitting process whenever possible (AAA[1]).

Recent evidence suggests that the clinical use of RECD measurement has increased overtime (McCreery et al[19]; Moodie et al[21]). However, circumstances sometimes prohibit individual RECD measurement in the pediatric population (Moodie et al[21]). For example, in some clinics, real-ear measurement equipment may not be available (Moodie et al[21]). In addition, excessive cerumen or high patient activity levels can preclude measurement (Moodie et al[21]). If direct RECD measurement is not possible, age-based predicted RECDs are available in commercially available software and real-ear measurement systems (Bagatto et al[4]). Even with optimal probe microphone placement, individual RECD values can vary by as much as ± 5.6 dB at 500 Hz to ± 10.9 dB at 6000 Hz when compared with age-based predicted RECDs (Bagatto et al[5]). This error can be expected to be even greater for children who have growth retardation (Blumsack et al[8]) or other developmental anomalies.

Recent research indicates that head circumference (HC)–based RECD predictions might provide a useful alternative or supplement to age-based RECD predictions in settings where stunted growth is common (Blumsack et al[9]) and in atypically developing children. In developing countries, the prevalence of stunted growth can range from 38% to 45% (de Onis et al[12]) and access to probe-microphone equipment for measuring RECDs may be very limited. At present, data relating HC to RECD values are available only for typically developing children aged 3 to 11 years (Blumsack et al[9]). These data indicate that when individual RECD measurements cannot be obtained, HC can be considered as a reliable alternative equivalent to age as a metric for RECD prediction. It is necessary to determine if the relationship between RECDs and HC is also present in children younger than 3 years. As recommended by the Joint Committee on Infant Hearing (JCIH[15]), hearing aid fittings often occur in the first few months of life in many areas of the world; therefore, expanding the investigation to include infant and toddler populations may support further clinical application. The purpose of the present study was to expand on the work by Blumsack et al[9] by including more participants and a larger variety of ages and to investigate the relationship between HC and age on RECD values in a sample of infants, children, and adults.

Method

Participants

Participants were 278 North Americans: 87 infants with an average age of 20.1 months (range = 1.6–35 months), 191 children with an average age of 6.0 years (range = 3.0–11.92 years), and 109 adults with an average age of 53.75 years (range = 18.0–83.0 years). The gender breakdown for each age-group is given as follows: infants: 45 males, 41 females, and 1 unknown; children: 90 males and 101 females; and adults: 42 males and 67 females. Participants were eligible to be included in the study if they were observed through otoscopic examination to have at least one ear canal free of debris with an intact tympanic membrane, no detectable middle ear fluid as confirmed by immittance measurement, and no noted craniofacial anomalies. Participants were recruited through Auburn University in Alabama, United States, and the National Centre for Audiology at Western University in London, Canada. The study protocol was approved by ethics review boards at both Auburn and Western universities. Participants were recruited using flyers posted on social media and at data collection sites, which included speech and hearing clinics, day care centers, churches, and through an existing research participant pool at the National Centre for Audiology. All included children were examined at the Auburn University; all adults were assessed at Western University.

Procedures

After informed consent was obtained from the care-giver/participant as appropriate as per the approved protocol, a cursory otoscopic examination of both ears was performed. The clearest ear was selected as the test ear for the RECD measurement. If both ear canals had cerumen judged to impede proper probe-tube placement, removal was completed using a Bionix™ (Bionix Development Corporation, Toledo, OH) lighted curette, and the clearest ear was selected as the test ear. Immittance measurement was conducted in the test ear. If the immittance results in the initial test ear were abnormal (see **Appendix A**), immittance testing was conducted in the other ear, if otoscopy revealed a clear ear canal for RECD measurement. If the criteria were not met in either ear, no further testing was conducted, and information regarding medical follow-up was given to the consenting adult.

