

Integrating the RECD into the hearing instrument fitting process

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Introduction

The amplification requirements for an individual are normally based on data obtained during audiometric assessment. The precise interrelationship between the amplification characteristics and the assessment data is most readily appreciated when they have been measured at the same reference point and in the same units. This is important if the audibility of speech and the relationship between uncomfortable loudness level (ULL) and maximum power output (MPO) are to be determined. Using the ear canal as the reference point has the additional advantage of accounting for differences in external ear acoustics among subjects. A probe-tube

microphone can be used to measure real-ear sound pressure level (SPL) directly; however, in certain populations (such as infants and children) the probe tube may not be tolerated for extended periods of time. An alternative is to derive (sometimes called "predict") the real-ear SPL by adding an individually measured acoustic transfer function to both, the audiometric and electroacoustic data. The acoustic transfer function in question is known as the "real-ear-to-coupler difference" (RECD). The purpose of this article is to encourage clinicians to measure the RECD. The article explains how the individually-measured RECD can be integrated into the hearing instrument fitting process. Phonak has developed a fitting tool known as RECDdirect which is a one-step process that minimizes RECD measurement time and removes the need for a separate probe-tube microphone system. It utilizes the fitting software and Supero hearing instrument in the RECD measurement process. The findings from a study using RECDdirect are presented in this article.

What is an RECD acoustic transfer function?

Although there is no formally recognized definition for the RECD acoustic transfer function, it is generally accepted to be the difference between the SPL measured in the occluded ear canal relative to the 2-cc coupler. The clinical protocol for measuring an RECD uses an insert earphone to deliver the signal and compares the SPL generated in the real ear with the SPL generated in the HA2 2-cc coupler. The difference, in decibels, between the two measurements is the RECD.

What does an RECD acoustic transfer function look like?

If life were straightforward, then the SPL measured in the occluded ear canal and 2-cc coupler would be the same: the RECD would be zero at all frequencies. However, this is not the case. There are differences between the occluded ear canal and the 2-cc coupler due to a combination of factors including the impedance properties of the ear, the volume of the occluded ear canal, and the acoustic leakage of amplified sound from the occluded ear canal. As a result, the SPL generated in the occluded ear canal is usually higher than in the 2-cc coupler. As an example, the SPL generated in an occluded ear canal and in the HA1 and HA2 2-cc coupler is shown in Figure 1¹⁾. In this example, the adult ear canal was occluded using an unvented personal (sometimes called "customized") earmould with approximately 45 mm of acoustic tubing. The signal was delivered via an ER3 insert earphone. The figure shows that the SPL in the ear canal is higher than in the coupler, for the reasons given above. In addition, the SPL measured in the couplers differs at the higher frequencies: the SPL is lower in the HA1 because it includes the influence of the earmould sound bore.

Figure 1

The SPL generated in the occluded ear canal of an adult (open circles) compared to an HA1 (grey circles) and HA2 (black circles) 2-cc coupler. The signal was delivered using an ER3 insert earphone attached to a personal earmould.

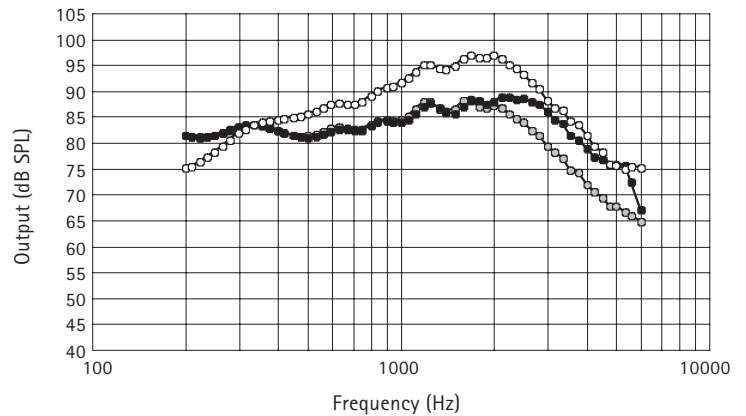
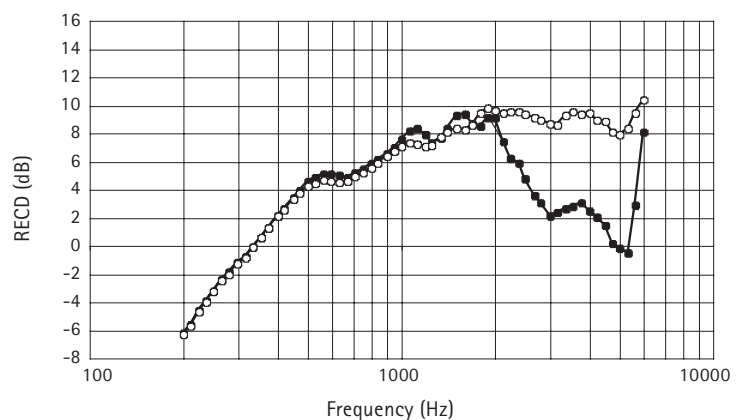


Figure 2

The RECDs obtained from the data in Figure 1. These were obtained by subtracting the SPL generated in the occluded ear canal from the SPL generated in the HA1 (open circles) and the HA2 (black circles) 2-cc coupler.



¹⁾Unlike the HA1, the HA2 includes an earmould simulator, so it does not require the earmould to be connected using putty.

The RECDs obtained for this individual are shown in Figure 2. A positive value indicates the extent to which the SPL is higher in the occluded ear canal compared to the coupler. The magnitude of the RECD is greatest at higher frequencies because the acoustic impedance of the 2-cc coupler decreases more than that of the occluded ear canal; this results in a greater difference in SPL between the two cavities. The effect of the earmould sound bore is eliminated from the RECD when the SPL is measured in the HA1 coupler. This happens because the earmould is used when measuring the SPL generated in both, the ear and the HA1 coupler: the effect of the sound bore is eliminated when these are subtracted to generate the RECD. The influence of the sound bore is present when the RECD is measured with an HA2 coupler since the earmould is only present when measuring the SPL in the ear canal but not the coupler. It may be more appropriate to refer to the latter as an earmould and real-ear-to-coupler difference (E-RECD). The latter will include the effect of amplified low-frequency sound escaping via the vent but it does not include the effect of sound directly entering the ear canal via the vent. This is discussed further in a later section.

