Facts and pitfalls in newborn hearing screening programs – don't waste money!

What is the aim of newborn hearing screening?

The aim of every screening procedure is to separate the members of the target group into different categories. Often, the separation is binary – thus only two categories exist like "yes" or "no".
The target group of newborn hearing screening are newborns. The goal is to find out whether there is a hearing problem or not. The screening result then is "pass" (no problem) or "refer" (problem possible).
The reason to perform newborn hearing screening is to detect a hearing disorder as early as possible and to take action against by supplying the child with a hearing aid or a cochlear implant. Early identification and intervention are crucial for the child's speech development. If hearing disorders remain undetected maturation of the neural structures of the hearing organ is restrained or does not take place at all - e.g. in ears in which sensory transduction is completely distorted. It is known that auditory nerve fibres die when there is no input signal to the auditory pathway. If that happens, no therapy is possible neither with hearing aids nor with cochlear implants. The focus on early detection and intervention relates to the importance of hearing capability in view of the development of speech and language skills, which have an impact on educational, economic, and social abilities. It is known that children with a hearing loss have language and educational delays. Lack of educational achievement often results in lifelong personal and societal monetary effects. Therefore, early detection of a hearing loss and early intervention are not only beneficial for the child concerned but also save a lot of money. When considering benefit-cost ratios, universal newborn hearing screening is a worthwhile investment for society as benefits outweigh screening costs (for more detail see Early Childhood Deafness (editors: Kurtzer-White and Luterman), Baltimore: York Press Inc (2001

What tests are used for newborn hearing screening?

Newborns are unable to evaluate their own hearing impairment. Therefore non-cooperative tests are used based on otoacoustic emissions and / or auditory brainstem responses. Both principles provide an acoustic stimulus to the baby and measure the physiological response to this stimulus. Dependent on the type of stimulus or response, the types of tests are differentiated. TEOAEs are measured when a transient stimulus is applied to the cochlea and the *"echo"* of the cochlea is measured. If the echo is present after the application of the stimulus (based on some statistical evaluations), the result is either pass or refer. (Please note that it is not an echo from a passive system, but an active response which can be measured.)
DPOAEs are measured when sinusoidal stimuli are presented to the cochlea and the response is measured. Based on statistical evaluation, for each frequency, a pass or a refer result can be differentiated. The overall pass or fail is deducted from these individual results.
ABR (or AABR) is measured, when broadband chirps or transient clicks are presented to the *ear*. The result is recorded via electrodes which have to be attached to the scalp of the patient during the measurement. Based on statistical evaluation, the presence of a response in the electrical signal leads to a pass – otherwise a refer is indicated.
For all these tests, devices of different brands and from different manufacturers can be used. These devices use different technology or algorithms to detect these signals and might offer different 'reliability'. However, all devices provide in the end a screening result: either 'pass' or 'refer'.

Why is it very unlikely that a 'refer' baby does not hear properly?

The probability of being non-hearing when being diagnosed as refer with a standard screening procedure is less than 7%!
The likelihood can be increased if you add diagnostic value to the initial stage of diagnosis. Additional information will be provided in the following section about specificity and sensitivity on the next page.

Why is it a waste of money to invest in newborn hearing screening devices without having the solution for tracking and follow up of the referrals in place?

Economically it is cheaper to pay for all cost related to undetected hearing loss in humans than than screening every newborn. This is true on the short term over a few years only. Only when adding up tracking software or increasing specificity by using diagnostic devices, the investment becomes worthwile. How to speed up this process and how to set up a full solution from concept to reality is described in the following pages.

What is the sensitivity and specificity of a test method / conduct of a test procedure?

The terms sensitivity and specificity are often used to compare the ability of a test method (or combination of tests or procedure) to another test method in order to find out which test method is more suitable to be used to answer the 'classification' question. Classification means to separate a population or group into two different classes.

All test procedures measure something (most often a symptom or side effect of the root cause to be detected) – but it is very unlikely that a measurement procedure record the root cause directly. But even if one is enabled to acquire the root measure directly – technical problems or bad measurement conditions can have an influence on the result of a measurement/recording. Therefore, the result of the measurement is not always exactly displaying the reality.