RECD measurements were obtained using an Audioscan® (Dorchester, Ontario, Canada) Verifit® 2 (software versions: Auburn: 4.8; Western: 4.12.5) and referenced to the HA-1 coupler (ANSI S3.46 2013). Calibration of the real-ear system was performed as per the manufacturer's instructions (AudioScan[2]). Coupler measures were obtained using the HA-4 coupler and RECD transducer within Verifit® 2. For the real-ear portion of the RECD, the probe tube was marked to indicate the appropriate insertion depth based on the participant's age and gender (Bagatto et al[4]). Using the marker as a reference, the tube was inserted so that based on the data from average, normally developing ears, the tip of the tube should have been within 3 to 5 mm of the tympanic membrane (Bagatto et al[4]; Bagatto et al[6]). An appropriately sized foam eartip (either 3M E-A-RLink 3A [yellow] or 3B [beige]) connected to the Verifit® 2 RECD transducer was introduced into the participant's ear canal. Sound was delivered through the foam eartip to measure the individual real-ear response. Because a majority of participants did not have custom earmolds, RECD measurements with an earmold were not considered in this study. To ensure that the RECD values were appropriate at all frequencies, adjustments were made in accordance with the Verifit® User's Guide 4.2. If the RECD curve deviated more than 10 dB from the average in the low frequencies, the foam tip was re-inserted deeper or was increased in size and then re-inserted to improve the seal. If the RECD curve deviated more than 10 dB from the average in the 4–6 kHz region, the probe was removed and inspected for cerumen or other blockage. If the probe tube was clear, it was re-inserted and the measurement was completed. If the probe tube was blocked or misshapen, a new probe tube was inserted into the ear canal and used to complete the measurement.

HC was measured with a Pedia-Pal™ HC measuring tape or other flexible, nonstretchable measuring tape with a centimeter scale. The measuring tape was placed over the most prominent part of the back of the head, positioned around the head above the ears and slightly above the eyebrows. The tape was held snugly in this position, and the HC was recorded to the nearest tenth of a centimeter (CDCP[11]). The tape was removed, and a second HC measurement was obtained using the same method.

Data Cleaning

Before the regression analyses, the data were cleaned to account for typical measurement errors that occur in the RECD measurement. Errors in measured RECD values due to procedural imperfections occur in two forms: slit leak venting and shallow probe-tube placement (Bagatto et al[4]). These are likely to occur in both the pediatric and adult clinical population. Given these data were collected using a routine clinical procedure (Moodie et al[21]), both types of errors were noted in the RECD values and were adjusted before the regression analyses. To account for slit leak venting, values at 250, 500, and 750 Hz were coded as missing if the measured RECD value was −5 dB or less. This occurred 20 times at 250 Hz, two times at 500 Hz, and not at all at 750 Hz. To account for shallow probe-tube placement, RECD values were inspected for early roll-off and coded as missing at some high frequencies if this occurred. Pediatric data were inspected differently from adult data because of the difference in the resonant properties of the ear canal with age. For the pediatric data, if the RECD value at 6000 Hz was less than the value at 4000 Hz, values from 6000 Hz and above were coded as missing and not included in the regression analyses. Data were coded as missing for 22 cases in the combined pediatric data (6 infants younger than 3 years; 16 children aged 3 to 11 years). For the adult data, if the RECD value at 3000 Hz was less than the value at 2000 Hz, values from 3000 Hz and above were coded as missing. Data were coded as missing for 24 adult cases.

Planned Analysis

Planned statistical analyses included the use of linear regression to assess relationships among HC, age, and RECDs at each of twelve auditory frequencies. Analysis of variances (ANOVAs) with paired comparisons were used to detect possible differences among HC and age and the combination of these two variables in their relative utility for predicting RECDs.