Why is the RECD transfer function useful?

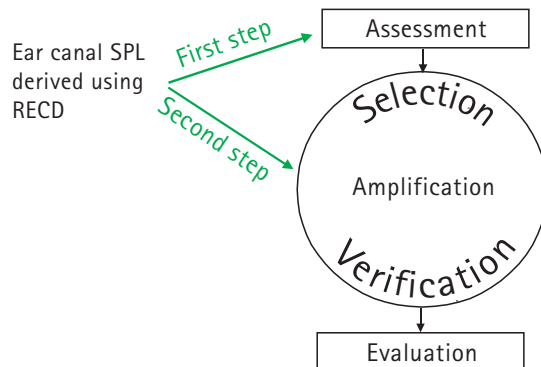
With co-operative subjects, it is generally possible to use a probe-tube microphone system to measure ear canal SPL directly: this is known as "in-situ" audiometry and real-ear measurement of hearing instrument performance. However, there are occasions when these clinical procedures are not tolerated by the subject, especially the infant and young child. In these subjects, in particular, it may be appropriate to derive ear canal SPL using the RECD in conjunction with traditional clinical procedures.

Integrating the RECD into the fitting process

The RECD can be integrated into several stages of the hearing instrument fitting process as shown in Figure 3. The first stage involves audiometric assessment when data have been collected using an insert earphone. The hearing threshold, in decibels hearing level (dB HL), is converted to ear canal SPL in a two-step process. In Step One, the assessment data are transformed from dB HL to dB SPL. The transformation factor is known as the

Figure 3

The ear canal SPL can be derived for audiometric and electroacoustic data using the RECD.



“coupler-to-dial difference” (CDD) and is similar, but not identical to the frequency-specific reference equivalent threshold SPLs (RETSPL) used in the physical calibration of the pure tone audiometer since these use different coupler configurations. This step occurs in the fitting software and does not require the clinician to make any measurements or calculations. Once the data have been transformed to dB SPL in the coupler, Step Two involves transferring the data from the 2-cc coupler to the ear canal. This is achieved by measuring and adding the RECD²⁾. This two-step process is illustrated in Figure 4. These calculations are usually performed automatically in the fitting software after the clinician has entered the assessment data and the RECD.

The second stage of the fitting process where the RECD is useful is when hearing instrument performance has been measured in a 2-cc coupler. Once again, the reference point can be transferred from the 2-cc coupler to the ear canal using the RECD. This is illustrated in Figure 5. Unless the hearing

instrument is saturated, the microphone location effects (MLEs) have also to be added: these are of the order of a few decibels and average default values are used by the fitting software. Thus, the real-ear SPL can be derived by adding the RECD to the 2-cc coupler SPL.

The clinician uses the selection process to select amplification characteristics of the hearing instrument that closely match target values. The verification process is used to confirm that there is a close match to target when the hearing instrument is worn by the subject. This means that selection and

Figure 4
Audiometric data (obtained with insert earphones) are converted from dB HL to dB SPL by adding the CDD transform. These are then transferred from the coupler to the real ear using the RECD transfer function. Hypothetical numbers have been used to illustrate this two-stage process.

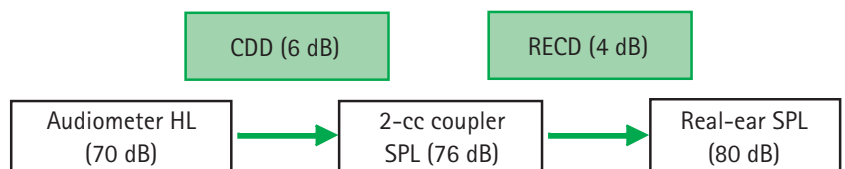
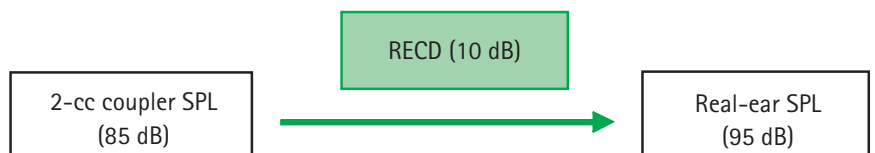


Figure 5
Electroacoustic data are transferred from the coupler to the real ear using the RECD transfer function. Hypothetical numbers have been inserted for illustration.



²⁾There is an alternative method which combines this two-step process and involves adding the RECD to the assessment data (Munro and Lazenby, 2001). This alternative method is useful when the supra-aural earphone is used for audiometric assessment since the RECD requires access to a 6-cc coupler (IEC 60318-3) and this is generally not available in clinical practice.

verification of amplification characteristics can take place in the "simulated real ear" as illustrated in Figure 6. The same model of 2-cc coupler should be used when measuring hearing instrument performance and RECD.

