Development of pure-tone auditory threshold in school children

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The overwhelming majority of publications concerning hearing in children is related to diseases, but normal development of hearing attracts little attention. Normal hearing, as defined by ISO 7029, refers to persons at the age of 18. While aging effects of hearing may be estimated by the use of formulas, children are not included. A field-study at a primary school in Germany showed a notably lower hearing sensitivity for children than for young adults. First graders did not hear well, but auditory performance improved with rising age. For validating this result, the first graders of the field study were again tested 3 years later. The second tests showed the expected improvement of their hearing threshold. So the hearing sense starts not with the full capability but underlies a certain development. Maybe training effects are the key to understanding this topic, as in other human skills.

1 Introduction

More than 10 years ago we started to research the human hearing sense to get insight in the origin of hearing impairment and find ways to their prevention. One result was the implementation of a procedure on the basis of self ascertained age lines (from 4400 selected audiograms) to eliminate the aging effect of hearing [1]. This procedure allows the comparison of entire groups of people age independently.

The normal hearing threshold, as established by ISO 7029 [2] for young adults at the age of 18 years was the starting point. Children usually are compared to this standard thresholds for adults. In many cases we found, that children have lots of deviations from normal (adult) hearing. Could that be a presage to a future hard of hearing society?

In November 2003 we started to examine a common primary school to this topic at Giessen (Germany) to learn more about the hearing ability of children. During one week, about 280 pupils and teachers could be tested. The teachers are not subject of interest in the present paper, although they are a very interesting group.

A first scan of the test results showed an obvious trend to better hearing of older pupils. This was surprising, when we had to assume, that hearing impairments are not curable and the whole life with lots of occasions for further damages are ahead.

To evaluate this result, we planned to retest the first graders three years after. In February 2007 this retest took place with 43 members of the former first grade and a new director of the school. The present paper will show and compare the results of the two field studies.

2 Methods and Material

At the beginning of the test procedure a customized questionnaire for children was performed. After that the auditory canals and the tympanic membranes were inspected by a mobile video otoscope type Videolab from Neomed with storing the images to hard disc. With a Grason Stadler tympanometer type GSI 38 the middle ear function was then checked. Pure tone air conducted thresholds were measured with two Maico audiometers type MA 53 and three Hortmann (GN-Otometrics) Audiometers type CA 540. All audiometers were configured with the Sennheisser ear phone HDA 200, which can perform frequencies up to 16 kHz, and calibrated according to ISO 389 [3,4].

Former executed test retest situations showed an improvement of the test results at retest like Axelson et. al. found in 1993 [5]. We deduced therefore a learning effect for recognizing pure tones at the hearing threshold that are not usually heard each day by the children. So we established a so called pre-audiometry to get improved results at the audiometry. This pre-audiometry was performed at the left ear while the audiometry usual starts at the right ear. The advantage of this sequence for the pupils is the experience of recognizing pure tones and to be familiar with the audiometry procedure. Pre-audiometry was performed with the MA 53 while the CA 540 were used for the audiometry. This separation was necessary because software and databases were not compatible. For better separation of test tones from disturbing noise we used pulsed pure tones.

The HDA 200 is a circum-aural earphone with an excellent noise isolation. The housing originates from industrial hearing protectors and the tests could be performed in a quiet room as we did in former studies with good results. In a muting booth or an echo free chamber only the lowest test frequency 125 Hz can be heard a little better. All tests were performed in quiet cellar rooms of the school. During the recurrent breaks we stopped the testing because of the noise at the staircase and the schoolyard. So a short rest for the staff and the pupils was good for new concentration.

For the evaluation some selection criteria were used. Only pupils with normal tympanogram were selected. All Children with otological drain tubes in the tympanic membrane as a consequence of middle ear inflammation were excluded. Some children with obvious acoustic trauma as a result of accidents with toy pistols or fire crackers also were excluded. So the number of selected pupils was reduced to 200 participants.

The age of the children was calculated as the rounded difference between date of test and date of birth. Children from 6.5 years to 7.4 years have an age of 7 years.

For analyze the data Microsoft Excel was used in the latest version 2007. Only low level functions that are implemented in Excel like mean and standard deviation were used. To check the results for statistical significance special functions for different count of group members were explicitly calculated [6].

The hearing threshold was measured at 17 test frequencies with pulsed pure tones. The frequencies were: 125 Hz, 250 Hz, 500 Hz, 750 Hz, 1 kHz, 1,5 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz, 8 kHz, 9 kHz, 10 kHz, 11,2 kHz, 12,5 kHz, 14 kHz and 16 kHz. In the charts are 3 frequencies not shown: 9 kHz, 11.2 kHz und 14 kHz. The last octave from 8 to 16 kHz would be much overvalued with 6 steps. The sound level was controlled in the usual 5 dB steps what is the base accuracy for each measure point.

3 Results

3.1 Comparison of two age groups

From the first field study 200 pupils out of 251 were selected with normal middle ear function and normal tympanic membranes. Two age groups were created: the “younger”, 94 children with an age between 6 and 8 years and an average of 7.4 years and the “older”, 106 children with an age between 9 and 12 years and an average of 10.3 years. The average age difference of the two groups was 2.9 years.