Results

The present study investigated the extent to which RECD values can be predicted by HC and/or age. It expands previous work used HC to predict RECDs (Blumsack et al[9]). The reliability of the repeated HC measurements was assessed using intraclass correlation. To evaluate the relationship between HC and/or age on RECD values, linear regression analyses were performed using RECD values per frequency as the dependent variable with three separate independent variables: (a) HC, (b) logarithm of age (days), and (c) backward regression with HC and logarithm of age (days). Statistically, the logarithmic regression analysis provided significantly better fits to the data than linear regression analysis; thus, age was converted to logarithm of age to normalize the residuals.

Before presenting the intraclass correlations, it is of importance to view the overall mean and variance data for our RECD measures. ►**Figure 1** shows the average comparisons. The average RECDs for 1- to 12-month-olds were compared with the 95% confidence intervals for DSL v5.0 predicted RECDs for 4-month-olds. These ages were chosen because this is the age-group with the most RECD variability (Bagatto et al[4]). The average RECDs for the current study fall within the confidence interval for the DSL-predicted RECDs for 4-month-olds.

In the combined sample of pediatric and adult participants, the mean HC was 52.58 cm (range = 39.30–62.35 cm). Linear regression analyses were performed on the combined pediatric and adult RECD data at 12 frequencies, with the logarithm of age (days) and HC (cm) as independent variables conducted separately and combined in a backward regression. Significance values for the regression estimates are presented for each frequency in ►**Tables 1–3**.

The regression coefficients and r^2 values for each frequency for the RECD data are also found in ►**Tables 1–3**. The r^2 values shown in the tables indicate a weak to modest association between the RECD values and HC or age. When HC is considered, r^2 values range from 0.047 at 10000 Hz to 0.462 at 750 Hz. For the logarithm of age, r^2 range from 0.028 at 12500 Hz to 0.469 at 750 Hz. When HC and age are combined, the r^2 values are not enhanced and range from 0.054 at 12500 Hz to 0.493 at 750 Hz.

From the regression data in ►**Tables 1–3**, different equations at each frequency were developed to predict RECDs based on HC, logarithm of age, and logarithm of age and HC combined. A visual representation of the raw data along with the linear equation for predicting RECDs based on HC and logarithm of age was developed. Scatterplots with trend lines for RECDs using HC and logarithm of age at 500, 1000, 2000, and 4000 Hz are provided in **Appendix B**.

►**Tables 1** and **2** use the simple linear equation formula, $y = mx + b$, where m is the slope and b is the constant or y-intercept, for each RECD frequency. For ►**Tables 1** and **2**, the different slopes and constants for each frequency can be put into the equation. The y variable for ►**Table 1** is the RECD, and

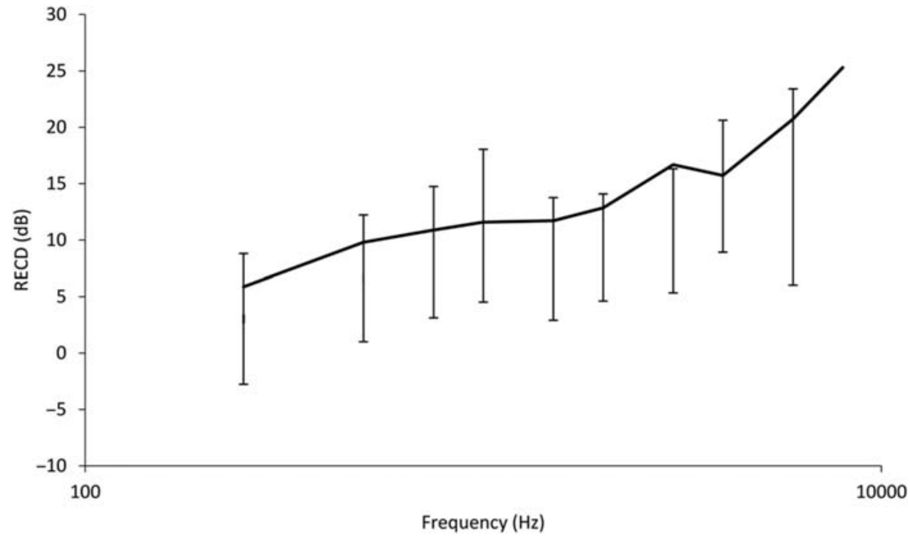

Fig. 1 Average Comparison for infants aged 1–12 months.