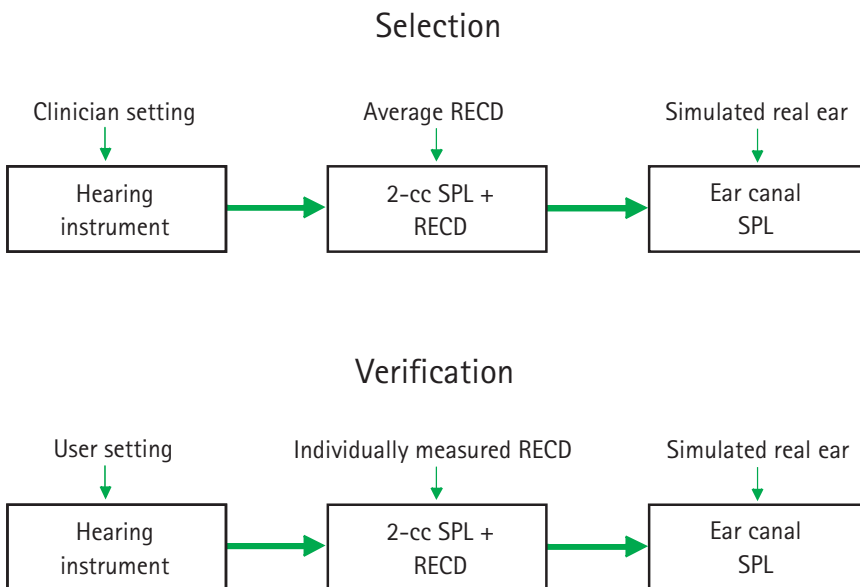
Despite the similarity between the selection and verification process shown in Figure 6, there are two important differences. Firstly, the selection of electroacoustic characteristics is under the control of the clinician. Secondly, at this stage, an individually measured RECD with the subject's personal earmould may not be available; therefore, age-appropriate average values are used in the fitting software.

Verification is required to ensure that the instrument is delivering the appropriate SPL to the ear canal. The electroacoustic characteristics are measured at the normal user settings and require the individually measured RECD obtained with the personal earmould.

The RECD obtained from an individual will differ depending on the earmould used to occlude the ear canal. The RECDs obtained using two different earmould configurations are shown in Figure 7. The adult ear canal was occluded using a disposable foam eartip (open circles) and a personal earmould (filled circles). The difference between the two RECDs is due to differences in acoustic leakage (low frequencies), depth of earmould insertion (mid frequencies), and length of sound bore (high frequencies).

In order to use the same RECD to derive real-ear SPL for audiometric and electroacoustic data, it is necessary to use the same earmould; otherwise, two RECD measurements per ear will be required. Clinical observation suggests that infants are often prepared to tolerate insert earphones if these are coupled to their ear using the personal earmould. This means that only one RECD (with personal earmould) per ear is required from the subject when deriving real-ear SPL of both audiometric and electroacoustic data. A detailed description of how to use the RECD to convert audiometric and electroacoustic data into real-ear SPL is given by Revit (1997), Munro and Lazenby (2001), and Scollie and Seewald (2002).

Figure 6
Selection and verification of amplification characteristics using the 2-cc coupler and RECD to simulate the real ear.



Why is it helpful to use the ear canal as the reference point?

There are at least two reasons why it is helpful to convert all variables to ear canal SPL. The first reason is related to the interrelationship between variables and the second, to variations in ear canal dimensions among individuals.

The interrelationship among variables
 The precise interrelationship between assessment data and the amplification characteristics can only be readily appreciated when these are measured at the same reference point. This is one of the key building blocks of the Desired Sensation Level fitting method for children (Seewald, 1995). The data can then be displayed on a single graph referred to as an "SPLogram" as shown in Figure 8. It is clear from this figure that average conversational speech is not audible to this subject without amplification. Amplified speech is audible and located in the middle of the subject's dynamic range. Also, the maximum output of the hearing instrument has been set close to the subject's uncomfortable loudness level. Similar approaches can now be implemented in other prescription fitting procedures including the National Acoustic Laboratory NL1 fitting software where it is called a "speech-o-gram" (Dillon, 1999). Traditionally, most clinicians have used real-ear insertion gain (REIG) and this can be calculated from the data presented in Figure 8 by subtracting the aided speech spectra from the unaided speech spectra. However, this is less informative since it does not provide information about the audibility of speech or the relationship between ULL and MPO (and it involves the measurement of two real-ear responses).

Figure 7

The RECDs obtained for an adult subject obtained by subtracting the SPL generated in the occluded ear canal from the SPL generated in the HA2 2-cc coupler. The ear canal was occluded using a disposable foam eartip (open circles) and a personal earmould (black circles). The signal was delivered via an ER3 earphone.

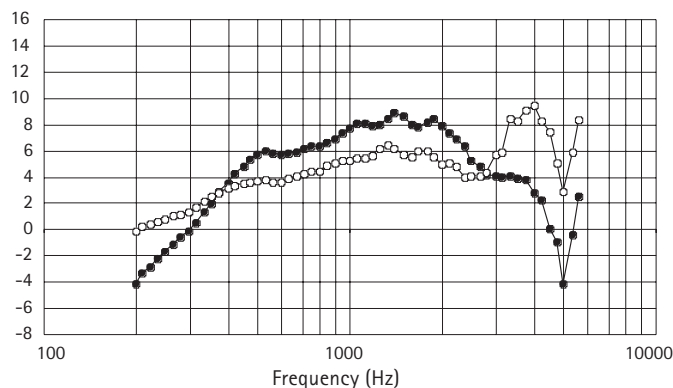
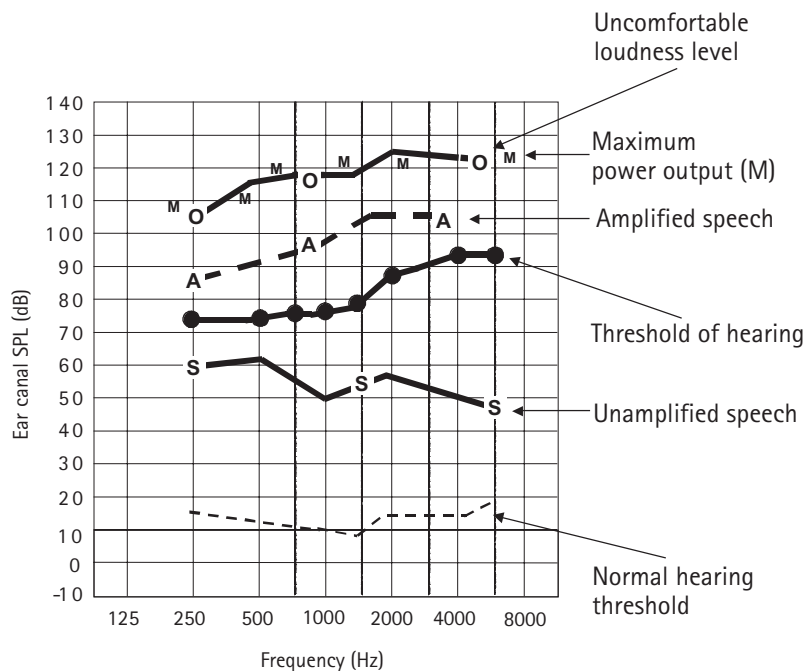