With respect to hearing, the measurement of OAE is only measuring the response of a nonlinear system – the cochlea. If nonlinearities can be measured – or if OAEs are present – then we talk of a PASS or VALID result in a screening setup. With PASS we mean, that the hearing is supposed to be normal. If no OAE could be detected (invalid result or refer result), then we assume, that the hearing can be impaired.

But again, the PASS as well as the REFER are the outcome of a technical measurement procedure and not the root itself. If a baby is screened and having a REFER result, it is not 100% sure, that there is a hearing problem! Dependent on the method and device used it can even be **very unlikely** that a "REFER baby" is a not hearing baby! In order to understand that a short explanation on how to describe the quality of a classification method is needed.

How to describe the quality of a screening method?

To get a better 'feeling' on the 'quality' or in order to 'quantify the quality' of a device or algorithm, the terms 'Sensitivity and Specificity' are often used.

Sensitivity (or true positive rate or hit rate) characterizes the portion of the people who really have the illness out of the amount of people who are identified by the test procedure / classification as being ill.

Specificity (or true negative rate or correct rejection rate) describes the ratio of the people who do not have the illness and are identified by the test correctly as not having it (see http://en.wikipedia.org/wiki/Sensitivity_and_specificity).

It would be perfect to have an algorithm or device with a 100% sensitivity and a 100% specificity. But that is not possible in general. Therefore most of the algorithms are often tuned to achieve nearly 100 % sensitivity in order not to miss anybody who suffers from the illness and then optimize the procedure to get a very high specificity. How can this be achieved? A simplified example: a population shall be screened for 'Diabetes mellitus'. The test method chosen is a simple counting of sugar crystals in the urine of the patient. If sugar crystals are present in the urine, the illness is present (REFER), if there are no sugar crystals in the urine, the illness is not present (PASS).

In order to reach 100% sensitivity level in this test method, the threshold of the sugar crystal counter is shifted to 1 unit. That means: if a single sugar crystal is detected, the result is REFER.

It is easy to understand, that it might be possible that some people do not suffer from diabetes although the given test method described them as REFER – because a single sugar crystal might be quite acceptable. But it is also clear, that no single patient with the illness is missed. So the sensitivity is 100%, the specificity is maybe poor. In reality, sensitivity and specificity are also always corrupted by the test environment and test conditions (spoiled urine, wrong tools, faulty analysis…). Additionally: not all human beings have the same physiological thresholds. Dependent on age, weight or other physiological side effects, the same quantified threshold can be significant for the illness in one person but not in another person. The amount of sugar crystals in urine is only a symptom which can be measured as an indicator for the illness itself!

For all that reason, the threshold is shifted to about 500 mg of glucose per liter of urine. Having this new threshold the specificity increases to about 70% while sensitivity reaches 80%.

Coming back to newborn hearing screening:
Modern screening devices using OAE methods have a sensitivity of near to 100%. The specificity is about 97% if the device is used very well and the measurement conditions are perfect. In general, when newborn hearing screening programs are started, many users do have some difficulties in applying the devices correctly to the patients (e.g. inserting the probe correctly to a tight fit to the babies' ears or doing the test immediately after birth, when amniotic fluid is still in the middle ear and ear canal). This normally reduces the specificity of the test to 80% in the starting phase. Only after a lot of training and awareness campaigns over many months, specificity will reach 97%. But let's assume the good numbers now and think about, what does it mean if a baby has received a refer result? What does that imply in reality?
Having a specificity of 97% means that 97 out of 100 screened babies have a pass result and 3 out of 100 have a fail result. Out of historical data we know that in a normal population the incidence of a newborn having a hearing loss is nearly 2 in 1000. That means 2 babies have hearing loss and 998 have no hearing loss.
If all these 1000 babies were examined with a hearing screener with the given specificity, we know that 3 out of 100 have a fail. That means 30 out of 1000 newborns have a fail result indicated by the screener. But only 2 of these 1000 babies are really suffering from the illness!
We assume that sensitivity is 100%, which means that the 2 non-hearing babies are in the group of 30 refer babies.
How can we detect the 2 real patients out of the group of 30? What is the real probability that a 'refer baby' is a non hearing baby?