x variable is the logarithm of age in days. Similarly, the y variable for ►**Table 2** is the RECD, and the x variable is the HC. If an individual's RECD values needed to be calculated and age or HC are readily available, then these equations could be used to predict RECD values at each frequency. For example, if a 563-day-old child with a HC of 46.4 cm needed to have RECDs completed, then these values could be inserted into the formulas based on the values in ►**Tables 1** and **2** for each frequency. The age-based predicted 1000-Hz RECD value would equal 10.1 dB, and the HC-based 1000-Hz RECD value would equal 10.7 dB. To calculate the other frequency RECD values, one would have to use different y and b values in the formula to calculate each frequency.

The difference, in dB, between the measured and predicted RECD value (using the regression coefficients shown in the tables) was calculated at each frequency for each participant. The mean (unsigned) absolute error values associated with the RECD predictions based on each analysis strategy are shown in ►**Table 4**, along with the 95% confidence interval and the standard deviation (SD) as a function of frequency. Results showed that when HC was used to predict the RECD value, the average error ranged from a low of 1.51 dB at 2000 Hz to a high of 5.53 dB at 12500 Hz. When age is used to predict the RECD value, the average error ranged from a low of 1.42 dB to a high of 5.64 dB at 2000 and 12500 Hz, respectively. When HC and age are combined, prediction errors ranged from a low of 1.47 dB to a high of 5.51 dB at 2000 and 12500 Hz. By examining the 95% confidence intervals in ►**Table 4**, it can be seen that HC and age predict the RECD value equally well and when combined, the predictive accuracy does not improve.

ANOVA and Paired Comparison

Sphericity could not be assumed in the population for any one of the 12 analyses (Muchly's test of sphericity $p \leq 0.05$). Therefore, multivariate results (Wilks' lambda–associated F values) are reported for all omnibus tests. Paired sample were used for pairwise follow-up comparison. ►**Table 5** displays statistics for the omnibus test as well as for follow-up pairwise comparisons. The Bonferroni (omnibus test alpha divided by the number of pairwise comparisons) is used to control for Type I error across follow-up analyses per Hertz level ($0.05/3 = 0.017$).

Results were somewhat mixed. Omnibus test statistical significance was reached at all levels except 4000, 10000, and 12500 Hz. Effect sizes, for most analyses, were medium or approaching medium (see Cohen[10]). At 4000, 8000, 10000, and 12500 Hz, effect sizes were small. After controlling for Type I error, four of the 36 pairwise comparisons reached statistical significance.

HC as a predictor alone was statistically significantly different from age and both HC and logarithm of age combined at levels 250, 1000, and 2000 Hz. At each of these frequencies, the mean predicted RECDs from HC measurements were greater than the mean RECD for HC and logarithm of age combined. Age as a predictor alone was statistically significantly different from HC and logarithm of age together at 500 Hz, with the mean for age greater than the mean for both age and HC together.

Discussion

The purpose of this study was to explore the relationship between RECD and HC across the life span. The key findings of this study are:

- In children and adults, HC is comparable with age as a metric for RECD prediction. This is consistent with the previous work by Blumsack et al.[9] Analyses of the present results indicated no advantage in predicting RECDs by combining HC and age.
- In children aged 1 to 12 months, RECD measurements using foam eartips were consistent with available age-based predictions (Bagatto et al[4]).