Figure 8

The SPLogram for one ear of a hypothetical subject with a hearing impairment. Normal threshold of hearing is shown by the thin peaked line. The dynamic range of the subject is the area between the hearing threshold (filled circles) and the uncomfortable loudness level (open circles). Unamplified speech (S) is inaudible to the subject. Amplified speech (A) is audible since it is located above threshold and approximately mid-way within the subject's dynamic range. The maximum output of the hearing instrument (M) has been set so that it is approximately the same level as the uncomfortable loudness level.



Variations in ear canal dimensions

The second reason for using the real ear as the reference point is that it eliminates variations across individuals due to differences in ear canal dimensions. The implications of different ear canal dimensions on audiometric data have been reported by Seewald and Scollie (1999), Ching and Dillon (2003), and Marcoux and Hansen (2003). Audiometric transducers such as the supra-aural and the insert earphone are based on calibration data which aim to give 0 dB HL in a normal hearing adult. However, this is not the case in the infant or child who has a smaller external ear canal than the "average" adult. The SPL generated by an insert earphone in the infant ear canal will be higher than the SPL generated in the adult ear canal for a given dial reading (Seewald and Scollie, 1999). Consequently, the severity of the hearing loss will appear less than in the adult. However, as the child grows, the ear canal volume will increase and the audiometer dial reading will need to be increased in order to reach the same SPL at the eardrum. Consequently the child will appear to have a progressive hearing loss. This means that the audiometer dial reading does not accurately reflect the hearing thresholds in subjects who

do not have adult-like ear canal dimensions. The high intersubject variability in the acoustic properties of the external ear is not restricted to infants and young children. For example, Saunders and Morgan (2003) reported that the distribution of eardrum SPL for a fixed dial level at 1 kHz was 40 dB in a group of 1814 adults. This demonstrates that it is inaccurate to assume that, across ears, a given HL signal will result in the same ear canal SPL. This problem can be eliminated if the reference point for measuring SPL is the ear canal (close to the eardrum) since the threshold of hearing will be the same regardless of the audiometric transducer and the external ear acoustics. In a case study of an 8-month-old hearing-impaired infant, Moodie et al. (2000) showed that the hearing threshold increased by as much as 18 dB when the child's RECD was used instead of average adult values to derive ear canal SPL.

Some authors (for example, Ching and Dillon, 2003; Marcoux and Hansen, 2003) have argued that it is preferable to use a standard pure tone audiogram (corrected for the difference between adult and infant ear canal acoustics) instead of the SPLogram since this format is familiar to clinicians and allows a direct

comparison between audiometric data of a child and that of a normal hearing adult. This is easily performed in the fitting software and is referred to as "predicted HL" values (HLp) by Seewald et al. (1993) and "adult-equivalent hearing level" (HLae) by Dillon (2001). It involves correcting the HL data for the difference between the infant and adult RECD (see Figure 9). In practice, some clinicians use both approaches: the corrected pure tone audiogram is used when comparing subjects against the normal 0 dB HL line but the SPLogram is used when selecting and verifying amplification characteristics.

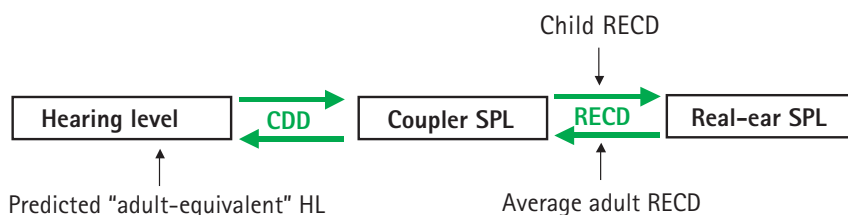
Variations in ear canal dimensions also have implications when using a hearing instrument. The smaller volume of the infant ear canal means that the amplified signal will have a higher SPL than in the adult ear canal. Therefore, it is necessary to measure or derive hearing instrument performance in the infants' ear canal.

Does middle ear pathology affect ear canal SPL?

A grommet (i.e., ventilation tube) or perforation of the eardrum will increase the effective volume of the ear canal and this results in a reduction in acoustic impedance. The output of an audiometer or hearing instrument will have to be increased for the ear canal SPL to be equivalent to the level generated in the ear when no grommet (or perforation) is present. There will be a corresponding reduction in the RECD (since the real-ear component of the RECD will be reduced). For example, if a grommet reduces ear canal SPL by 10 dB, the audiometer dial reading will need to be raised by 10 dB (and the RECD will be decreased by the same amount). The opposite affect occurs in an ear with middle ear effusion although the affect on ear canal SPL is much smaller. A series of studies by Martin et al. (1996, 1997, 2001) has confirmed the effect of middle ear pathology on the RECD. Once again, the problem can be eliminated if the subject's RECD is used to derive real-ear SPL. A detailed discussion of the influence of impedance on ear canal SPL is provided by de Jonge (1996) and Voss et al. (2000).

Figure 9

Eliminating errors due to ear canal acoustics. This can be achieved by expressing audiometric data in ear canal SPL or predicting adult-equivalent hearing level. The former is achieved using the subject's RECD while the latter is achieved using an average adult RECD.



Is it necessary to measure an RECD from each individual?

