Relationship between DPOAE and behavioural pure-tone thresholds

The relationship between DPOAE level and behavioural pure-tone threshold - or rather the lack of it – is strongly debated. Earlier, it was common to define confidence limits to determine the degree of certainty with which any measured response could be assigned to either normal or impaired hearing (Gorga et al., 1996, Gorga et al., 2000a), or to define a 'DPOAE detection threshold' as the stimulus level at which the response equalled the noise present in the instrument (Dorn et al., 2001).

However, since the noise is of technical origin (e.g., microphone noise) the threshold evaluated in this way does not match the behavioural threshold. A more relevant measure is the intersection point between the extrapolated DPOAE I/O-function and the primary-tone level axis at which the response's sound pressure is zero and hence at which outer hair cell amplifiers are inactive (Boege and Janssen, 2002, Gorga et al., 2003). A linear dependency between the DPOAE sound pressure and the primary-tone sound pressure level is present (Boege and Janssen, 2002) when using the "scissor" paradigm for eliciting DPOAEs (Kummer et al., 2000). Because of the linear dependency, DPOAE data can be easily fitted by linear regression analysis in a semi-logarithmic plot, where the intersection point of the regression line with the *L*2 primary-tone level axis at *p*dp = 0 Pa can thus serve as an estimate of the DPOAE threshold (Fig. 3). The estimated DPOAE threshold *L*dpth is independent of noise and seems to be more closely related to behavioural threshold than the DPOAE detection threshold (Boege and Janssen, 2002, Gorga et al., 2003, Janssen et al., 2006). Extrapolated DPOAE I/O-functions are used to determine DPOAE thresholds which can be displayed in an audiogram form (DPOAE-audiogram). In Fig. 4a DPOAE I/O-functions at 1, 2, 3, and 6 kHz are shown in double- and semi-logarithmic plot obtained in a high-frequency hearing loss ear. At *f*2=1, 2, and 6 kHz hearing threshold estimation could be done using extrapolated DPOAE I/O-functions, since at these frequencies at least 3 measuring points were available. At *f*2=3 kHz only two valid DPOAEs (at L2 = 55 and 60 dB SPL) were measurable. At this frequency a simplified estimation was done corresponding to the lowest L2 where a valid response could be obtained minus 15 dB. Circle symbol in the DPOAE audiogram means threshold estimation by means of extrapolated DPOAE I/O functions, square symbol means simplified estimation, arrow symbol means no DPOAE are measurable and thus the hearing loss is higher than 50 dB HL (Fig. 4b). The DPOAE slope profile gives information on the loss of compression of the cochlear amplifier when the slope of the I/O-function is calculated between *L*2 = 40 and 60 dB SPL (Fig. 4c). With increasing hearing loss the slope increases indicating increasing loss of compression.