It now becomes clear that it is very unlikely that a refer baby is not hearing – if it is analyzed only with a screening device. As only 2 out of 30 are non hearing in reality, the probability of being non hearing when being diagnosed as refer is less than 7%!

Why is PATH medical entitled to know about the benefits and pitfalls in newborn hearing screening programs?

PATH medical GmbH is a Germany based company with focus in development not of products but of solutions in the field of objective and subjective audiometry. Although the company was founded only in 2007, it owns a combined working experience of over 100 years in OAE and ABR algorithms! The team at Path Medical has been responsible for the development of OAE newborn screening applications since 1998. PATH engineers developed handheld screeners, EchoScreen (now distributed under Natus' brand) and the AccuScreen (distributed under Madsen's brand). In addition to that, since 2002, PATH engineers developed the automated data exchange to a UNHS tracking systems in order to follow up referred babies and increase the quality of service in regional and national UNHS.
Since 2004, more than 2 000 000 newborns' data were processed with PATH medical's tracking software in Germany only. Today, pathTrack is used in seven federal states in Germany and Italy. In more than five nations pathTrack is to be evaluated at the moment (Nov 2013).
Since 2010, PATH medical offers the handheld but diagnostic device Sentiero, which is suitable for follow up of traditional newborn screening but in addition to that it enables the user to perform diagnostic tests from day 0 after birth.
This overview on data on universal newborn hearings screening programs (UNHS) is not seen from an academic point of view – though literature from research is referenced. The approach is a practical one and thought as a means of inspiration for opinion leaders to tackle the hurdles while setting up a quality driven UNHS instead of a politically driven program.

That is very important to know – as well as it is important to tell the parents not to be too anxious about their baby at this stage of the diagnosis!

It is also very clear now, that a screening program MUST NOT STOP at this stage of the diagnosis!
The goal of universal newborn hearing screening programs is NOT to categorize babies into "able to hear" or "not able to hear" (with the very low likelihood of screening results). The goal is to start a therapy as early as possible if it is really needed. Every baby should be enabled to acquire speech in due time and acquire all needed skills in order to participate and interact in society.

For this reason, every universal hearing screening program just STARTS after the initial screening phase. *Or to phrase it differently*: Every universal hearing screening program must be prepared to take care about the refer babies BEFORE purchasing the first screening device!
Why? Many countries proved this fact already and we should learn about the errors of already implemented screening procedures when we set up a new one in a new region. To support this claim here, let's go back to the numbers in the following section!

What is the economical benefit of a UNHS and why do we loose money by buying simple screeners only?

If we started an UNHS program by purchasing screening devices first, then we would have about 30 'refer' patients out of 1000 newborns. If we did not follow up these refer patients, then we would not know which 2 out of the 30 really have a problem until they grow up and reach the age of about 2 or 3 years. If we started therapy at this age only, we should have saved the money for the screening devices in the first place as we did not reach any advantage yet. The saved money could have been invested in special schooling or to support handicapped people instead. What numbers are we talking about?
Schroeder et al. (2006) reported that the potential saving of expenses arising for a single person suffering from a profound hearing loss was about $11,108 per year when diagnosed with UNHS. That means a person with an average lifespan of 79.2 years, the lifetime savings of applying the UNHS totals to $879,780 (see Porter, Neely, Gorga 2009 – taken from Ear Hear. 2009 August ; 30(4): 447–457).
To be clear: these is the savings for a single person in average – but given the assumption, that the state really cares about the person or that the community believes that a human being's life contribution can be counted in $. Anyhow – the savings to the social community only occur if the real non-hearing baby is detected out of the group of 'refer' babies.

Therefore we must ask every of the 30 refer babies to go to a follow examination in a follow up center or specialized clinic. Dependent on the infrastructure and the country or region, it might be very difficult that all of the 30 refer patients will show up for follow up. We know from UNHS programs in the US, that sometimes only 50% of the refer patients show up for follow up (exactly 46,3%, N= 32,496 , CDC, 2008 cited from http://www.asha.org/policy/tr2008-00302/). What does that imply?