Numerous studies have revealed the extent to which the acoustic properties of the ear canal change during the first few years of life. As a child grows, the ear canal increases in volume and the RECD becomes smaller, especially at the higher frequencies. Figure 10 shows the RECD measured in a typical infant and adult. The difference at 3 kHz is in excess of 10 dB. It is also known that RECDs are highly variable for individuals within the same age range (Feigin et al., 1989; Bagatto et al., 2002) so the actual difference for a given infant may be considerably higher. Bagatto et al. (2002) measured RECDs from a total of 392 subjects, spanning in age from 1 month to 16 years, when the ear canal was occluded with a personal earmould and an oto-admittance tip. Figure 11 shows the RECD values obtained at 4 kHz when using an oto-admittance tip. The largest RECD was measured at 1 month of age. However, it is difficult to predict what the RECD will be for a given ear because of substantial intersubject variability; for example, the range is 15 dB at 1 month of age and 25 dB over the first two years of life. For this reason it is advisable to measure the RECD for each infant. If the measurement cannot be completed, then it will be necessary to resort to age-appropriate average values.

Figure 10
A typical RECD from an infant (open circle) and an adult (filled circle). The data come from Bagatto et al. (2002; infant) and Munro and Davis (2003; adult).

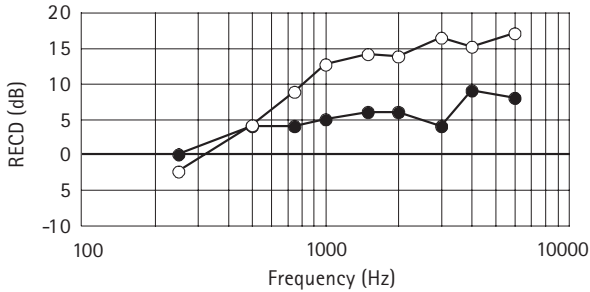
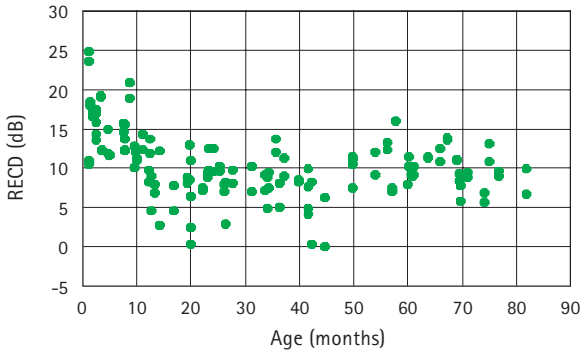


Figure 11
RECD values as a function of age at 4 kHz. The RECDs were measured with an insert earphone and oto-admittance tips. Each point is a different subject (adapted from Bagatto et al., 2002).



How important is it to measure an RECD from each ear?

Some subjects may show limited co-operation which is sufficient to obtain an RECD from one ear alone. How important is it to complete the measurement from both ears? Munro and Buttfield (2004) compared the RECD from the right and left ear of a group of adult subjects whose ear canals were free from occluding wax and who had normal middle ear function as measured by tympanometry. Over the frequency range of 0.5 and 4 kHz, the difference was less than or equal to 3 dB in most subjects (see Figure 12). This suggests that it may not always be necessary to measure an RECD from each ear if co-operation is limited. This is consistent with Tharpe et al. (2001) who showed that the difference between test-retest on the same ear is of the same order of magnitude as the difference between the right and left ear.

How frequently should the RECD be measured?

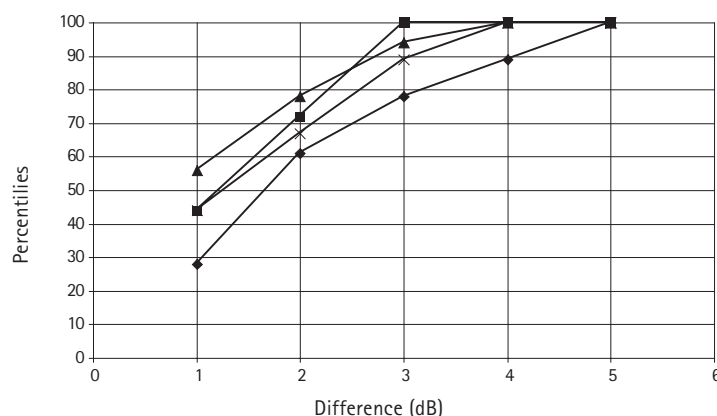
The RECD will change over time for two reasons:

- the ear canal dimensions will increase with age; and
- the fit of the personal earmould will change over time.

The data from Bagatto et al. (2002) show that the largest changes in RECD occur within the first two years of life. This suggests that the RECD should be measured frequently during the first few years of life. There have been no studies that have specifically addressed the frequency of measurement. Ideally, the RECD should be measured whenever the personal

Figure 12

Cumulative distribution of right/left differences at 0.5 (diamond), 1 (square), 2 (triangle), and 4 kHz (cross) for RECDs measured with personal earmoulds (adapted from Munro and Buttfield, 2004).



earmould is replaced although it is recognized that this may not always be possible. Clinical experience suggests that it may be sufficient to measure the RECD at 3-month intervals until two years of age and then at 6-month intervals until five years of age.

Is the RECD repeatable?

Many studies have shown that the test-retest difference in adults is very small and clinically acceptable. For example, Munro and Davis (2003) measured test/retest differences in a group of 16 cooperative adults and reported mean differences close to 0 dB with a standard deviation less than 1 dB.