When we view at the averaged measurement values for each frequency at the right ear, which are listed in Table 1 and illustrated in Fig 1, we recognize, that the older age group is significantly ($p<0.05$) better than the younger age group without exception. Table 2 and Fig. 2 show the results of the left ear, where we have one exception. The difference of the averaged hearing levels at 16 kHz have the same tendency but is smaller and differs not significant.

In Fig. 1 and Fig. 2 the standard deviation is not drawn in, but can be read in Table 1 und Table 2. It is conspicuous that the sensitivity improves from low to high frequencies, and the two curves are going nearly parallel. In contrast with that, Schechter et. al. [6] (1985) found out, that the younger age groups are more sensitive at high frequencies up from 8 kHz. At low frequencies he had the same tendency. It seems to be a twist of the curves round a point between 6 and 8 kHz at his data and not a parallel movement like here. One major difference is the constitution of the age groups. The youngest age group was 6-10 years the next age group 11-15 years old.

At the left ear the average threshold is a little better than at the right ear. But the differences are only marginal. Instead of that the mean improvement between the age groups is with 3.4 dB a little lower than at the right ear with 3.8 dB. The pre-audiometry was performed at the left ear and maybe the greater experience at that ear is the reason for the better result. The curve shapes of both ears show a good similarity. Conspicuous are the two edges at 8 and 12.5 kHz which disturb the smooth course.

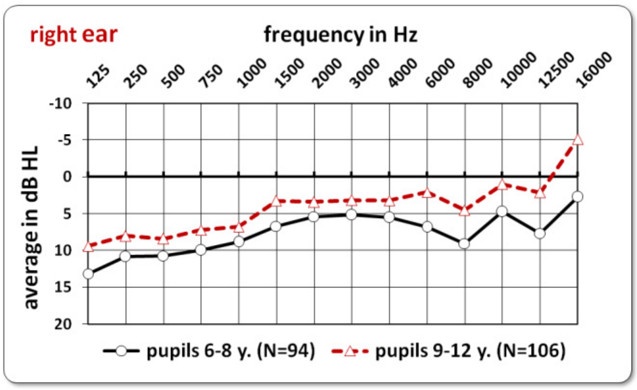

Fig. 1 Two age groups compared in 14 frequencies from 125 Hz to 16 kHz at the right ear

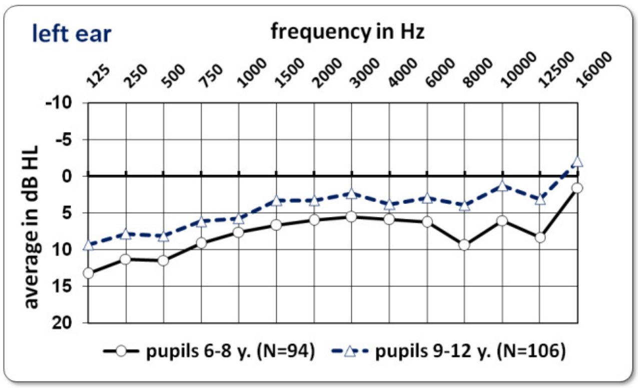

Fig. 2 Two age groups compared in 14 frequencies from 125 Hz to 16 kHz at the left ear

	younger		older		right ear	
freq.	mean	st.dev.	mean	st.dev.	delta	sign.
125	13.1	6.7	9.4	4.8	3.8	yes
250	10.9	6.2	8.0	4.2	2.8	yes
500	10.7	5.4	8.4	4.0	2.3	yes
750	9.9	6.0	7.2	4.5	2.7	yes
1000	8.8	5.2	6.8	4.8	2.0	yes
1500	6.7	5.6	3.3	4.8	3.4	yes
2000	5.4	5.0	3.4	4.8	2.0	yes
3000	5.2	5.9	3.2	5.0	2.0	yes
4000	5.5	6.3	3.2	5.0	2.3	yes
6000	6.8	7.7	2.1	5.3	4.7	yes
8000	9.0	8.0	4.5	6.4	4.5	yes
9000	7.4	8.9	2.2	7.1	5.2	yes
10000	4.7	8.2	1.0	7.5	3.7	yes
11200	5.4	8.3	0.9	8.2	4.5	yes
12500	7.7	9.9	2.1	8.6	5.5	yes
14000	4.7	11.8	-0.8	9.6	5.4	yes
16000	2.7	15.1	-5.1	13.1	7.9	yes
mean:	**7.3**	**7.7**	**3.5**	**6.3**	**3.8**	

Table 1: Averaged levels with standard deviation in dB HL (mean) for 17 frequencies in Hz. Delta is the difference of mean for both groups. The last column (sign.) shows the significance of the results. In the last row is the total mean of each column calculated. Right ear.