What is the probability that the 2 really non hearing babies are in the group of 15 babies showing up (50 % of the group of 30)? The probability is only 25%! The probability that we miss at least one is 75%!

What ratio for follow up do we need in order to have a probability of 90% to find the 2 non hearing babies under the given circumstances? 95% of the follow up group must come back – that would mean: 29 babies (exactly 28.46) of the 30 refer babies must show up.
Is that realistic? Literature tells us about referral rates from 2 – 12 %. (Cox and Toro, 2001; Lin et al., 2003; Owen, Webb, and Evans, 2001; White, 1997 taken from: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2705472/) and in the starting phases of UNHS programs, the referrals increase to higher than 20% - most of all due to a lack of training and preparation as already mentioned before.

Taking into account the economical figures mentioned above, it becomes clear, that nobody should start with a screening program without having the tools to deal with the referrals first!
One way out of this dilemma would be to set up a universal tracking program to follow up the referrals with the help of software tools (see pathTrack facts, http://pathme.de/images/stories/tracking_10facts.pdf) together with appropriate tools for follow up diagnostics. This takes time and is hard work to do. It needs staff with dedication to their job. The results of the tracking effort will only be visible after 3-4 years (with the decrease of hard of hearing children and slow speech acquisition) but it is clear that the cost is much lower than the estimated cost of undetected hearing loss. E.g. for a region of 50 000 newborns per year in Germany 1,5 people were employed in a tracking centre to follow up the babies. In Germany, labor cost is high and could reach 100 000 EUR per year. They needed a budget for travelling and giving lectures and training. Also travelling is expensive in Germany – about 25 000 EUR per year. And they needed a software to support their activities (pathTrack) together with a technical maintenance contract, computers, licenses etc, which cost about 25 000 EUR a year. This sums up to 150 000 EUR per year. In comparison to saving cost for about 100 non–detected non–hearing babies per year in the group of 50 000 newborns (100 * 11 000 $ = 1 100 000$) The saving per year is more than 650 000 EUR. A nice side effect has been in Germany and is always seen whenever dedicate people in the tracking center care about their tasks: the quality of screening and therefore the specificity of the screening increases from maybe 80% in the starting phase to 97%! This again reduces the task for the tracking staff to follow up false refer babies and they can focus on training newcomers, nurses etc.
So it seems to be a clear and simple calculation so far. But we also have to take into account that all refer babies will be sent to a follow up site which involves additional cost again. All refer babies' families will have to organize a travel with the baby to the follow up site – the more difficult the infrastructure is, the more unlikely it will be that they will show up. But let's assume, that our tracking staff is dedicated enough to convince them to show up!

Would it be cheaper to refrain from newborn hearing screening programs or pay for the collateral cost for the whole society?

Based on the economical aspects, it is shown, that the cost of treating every referred patient with a full diagnostic instrument involves costs of about 400$ per patient (see Porter et al 2009). They might do sedation, full blown ABR measurements, conformational OAE.
For every 1000 newborns that would mean that 30 will show up for follow up and cost 12 000 $. In the region cited above with 50 000 births a year, that would mean expenses of another 600 000$ (about 450 000 EUR) per year. On the other hand, the medical doctors would not declare that as a cost of 600 000$ but as an income … but that's a different story to be told later.
To repeat and summarize so far: if we did not have an UNHS program in our region of 50 000 births per year, then we would have cost of 1 100 000 $ per year. As we do have a UNHS (including tracking) in the same region we do have cost of 150 000 EUR + 450 000 EUR = 600 000 EUR. The difference is becoming only 200 000 EUR – but still prominent. Now we have to keep in mind, that somebody needs to purchase the screening devices as well as the diagnostic devices for follow up – at what cost? Including the cost to purchase a screening device, workforce etc it can be assumed the cost per newborn would be 21 EUR In the community with 50 000 births, this sums up to 1 050 000 EUR. This number was not taken into account so far – now it is clear that we should *actually* not start a UNHS program at all! It is cheaper to have the cost for undetected hearing loss babies than screening and following up all the newborns.
Full stop – end of the story?