Sinclair et al. (1996) carried out one of the few studies that have investigated test-retest variability in children. They studied 90 children (birth to 7 years) and 10 adults. The mean difference on retest was less than 2 dB, irrespective of the age of the subject and the test frequency. The range of retest values across subjects was not reported although reliability coefficients were all positive and varied from 0.70 to 0.91 across age groups. Therefore, this study suggests that, in the hands of experienced clinicians, the RECD measurement is very repeatable. However, a less favorable outcome has been reported by Tharpe et al. (2001) who measured test-retest differences at various intervals throughout the first year of life in a group of 22 infants. The mean difference on retest was less than 1 dB; however, the standard deviations were typically around 2 dB from 0-6 months of age and 4 dB from 7-12 month of age. This

would give a 95% range of approximately ± 4 dB and ± 8 dB, respectively. These values are similar to those reported by Westwood and Bamford (1995) who measured the test-retest difference of the real-ear aided response in 33 infants under 12 months of age. Tharpe et al. performed measurements at every visit regardless of the state of the infant; therefore, there may have been occasions when it would have been more appropriate to rely on average age-appropriate default values. This is an area that requires further investigation, especially in light of the rapid growth in newborn hearing screening and early intervention programmes.

Is it valid to use the RECD to derive real-ear SPL?

A number of studies have used the RECD to derive real-ear SPL of audiometric data. Munro and Davis (2003) compared the measured and derived real-ear SPL of audiometer output in 16 adult subjects. The RECD was measured in the HA1 and HA2 2-cc couplers with several insert earphone and earmould configurations. The mean difference between the measured and derived real-ear SPL was less than 1 dB and rarely exceeded 3 dB in any subject. Similar findings have been reported by Scollie et al. (1998).

A number of studies have used the RECD to derive real-ear SPL of electroacoustic data. Munro and Hatton (2000) compared the

measured and derived real-ear SPL of hearing instrument output in 24 adult subjects.

The RECD was measured with the ear canal occluded with three earmould configurations: personal earmould, disposable foam eartip, and an oto-admittance tip. In addition, the test signal was presented via an insert earphone as well as via a loudspeaker in the sound field. When using the subject's personal earmould, the mean difference between the measured and derived real-ear aided response was close to 1 dB and rarely exceeded 5 dB in any subject. Similar findings were reported by Seewald et al. (1999) who derived the real-ear aided response and the real-ear saturation response using the RECD.

The signal processed by a hearing instrument will normally produce a higher SPL in the ear canal than signals entering the ear canal directly via a vent in the earmould. However, there are occasions under which this is not the case and the RECD procedure may yield invalid results. Hoover et al. (2000) have shown this scenario to occur when the hearing instrument provides very little gain and there is a negative RECD. This may occur, for example, if the subject has good low frequency hearing and uses an open earmould. The derived ear canal SPL may underestimate the actual ear canal SPL.

With the exception of the relatively rare situation described by Hoover et al. (2000), these studies mentioned above have demonstrated that, if the RECD is measured with care, the derived real-ear SPL will be within a few decibels of the directly measured ear canal SPL obtained using "in-situ" audiometry or real-ear measurements.

Tips on measuring the RECD

The importance of integrating the RECD into routine clinical practice has been recognized for many years. The emphasis on early intervention in permanent childhood hearing impairment means the importance of accounting for differences in external ear acoustics is more important than ever.

It is more than 15 years since Feigin et al. (1989) demonstrated that the infant RECD varies significantly from the adult, and it is more than 10 years since Moodie et al. (1994) described a simple clinical procedure for measuring the RECD. However, implementation into clinical practice has been somewhat slow. In a survey of current practice in "good paediatric services", the percentage routinely performing RECD measurements was 20% and 40% in the UK and USA, respectively (Bamford et al., 2002).

Perhaps the most difficult part of the RECD measurement procedure is the positioning of the probe tube within the ear canal. Provided the tip of the probe tube is extended more than 5 mm past the tip of the earmould, then this is appropriate for frequencies up to 2 kHz. However, the tip of the probe tube is required to be positioned within 5 mm of the eardrum if the clinician is interested in frequencies up to 6 kHz.

Tharpe et al. (2001) have investigated a number of practical considerations when measuring RECDs in infants. One consideration was

the placement of the probe tube within the ear canal. The study compared a constant insertion depth versus an acoustic method (inserting tip of probe tube beyond the 6 kHz standing wave ratio node) for placement of the probe tube. The results showed that there was little to be gained by using the more time-consuming acoustic insertion depth method.

Some real-ear systems use the standard coupler microphone for measuring the coupler SPL and the probe-tube microphone for measuring real-ear SPL. Because two different microphones are used, it is important that they are correctly calibrated with respect to each other. Ching and Dillon (2003) provide useful information on how to check the calibration of these microphones with reference to each other.

Hints to optimize RECD measurement have been provided by Bagatto (2001). This includes information on a variety of procedural issues such as correct probe-tube insertion depth. It also contains a useful section on troubleshooting.

Are there any questions left to be answered?

The clinical protocol for measuring the RECD assumes that the values obtained using the insert earphone can be applied to a coupler measurement performed with a hearing instrument. However, Munro and Salisbury (2002) have shown that the RECD is somewhat dependent on the measurement transducer: for certain test conditions, the RECD obtained with two models of insert earphone resulted in different values. Munro and Toal (2004) compared the mean RECD measured with the ER3 insert earphone and several hearing instruments. Again, there were some test conditions where the RECD obtained with an insert earphone differed from that obtained with a hearing instrument. Figure 13 shows the mean RECD measured with an insert earphone and two models of behind-the-ear (BTE) hearing instrument. The top panel shows the results using the HA1 2-cc coupler and the bottom panel shows the results with the HA2 2-cc coupler. Although the mean RECDs are similar for the three transducers, they are not the same. Differences occur in the mid-frequencies and this is most marked when the RECD has been measured using the HA2 2-cc coupler. Since the acoustic impedance may be different for an insert earphone and a hearing instrument, the RECD measured with an insert earphone may not