At the outset, it is important to emphasize that measurement of a patient's individual RECD is recommended (Bagatto et al[4]; AAA[1]; McCreery et al[18]). Individual RECD values for children who are of the same age can vary from 15 to 20 dB in children with intact tympanic membranes or more in children

Table 1 Linear Regression Coefficients for Log of Age

	Frequency (Hz)											
	250	500	750	1000	1500	2000	3000	4000	6000	8000	10000	12500
Slope	−3.42095	−3.3843	−3.64435	−3.23668	−1.99358	−1.93682	−2.35349	−1.62841	−4.27675	−3.85332	−2.56383	−1.96775
Constant	13.88741	17.95712	19.63231	18.98639	16.14583	17.79744	20.95666	17.96913	30.44755	33.72467	31.13112	25.48138
r^2	0.351	0.45	0.469	0.446	0.262	0.27	0.284	0.081	0.325	0.132	0.057	0.028
p value	0	0	0	0	0	0	0	0	0	0	0	0

Table 2 Linear Regression Coefficients for HC

	Frequency (Hz)											
	250	500	750	1000	1500	2000	3000	4000	6000	8000	10000	12500
Slope	−0.469	−0.48133	−0.51881	−0.46055	−0.28735	−0.28058	−0.3541	−0.27801	−0.60961	−0.48367	−0.33657	−0.37963
Constant	26.83674	31.66857	34.41017	32.0997	24.41653	25.90679	31.49259	26.98419	47.79918	45.92739	40.02222	38.65219
r^2	0.33	0.449	0.462	0.44	0.266	0.276	0.309	0.114	0.316	0.1	0.047	0.05
p	0	0	0	0	0	0	0	0	0	0	0	0

Table 3 Backward Regression Coefficients for Log of Age and HC

	Frequency (Hz)											
	250	500	750	1000	1500	2000	3000	4000	6000	8000	10000	12500
Slope age	−2.26621	−1.80883	−2.02908	−1.8085	−1.00537	−0.93523	−0.82612	0.388108	−2.50118	−4.18015	−2.3478	1.762007
Slope HC	−0.18307	−0.25162	−0.26047	−0.2303	−0.15935	−0.16151	−0.24824	−0.32774	−0.28844	0.053092	−0.03509	−0.60589
Constant	19.55446	25.789	27.78766	26.19712	21.13521	22.8544	28.75802	28.26889	39.50065	32.05828	32.23258	44.49826
r^2	0.362	0.475	0.493	0.469	0.28	0.289	0.316	0.115	0.34	0.132	0.057	0.054
p age	0	0	0	0	0.006	0.008	0.049	0.528	0.001	0	0.059	0.198
p HC	0.016	0	0	0	0.003	0.001	0	0	0.006	0.755	0.845	0.002

with tympanic membrane perforations, patent tympanostomy tubes, middle-ear dysfunction, or other ear canal malformations (Martin et al[17]; Bagatto et al[5]; McCreery et al[18]). However, some circumstances such as excessive cerumen or high patient activity (Moodie et al[21]) may preclude obtaining individual RECD values. Individual RECD measurement also may be precluded because equipment is not available or clinicians may have inadequate training on the use of the equipment. When individual RECD values cannot be measured, RECD predictions based on age are available in applications of prescriptive software (e.g., Scollie et al[25]). The most recently available RECD predictions provide values for ages to the nearest month through age 5 years and to the nearest year, age 6 years through 12 years, for both foam tip and earmold coupling (Bagatto et al[3,4]).

The current study revealed that HC could be used as an alternative metric to age to predict RECD values measured with a foam tip. However, children fit with amplification typically use a custom earmold to direct sound to the ear. Because most clinicians consider measuring RECD to be part of hearing aid verification, it is typically measured with a child's personal earmold (Moodie et al[21]). This creates a mismatch between the RECD that is used to estimate hearing aid output in the coupler and the RECD used to assess the child's hearing thresholds. Earmold tubing diameter and length can affect hearing aid output in the 2000- to 3000-Hz range. RECDs measured using an earmold with a large vent or a loosely fitting earmold can result in large negative RECD values. Conversely, very tight-fitting earmolds may cause the probe microphone tube to be crimped, preventing the individual RECD from being measured altogether. Foam tip to earmold correction values have been developed and implemented into some fitting software (Moodie et al[20]). These correction values are applied when a foam tip RECD has been measured for assessment and an earmold RECD is needed for verification. These values do not depend on age and may be more accurate than applying the current earmold RECD prediction values (Bagatto et al[3]). Further investigation is needed to determine if HC could accurately predict RECD values when RECDs are measured with personal earmolds.