NO. First of all – the yearly savings of a baby detected with UNHS will sum up also the other years. As mentioned above, in an expected lifetime of 79.2 years, the savings of applying the UNHS totals to $879,780 per person – within our region of 50 000 newborns per year having 100 non-hearing babies, that would mean 879 780 000 $ in total for the newborns of the first year. Next year, the same amount again and so on… but maybe a country is not so concerned about the non hearing babies in the first place and life expectation is not so long too … Shall we implement a UNHS from the beginning?

Besides social and ethical aspects, which are in strict favor of providing these services to the public, there is a simple way to have an economical benefit visible while avoiding high expenses in the first place. The solution is to bring down the initial false referral rate to a reasonable degree and to avoid having all referral babies to 'suffer from' the full blown diagnostics (at 400$ per patient).
Certainly, the political problems start here in countries where some groups might have an interest to keep cost high on both sides – for screening devices as well as for diagnostic devices. But in countries where you can start from the beginning – it might be simple. The following calculation shall demonstrate this.

How can we save cost while increasing quality of service during the process of setting up an universal newborn hearing screening program (UNHS)?

It is very difficult to organize and persuade 95 % of the referrals to join into the conformational diagnostics If the babies do not show up at due time for conformational diagnostics, valuable time of therapy might be wasted and again the investment cost of early intervention screening gets lost again. No advantage for our economical calculation of the pros and cons. "The mean age of confirmation of HL for infants whose mothers had graduate degrees was more than seven months earlier than for mothers whose highest level of education was at or below high school." (cited from Holte et al 2012: http://www.uiowa.edu/~ochl/holte-et-al-2012.pdf)
So this becomes the most prominent problem.

If less than 95% of the referrals do not show up, there will not be a significant change in detection and treatment of hearing loss children/babies and therefore the investment in screening devices is an economical loss.

When introducing an UNHS it is clear now out of the previous arguments that we must start with the investment of tracking staff and follow up equipment first. The reason, why in the old days screening devices where strictly separated from diagnostic devices was often because of the fact that diagnostic devices were stationary and staff and patients had to go to the devices' place. Also diagnostic devices often needed the babies being sedated – that increased costs as planning and organization involved many people.
Only screening devices were thought of being capable to be brought to the babies' site and were thought of being simple enough that non-audiological-experts can operate it in a nursery.

Nowadays there are handheld devices available which offer the ability of conformational diagnostics in ABR, ASSR, TEOAE or DPOAE while being operated as easily as a screening device or a Smartphone.

The advantage is also, that with the same devices after an initial screening protocol failed/referred, another diagnostic protocol can be used in the same session – without changing any setup. Having an additional test after the screening test will reduce the false fail rate (see also explanation on ABR, ASSR, DPOAE, TEOAE methods and protocols and case studies given in HowToManual, see http://old.pathme.de/download/MA_How_Two_ABRonly_engl_rev02.pdf)

Some advantages are that the same device with it's diagnostic features can be used in the stage of early intervention (EI) before the mother leaves the hospital with the baby – so 100 % of all newborns and all referrals can be tested again with diagnostic protocols without the need of making another appointment.
Additionally, the same devices have a calculated cost per patient of about 22 EUR which includes that in about 3% of the patients an immediate conformational diagnostics has to be conducted.

Another advantage is, that with the same devices, the follow up examination can be done. No need for full blown diagnostic devices and high cost (of 400$).
Even if the follow up examination has to be done after a few weeks again (amniotic fluid, collapsed ear canal) etc. the cost is similar to the cost of the diagnostics in the initial phase.

All these measures lead to a reduced false refer rate – that implies that not 30 babies out of 1000 newborns will have an unclear status after EI, but maybe only 5-10 babies. This means 250 – 500 referrals for the follow up in a group of 50 000 newborns / year. This implies in numbers the following cost of initial diagnostics:
50 000 * 22 EUR = 1100000 EUR
500 * 22 EUR = 11 000 EUR
150 000 EUR for tracking center – the focus will be on training as follow up/number of unclear cases is reduced tremendously.