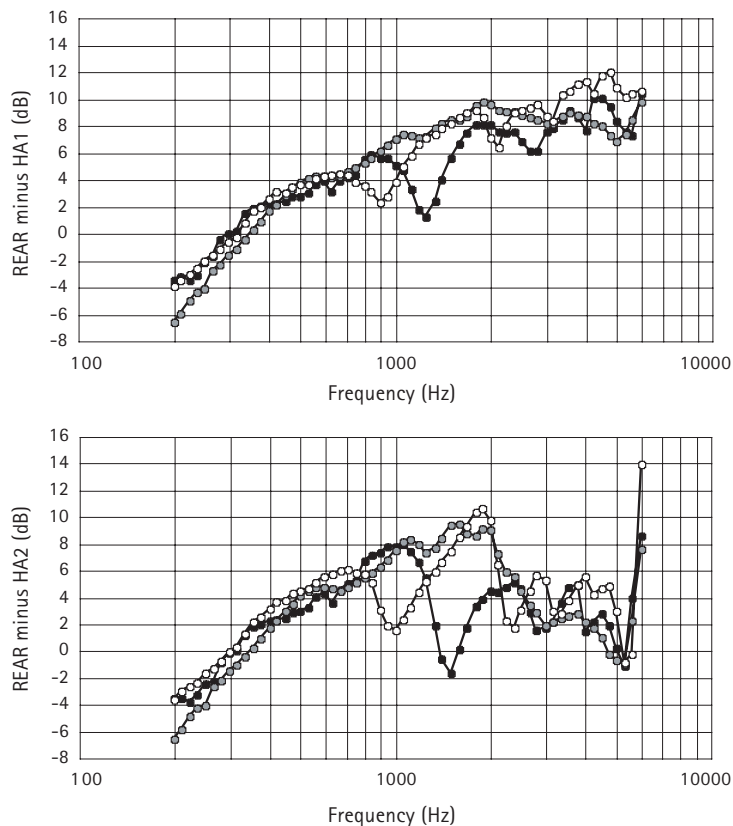
always be representative of the differences in performance of a hearing instrument when measured in the real ear and the 2-cc coupler. One application of the RECD is to convert hearing instrument data from coupler SPL to real-ear SPL, then a solution would be to use the hearing instrument for measuring the RECD. Until recently, however, this has been difficult in clinical practice since it relies on sound field measures and these are influenced by the location of the probe-tube reference microphone and movement of the infant during the measurement. These problems can be circumvented if sound field measurements are not required.

One way forward

Phonak have developed the RECDdirect fitting tool for the Supero hearing system. The objective of the RECDdirect fitting tool is to rationalize the measurement procedure into a one-step process while minimizing both measurement time and the need for additional equipment. The fitting software is used to generate a broadband noise that is delivered to the ear using the hearing instrument. The ear canal SPL is measured using a probe tube connected directly to the hearing instrument (in much the same way as fitting a direct audio input shoe to a hearing instrument). This circumvents the need for an insert earphone and a separate probe-microphone system. The Supero coupler response is stored within the fitting software and this is automatically subtracted from the ear canal SPL to generate an RECD. This reduces the time and effort required to measure an individual RECD.

Figure 13

The mean RECD measured with an ER3 insert earphone (grey circles) and two models of BTE hearing instrument. The RECD was measured using an HA1 2-cc coupler (top panel) and an HA2 2-cc coupler (bottom panel). From Munro and Toal (2004).



Is the RECDdirect fitting method valid?

For the RECDdirect method to be valid, it should result in a hearing instrument fitting that is close to the real-ear prescription target. A study was undertaken by Munro and Toal (2004a) to investigate the extent to which the initial "quick-fit" (pre-fitting) setting using the Supero hearing instrument and RECDdirect deviated from DSL [i/o] targets for average conversational speech. The initial quick-fit settings were obtained using three different RECD values:

1. average PFG 8.2 default values for adults with an unvented earmould,
2. an individually measured RECD using the conventional RECD clinical protocol with an insert earphone
3. an individually measured RECD using RECDdirect.

An unvented earmould was manufactured for one ear of 21 adult subjects. These subjects were then fitted with a Supero 412 BTE hearing instrument using linear processing and set to DSL targets for a flat hearing impairment of 50 dB HL. The program selector, noise canceller and volume control were all deactivated. For the individually measured RECDs, a new probe tube was calibrated and inserted 30 mm past the tragus for each subject.

The ability of each of the fittings to meet the DSL target for amplified speech was measured using an Audioscan RM500 real-ear measurement system. The real-ear aided response (REAR) was measured with a speech-weighted pure tone. The reference microphone was positioned next to the hearing instrument microphone during the measurement. The REAR was repeated to ensure that this was very similar (<1 dB) to the first-aided

response. The data were exported to an excel spreadsheet using xdata32 software as this provided information at $1/12$ -octave intervals.

The mean RECDs are shown in Figure 14. The results are very similar except at 2 kHz. The difference at 2 kHz is consistent with the transducer-dependent effects reported by Munro and Salisbury (2002) and Munro and Toal (2004a, 2004b submitted).

A comparison of the DSL target and the median real-ear response is shown in Figure 15³⁾. The median difference is small for all conditions, especially when the RECD has been individually measured (insert earphone or RECDdirect).

Figure 14
Mean RECD measured using RECDdirect (filled circles) and insert earphone (open circles).