As previously stated, using age-based RECD predictions for typically developing North American infants and children is not without error. Studies indicate that when individually measured RECDs are compared with available age-based norms, values vary as widely as ±5.6 dB at 500 Hz to ±10.9 dB at 6000 Hz for infants and children (Bagatto et al[4]). The error between age-based predictions and individual RECD values is even larger in undernourished children (Blumsack et al[8]). Thus, alternatives to using age as a metric for RECD prediction warrant investigation. Blumsack et al[9] considered height, weight, and HC as possible metrics for predicting RECD values. They found that although height and weight could predict RECDs at some frequencies, HC was the only variable that could predict RECD values at 500 through 6000 Hz for both ears.

In North America (for typically developing infants and children), RECD predictions based on age would yield results similar to predictions based on HC. Therefore, measures of HC would not be necessary. However, HC is used worldwide as a

Table 4 Mean RECD Prediction Error Values for Age, HC, and Age/HC Combined

	Frequency (Hz)																	
	250			500			750			1000			1500			2000		
	Age	HC	Both	Age	HC	Both	Age	HC	Both	Age	HC	Both	Age	HC	Both	Age	HC	Both
Average (dB)	2.2	2.2	2.2	1.8	1.8	1.7	1.9	1.9	1.8	1.7	1.8	1.7	1.6	1.6	1.6	1.5	1.5	1.5
SD	1.7	1.7	1.7	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.4	1.2	1.2	1.2	1.2	1.2	1.3
Confidence interval (±)	3.4	3.4	3.3	2.7	2.8	2.7	2.8	2.9	2.8	2.6	2.6	2.6	2.5	2.4	2.4	2.5	2.3	2.4
	Frequency (Hz)																	
	3000			4000			6000			8000			10000			12500		
	Age	HC	Both	Age	HC	Both	Age	HC	Both	Age	HC	Both	Age	HC	Both	Age	HC	Both
Average (dB)	1.7	1.7	1.7	2.5	2.4	2.4	2.8	2.8	2.8	4.7	4.8	4.7	5.2	5.2	5.2	5.6	5.5	5.5
SD	1.4	1.4	1.4	2.1	2.0	2.0	2.5	2.5	2.5	3.7	3.8	3.7	3.6	3.7	3.6	4.3	4.3	4.3
Confidence interval (±)	2.8	2.7	2.7	4.2	4.1	4.1	5.0	5.0	5.0	7.5	7.6	7.5	7.3	7.4	7.3	8.6	8.6	8.5