- ➔ 1 261 000 EUR / year with an UNHS with conformational diagnostic devices…
- ➔ saving 450 000 EUR for follow up diagnostics and different devices (cost of anesthesia is not included)
- ➔ total cost of investment / year 800 000 EUR.
- ➔ As a reminder: undetected hearing loss costs 1 100 000 $ per year = 810 000 EUR.

This shows that savings can be achieved even in the first year without taking into account life expectation and cumulated cost over multiple years as stated above.
Additionally:

- ➔ The same devices can be used for standard ENT examinations for all age population with additional reimbursement effects.

Sometimes it seems too hard for institutions to think about that long timespan and to invest in this sustainable stage of the follow up. Therefore, the simple investment in screening devices for newborn screening is easier to do and is often enough to show in the public (politicians or politically active scientist are often key opinion leaders in this investment tenders).
The hope is, that this document can contribute to make things more transparent for key opinion leaders and economically responsible staff.

What could be part of a conformational diagnostic of newborns and why?

The aim of paediatric audiological evaluation of hearing capability in newborns who are referred from newborn hearing screening (follow-up) is to exclude a hearing deficit or to confirm and identify a hearing loss with the determination of its degree in cases where a hearing deficit cannot be excluded. Main purpose of follow-up diagnosis is to establish a working hypothesis for a successful hearing aid fitting.

Subjective tests are only able to assess disorders of sound processing as a whole. Tympanometry, otoacoustic emissions (OAEs), and auditory brain stem responses (ABRs) in combination, allow for a differentiation between sound-conductive, cochlear, and neural hearing loss. Like tympanometry, OAEs are a fast and easy-to-handle method. Registration of transiently evoked otoacoustic emissions (TEOAEs) is an indispensable part of follow-up diagnosis. In cases of conspicuous TEOAEs, measurement of distortion product otoacoustic emissions (DPOAEs) has to be imperatively performed, preferably, at close-to-threshold stimulus levels. In the following, an overview is given on possibilities and limitations of OAEs to determine type (site) and degree of a hearing loss. Especially, the efficacy of extrapolated DPOAE I/O-functions for getting quantitative and frequency-specific information on the hearing loss is discussed.

OAEs are a fast measure to confirm normal middle ear and cochlear function. This is the case if OAEs are present over a wide frequency range. In case of missing OAEs middle ear or cochlear (OHC) pathology is likely. OAEs then should be followed by tympanometry. If the tympanogram is abnormal, a sound-conductive hearing loss is likely. If the tympanogram is normal, and OAEs are abnormal or absent, then a cochlear disorder is likely.

If both tympanogram and OAEs are normal, ABRs are needed to reveal whether there is a cochlear (inner hair cell) or neural pathology. For example, in auditory neuropathy, where synchronization of neural activity is malfunctioning (either due to inner hair cell synaptic or neural dysfunction), normal OAEs and abnormal ABRs occur [5, 6].

Especially for hearing aid adjustment in infants, a quantitative evaluation of the hearing loss is necessary. When elicited by high stimulus levels (which is common in clinical practice), TEOAEs are absent at a cochlear hearing loss exceeding 20 dB HL, whereas DPOAEs are absent only at a cochlear hearing loss exceeding 40-50 dB HL. Thus, when using TEOAEs and DPOAEs elicited at high stimulus levels only, a rough estimate of the hearing loss is possible. For example, when TEOAEs are absent and DPOAEs are present, then the hearing loss is suggested to be not more than 30 dB HL.

The relation between DPOAE level and auditory threshold 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 [7, 8], or to define a 'DPOAE detection threshold' as the stimulus level at which the response equaled the noise present in the instrument [9]. However, since noise superimposes the response threshold evaluated in this way does not match the behavioral threshold.

A more reliable measure is the intersection point between the extrapolated DPOAE I/O-function and the primary-tone level axis [10, 11]. 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 L2 primary-tone level axis at pdp = 0 Pa can thus serve as an estimate of the DPOAE threshold. The estimated DPOAE threshold is independent of noise and seems to be more closely related to behavioral threshold than the DPOAE detection threshold [10, 11].