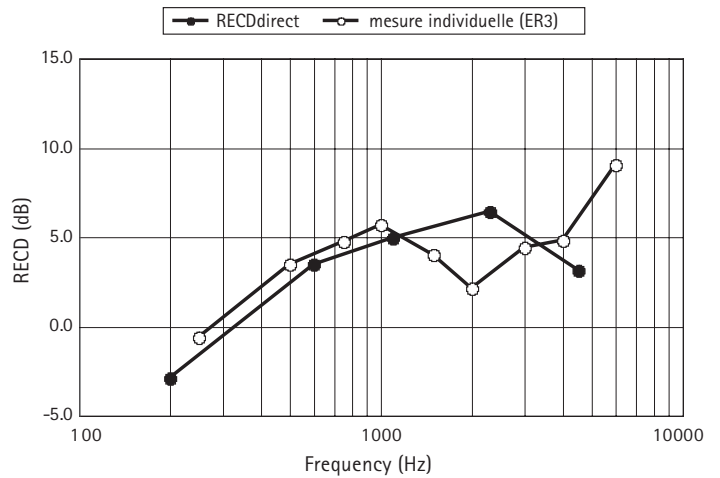
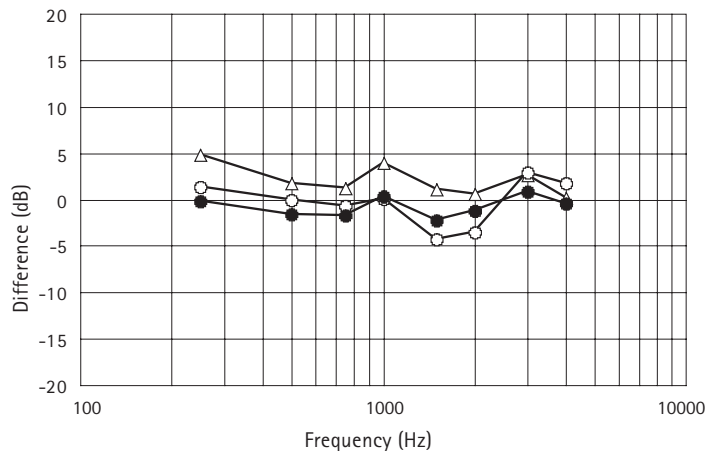


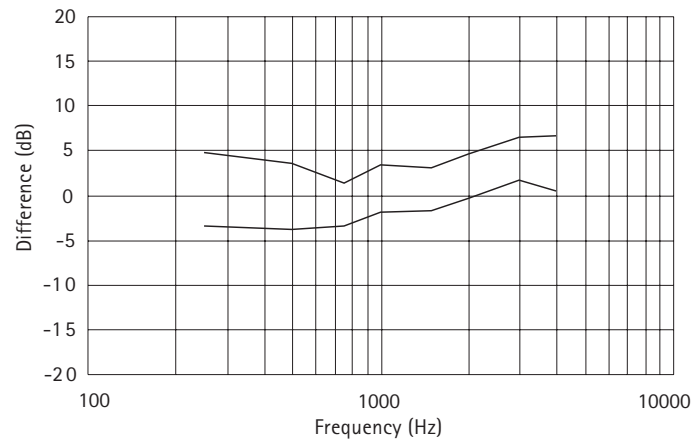
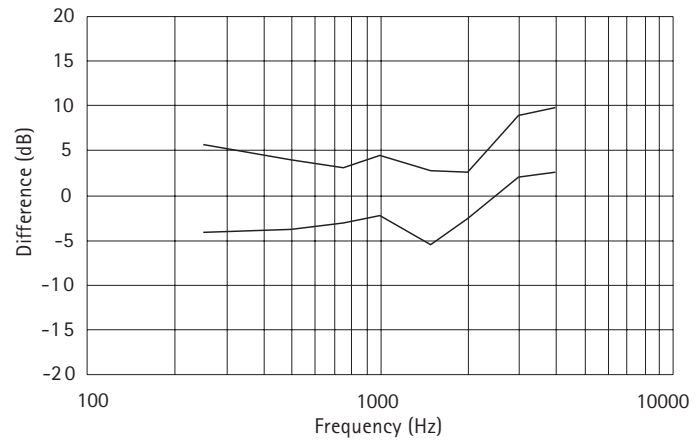
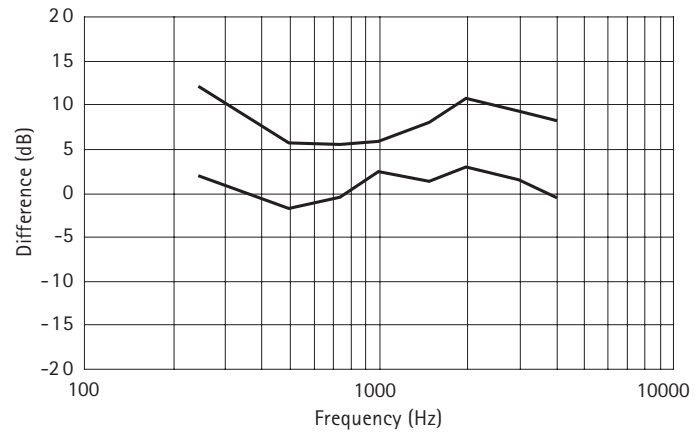
Figure 15
Median difference between DSL target and the measured real-ear responses for the default RECD (open triangles), insert earphone RECD (open circles), and RECDdirect (filled circles).



³⁾In order to make a valid comparison with the DSL target values, a correction for microphone location effects was added to the measured real-ear aided response since this was measured with a reference microphone positioned close to the hearing instrument.

Figure 16

The 95% range for the data in Figure 15 for default RECD (top panel), insert earphone RECD (middle panel), and RECDdirect (bottom panel).



The match to target was then inspected for individual subjects. The 95% range is shown in Figure 16. The deviation was almost always within 5 dB of the DSL target, irrespective of which RECDs were used in the pre-fitting calculations. However, the best match to DSL targets (for median and individual subjects) was obtained when the pre-fitting settings were calculated using RECDdirect data. These data suggest that the RECDdirect fitting tool is a valid procedure for selecting the initial settings of the hearing instrument. The actual real-ear SPL can be verified in the usual manner by adding the RECD values (obtained with RECDdirect) to the 2-cc coupler response of the hearing instrument. Finally, despite the success of the RECDdirect fitting method in the above study, it does not replace the need for an RECD obtained with an insert earphone when deriving the real-ear SPL of audiometric data.

Conclusions

The acoustics of the external ear differ significantly between infants and adults and from one infant to another. These differences have important implications for audiometric assessment and hearing instrument fitting. The solution is to integrate the RECD measurement into the assessment and fitting process of infants and children. A simple and efficient procedure for measuring the RECD has been available for many years. However, implementation into routine clinical practice has been somewhat slower than desired. Recent developments such as the RECDdirect fitting tool have the potential to close the gap between theory and routine clinical practice.

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