Table 5 Pairwise Comparisons

	Frequency (Hz)											
	250	500	750	1000	1500	2000	3000	4000	6000	8000	10000	12500
Omnibus test $F_{(df)}$, *p* value	10.86 (2, 365), <0.001*	11.78 (2, 383), <0.001*	11.95 (2, 385), <0.001*	14.86 (2, 385), <0.001*	6.62 (2, 385), 0.001*	10.87 (2, 385), <0.001*	8.23 (2, 361), <0.001*	1.87 (2, 361), 0.155	9.03 (2, 337), <0.001*	3.26 (2, 337), 0.039*	0.701 (2, 337), 0.497	2.88 (2, 337), 0.058
Omnibus effect size, eta squared	0.056	0.058	0.058	0.072	0.033	0.053	0.044	0.010	0.051	0.019	0.004	0.017
Pair 1: log of age and HC $t_{(df)}$, *p* value	−1.74 (366), 0.083	0.49 (384), 0.624	0.066 (386), 0.948	−0.484 (386), 0.628	−0.487 (386), 0.626	−1.22 (386), 0.225	0.662 (362), 0.508	1.55 (362), 0.122	−0.56 (338), 0.576	−1.43 (338), 0.154	−0.556 (338), 0.579	2.19 (338), 0.029
Pair 2: log of age vs. HC and log of age together $t_{(df)}$, *p* value	0.58 (366), 0.562	2.52 (384), 0.012*†	2.27 (386), 0.024	2.13 (386), 0.034	0.857 (386), 0.392	0.455 (386), 0.649	1.65 (362), 0.100	1.43 (362), 0.155	1.51 (338), 0.251	−0.258 (338), 0.797	−0.017 (338), 0.987	1.76 (338), 0.08
Pair 3: HC vs. HC and log of age together $t_{(df)}$, *p* value	2.90 (366), 0.004*†	1.61 (384), 0.108	1.97 (386), 0.049	2.76 (386), 0.006*†	1.87 (386), 0.063	2.97 (386), 0.003*†	1.53 (362), 0.128	0.565 (362), 0.572	1.84 (338), 0.066	1.31 (338), 0.194	0.606 (338), 0.545	0.715 (338), 0.475

*Indicates statistical significance.
†Pairwise comparison alpha = 0.017 based using Bonferroni test (0.05/3).

growth measurement (de Onis et al[13]). HC can be measured easily, inexpensively, and reliably. In developing countries where atypical physical development is more common (de Onis et al[12]), HC-based RECD predictions may have value for pediatric hearing assessment and hearing aid fitting. Future research studying individuals with nutritionally related stunted growth, constitutional growth retardation, premature birth, or developmental anomalies would be useful to determine if in such individuals HC-based RECD predictions could be a more accurate alternative to predictions based on age.

Summary and Conclusions

This work re-examinedHC as an alternative metric for predicting RECD values in children and expanded the work to determine if HC could reliably predict RECDs in infants. HC was measured and applied in regression analyses alone and in combination with age to determine its predictive accuracy for RECD values across frequency. The measurement and use of a patient's individual RECD remain the best clinical practice. However, when the RECD cannot be measured, either HC or age can be considered as a viable metric for RECD prediction in typically developing North American infants, children, and adults. Further research is necessary to determine if the observed relationship between RECD and HC can be seen when patients' personal earmolds are used or if HC-based predictions generalize to populations with prematurity, nutritionally related growth retardation, constitutional growth retardation, and/or other developmental anomalies. Other anthropomorphic measurements, such as pinna-to-pinna measurements, could also be investigated to determine if they could be a viable alternative to age for predicting RECD values.

Abbreviations

HC head circumference
RECD real-ear-to-coupler difference
SD standard deviation

Notes
Presented as a podium presentation at the World Congress of Audiology, Vancouver, British Columbia, Canada, September 21, 2016; presented as a poster at the 7th Annual International Pediatric Audiology Conference, Atlanta, GA, October 4, 2016; and presented at the fall meeting of the West Virginia Audiology Association, Pipestem, WV, September 29–30, 2017.

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Conflict of Interest
None declared.

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Appendix A: Immittance Procedures

For participants $\leq$ to 6 months, use 1000 Hz probe tone.
Criteria for inclusion:

- Single peak or highest of two peaks
- Negative-tail compensated static admittance: $>$ 0.6 mmhos (Margolis et al[16])

For participants age $>$ 6 months up to and including 36 months, use 226 Hz probe tone.
Criteria for inclusion:

- Peak compensated acoustic admittance: 0.2 to 0.7 mmhos (Roush et al[24])
- Tympanometric width: 102 to 204 daPa

For children aged $>$ 36 months, use 226 Hz probe tone.
Criteria for inclusion:

- Peak compensated acoustic admittance: 0.4 to 1.4 mmhos (Nozza et al[22])
- Tympanometric width: 60 to 168 daPa (Nozza et al[23])

Appendix B: Scatterplots with Trend lines