It should be emphasized that a linear dependency between the DPOAE sound pressure and the primary-tone sound pressure level is only present when using a special stimulus setting - the "scissor" paradigm [12] - which accounts for the different compression of the primary-tone traveling waves at the f2 place [10, 12-14].

Due to the steep slope of the traveling wave towards the cochlear apex, maximum interaction site is close to the f2 place. Thus, OHCs at the f2 place contribute most to DPOAE generation. The number of OHCs contributing to DPOAE generation depends on the size of the overlapping region, which is determined by the primary-tone level setting L1|L2 and the frequency ratio f2/f1 of the primary-tones. To preserve optimum overlap of the primary-tone traveling waves at a constant frequency ratio f2/f1=1.2, the primary-tone level difference has to be increased with decreasing stimulus level resulting in a L1|L2 setting described by L1=0.4L2+39 dBSPL (scissor paradigm). When converting DPOAE sound pressure level

(SPL) to hearing loss level (HL), the estimated DPOAE thresholds can be plotted in an audiogram form (DPOAE-audiogram).

DPOAE-audiograms can be applied in babies with a refer result in newborn hearing screening to reveal a transitory sound-conductive hearing loss due to Eustachian tube dysfunction and/or amniotic fluid in the tympanic cavity or to confirm a persisting cochlear hearing loss in follow-up diagnosis.

DPOAE-audiograms can be obtained by means of an automated measuring procedure with simple handling and short measuring time. At normal hearing (< 10 dB HL) a DPOAE-audiogram can be obtained in 2 or 3 minutes. At slight hearing losses (10 – 20 dB) measuring time is longest (up to 7.5 minutes), because DPOAE amplitude is low but DPOAEs are present at almost all primary tone levels. The higher the hearing loss the lower is the number of primary tone levels at which a valid DPOAE can be measured. Consequently, the shorter is the measuring time. Thus, measuring time decreases rapidly at a hearing loss higher than 20 dB HL, about 3 minutes at an average pure-tone hearing loss of 40 dB HL, and about 2 minutes at an average pure-tone hearing loss of 60 dB HL.

A reliable diagnosis of a hearing deficit in newborns referred from newborn hearing-screening is only ensured if as many as possible objective audiometric tests are performed: Tympanometry for evaluating middle ear status, otoacoustic emissions for assessing the function of cochlear amplification, and auditory evoked potentials for assessing synaptic and neural functionality. TEOAEs more qualitatively assess cochlear function and are therefore more suited for topological diagnostics. DPOAEs – especially DPOAE-audiograms - provide more quantitative information about the hearing loss.

DPOAE-audiograms are able to assess cochlear hearing loss more precisely than behavioral tests in infants where the conditioned free-field audiogram does not reflect the real threshold. Moreover, unilateral hearing loss can be detected. DPOAE-audiograms can reveal a transitory sound-conductive hearing loss in the early post-natal period. DPOAE-audiograms are an alternative method to tone-burst or chirp evoked ABRs or auditory steady-state responses (ASSRs) in case of a mild or moderate hearing loss. Test time for establishing a DPOAE-audiogram takes only a couple of minutes. Thus, DPOAE-audiograms have an essential advantage over ABRs or ASSRs. DPOAE-audiograms can help to establish a working hypothesis for a more successful hearing aid fitting.

Since DPOAEs only reflect outer hair cell functionality they are not present at frequencies where the hearing loss is higher than 50 dB HL. However, the incidence of a hearing loss higher than 50 dB in children with a hearing problem is low. Thus, in most of the children with hearing problems DPOAE are measurable at least at high stimulus levels. In cases where DPOAEs are not measurable, ASSRs have to be measured for getting frequency-specific information on the hearing loss in the entire range of hearing.
For more detail concerning follow-up diagnostics see the HowTo Manual references in http://pathme.de/index.php/en/support/downloads.

Literature hints in addition to the inline mentioned weblinks:

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