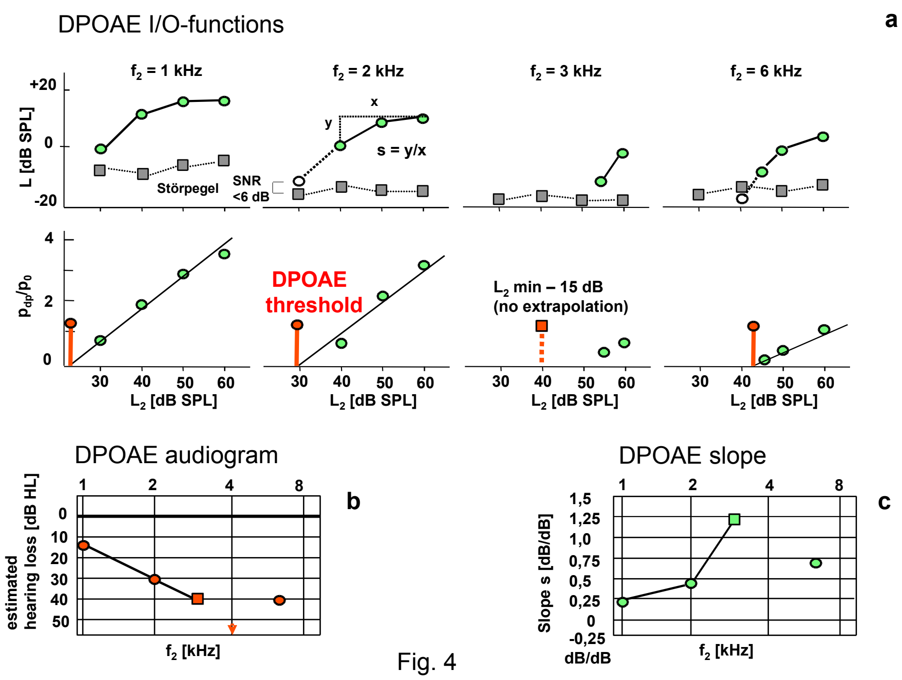

Fig. 4

Otoacoustic emissions (TEOAE and DPOAE) are widely regarded as being suitable for screening in newborns and infants, as they are not present in the case of outer hair cell dysfunction. (e.g. Kemp and Ryan, 1991, Gorga et al., 2000b, Norton et al., 2000b, Norton et al., 2000a). The premise for this approach is that inner ear hearing-loss always includes OHC damage or malfunction. However, conductive losses also cause “refer” results under screening conditions, mainly due to the attenuation of an existing OAE signal.

A major disadvantage of using OAEs in screening protocols is a lower validity as compared to ABR methods (Norton et al., 2000b, Barker et al., 2000). This is especially true in populations with a high prevalence of slight threshold elevation due to a temporary sound-conductive hearing loss, as it is found in term neonates in the first 36 hours of life because of Eustachian tube dysfunction or amniotic fluid in the tympanic cavity or due to a persisting sensory hearing-loss in premature and neonatal intensive care unit infants. In order to maintain a high sensitivity, the specificity may be reduced dramatically, making a screening procedure inefficient. To avoid high referral rates, OAE referrals should be followed up with an ABR screening before diagnostic assessment, i.e., two-stage screening (Rhodes et al., 1999, Norton et al., 2000a). DPOAE-audiograms may be an alternative means for revealing a temporary hearing loss in the early postnatal period caused by a temporary sound conductive hearing loss due to amniotic fluid or Eustachian tube dysfunction. When applying DPOAE audiograms before ABR screening, time and costs can be saved in those babies where DPOAEs are measurable and thus no additional ABR is needed.

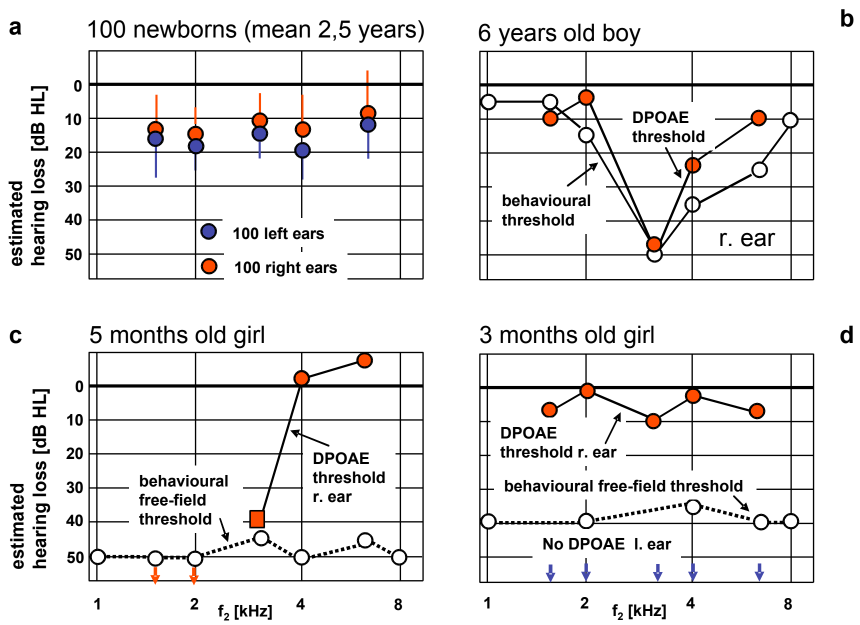

Fig. 5

Fig. 5a shows mean and standard deviation of estimated DPOAE thresholds measured in 100 left and 100 right ears from 100 newborns at neonatal care unit. Mean age was 2.5 days. There was no significant difference between left and right ears. Results indicate that DPOAE threshold measurements can be done under hearing screening conditions. The average threshold was lower than 15 dB at all test frequencies. Mean test time for getting an DPOAE audiogram per ear was about 4 minutes. The high standard deviation may be due to temporary sound conductive problems. When considering the one day old babies only an elevated threshold at high and low frequencies is present (not shown in Fig. 5). This finding can be attributed to middle-ear problems due to amniotic fluid in the tympanic cavity and Eustachian tube dysfunction. For example, in a 3 days old neonate with a “pass” response after ATEOAE screening the DPOAE-audiogram indicated a low frequency hearing loss. The DPOAE-audiogram 83 days later revealed normal hearing function. In this baby, Eustachian tube dysfunction could have been the cause for the hearing loss within the first days of life where middle ear stiffness is increased and therefore low frequencies are affected. In another newborn with a “refer” ATEOAE screening response the DPOAE-audiogram indicated a hearing loss of more than 50 dB at 1.5, 2, 3, and 6 kHz and a 40 dB hearing loss at 4 kHz. The second measurement 11 days later revealed normal hearing function. In this baby, both a low- and a high-frequency sound-conductive hearing loss might have been present where middle-ear stiffness is increased due to Eustachian tube dysfunction and thus low frequencies were affected and middle-ear mass is increased due to amniotic fluid and thus high frequencies were affected.

DPOAE-audiograms can thus be applied in newborns to reveal a temporary sound-conductive hearing loss or to detect a persisting cochlear hearing loss. In follow-up diagnostics, DPOAE-audiograms can serve as an advanced tool for bridging the gap between screening and audiological testing.

Also, DPOAE-audiograms are useful in pediatric audiology since they provide frequency specific information about the hearing loss in a couple of minutes. Thus, they have an advantage over TEOAEs or click-evoked ABRs (because they can not quantitatively assess cochlear hearing thresholds at distinct test frequencies) and ASSRs (because their measuring time is extremely long). Three case examples shall demonstrate the efficacy of DPOAE-audiograms in pediatric audiology (Fig. 5 b, c, d). In a 6 years old boy, pure-tone audiogram and DPOAE-audiogram exhibited a close correspondence (Fig. 5 b). However, in the younger children there was a high discrepancy between the behavioural free-field audiograms and the DPOAE-audiograms. The free-field audiogram of a 5 months old girl (Fig. 5 c) indicated a hearing loss of 50 dB HL in the entire frequency range. However, the DPOAE-audiogram revealed a hearing loss only in the mid and low frequency region. Fig. 5 c shows the free-field audiogram and the DPOAE-audiograms of the left and the right ear of a 3 months old girl. The free-field audiogram indicated a hearing loss of 40 dB HL. In the left ear no DPOAEs were measurable indicating that the hearing loss must be higher than 50 dB (arrows in Fig. 5 d). In the right ear the DPOAE-audiogram revealed normal hearing.

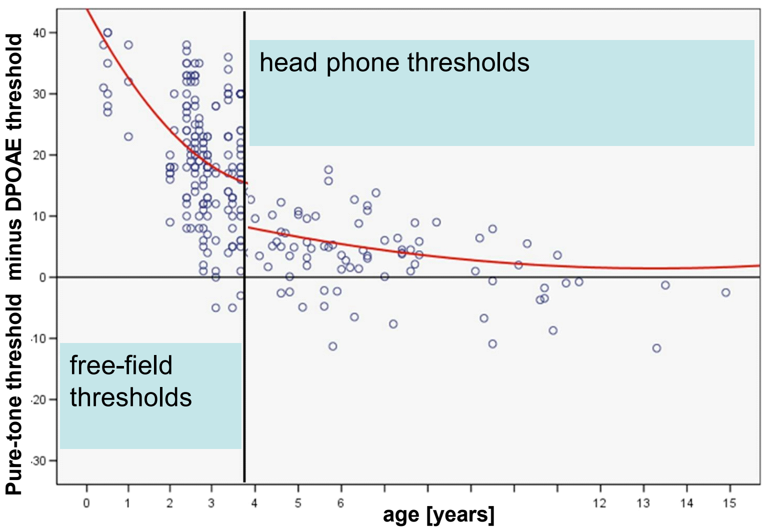

Fig. 6

DPOAE-audiograms may assess cochlear hearing loss more precisely than behavioural tests, especially in infants where the conditioned free-field audiogram does not reflect the real threshold. This is shown in Fig. 6, where the difference between estimated DPOAE threshold and behavioural pure-tone threshold is plotted over the child's age. The younger the child the greater is the difference between the behavioural and the objective measure. Moreover, unilateral hearing loss can be detected. DPOAE-audiograms are obtained by an automated measuring procedure with simple handling and short measuring time. No sedative is necessary in most cases. It should be emphasized that DPOAEs only reflect outer hair cell functionality and therefore are not present at a hearing loss higher 50 dB HL. However, the incidence of a hearing loss higher than 50 dB is low. Thus, in most of the children DPOAE are measurable. In cases where DPOAEs are not measurable ABRs or ASSRs have to be applied.