	younger		older		left ear	
freq.	mean	st.dev.	mean	st.dev.	delta	sign.
125	12.6	4.8	8.7	5.0	3.8	yes
250	10.8	5.5	7.4	4.7	3.4	yes
500	11.0	5.6	7.7	4.9	3.2	yes
750	8.7	5.2	5.4	4.6	3.3	yes
1000	7.1	5.0	5.1	4.6	2.0	yes
1500	6.5	5.4	3.0	4.6	3.5	yes
2000	5.5	5.6	2.9	5.2	2.6	yes
3000	4.8	4.7	1.6	4.5	3.2	yes
4000	4.8	4.3	2.9	5.5	1.9	yes
6000	4.9	4.8	2.1	5.4	2.8	yes
8000	8.0	6.9	3.2	6.1	4.8	yes
9000	5.2	8.1	0.5	5.5	4.7	yes
10000	4.4	7.5	0.5	5.4	3.9	yes
11200	5.2	8.6	1.6	6.3	3.6	yes
12500	6.7	10.3	1.6	6.9	5.1	yes
14000	3.2	10.4	-0.8	8.4	4.0	yes
16000	-1.1	13.1	-3.3	13.3	2.2	no
mean:	**6.4**	**6.8**	**2.9**	**5.9**	**3.4**	

Table 2: Averaged levels with standard deviation in dB HL (mean) for 17 frequencies in Hz. Delta is the difference of mean for both groups. The last column (sign.) shows the significance of the results. In the last row is the total mean of each column calculated. Left ear.

3.2 Test and retest

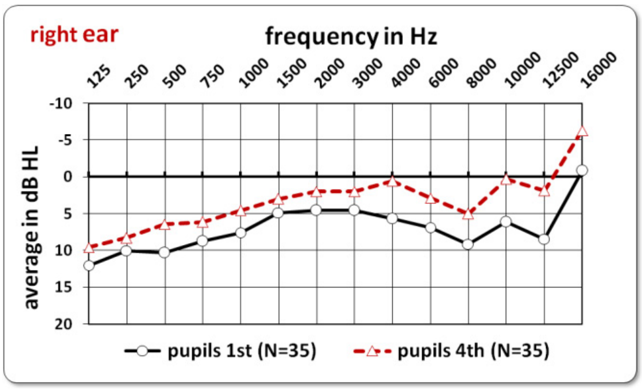

Fig. 3 Comparison of 35 pupils at the 1st grade and the 4th grade - right ear

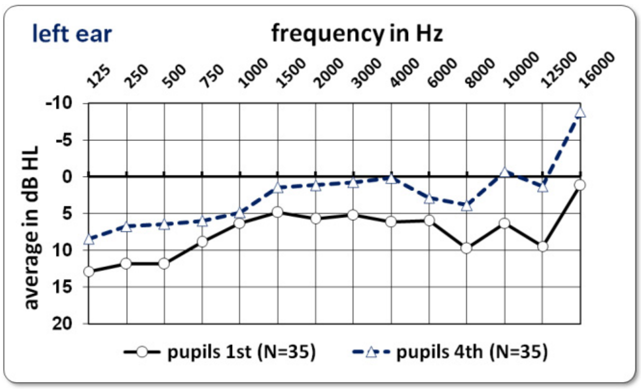

Fig. 4 Comparison of 35 pupils at the 1st grade and the 4th grade - left ear

	younger		older		right ear	
req.	mean	st.dev.	mean	st.dev.	delta	sign.
125	12.0	6.3	9.6	6.6	2.4	no
250	10.0	5.5	8.3	5.5	1.7	no
500	10.3	4.5	6.4	5.9	3.9	yes
750	8.7	5.4	6.1	6.1	2.6	no
1000	7.6	4.7	4.6	6.3	3.0	yes
1500	4.9	5.4	3.0	5.9	1.9	no
2000	4.6	4.7	2.0	5.4	2.6	yes
3000	4.6	4.8	2.0	5.6	2.6	yes
4000	5.7	5.9	0.6	5.6	5.1	yes
6000	6.9	7.2	2.9	6.7	4.0	yes
8000	9.1	8.0	5.0	8.9	4.1	yes
9000	8.3	9.4	3.7	8.2	4.6	yes
10000	6.1	9.6	0.3	7.1	5.9	yes
11200	5.4	9.4	3.3	7.1	2.1	no
12500	8.4	11.4	1.9	9.0	6.6	yes
14000	4.0	11.9	-0.7	11.5	4.7	no
16000	-0.9	13.5	-6.3	12.9	5.4	no
mean:	**6.8**	**7.5**	**3.1**	**7.3**	**3.7**	

Table 3: Averaged levels with standard deviation in dB HL (mean) for 17 frequencies in Hz. Delta is the difference of mean for both groups. The last column (sign.) shows the significance of the results. In the last row is the total mean of each column calculated. Right ear.

	younger		older		left ear	
freq.	mean	st.dev.	mean	st.dev.	delta	sign.
125	12.9	4.2	8.4	7.7	4.4	yes
250	11.9	5.4	6.7	7.4	5.1	yes
500	11.9	4.0	6.4	6.9	5.4	yes
750	8.9	4.5	6.0	6.6	2.9	yes
1000	6.3	4.0	4.9	5.5	1.4	no
1500	4.9	5.4	1.4	5.7	3.4	yes
2000	5.7	5.9	1.1	6.2	4.6	yes
3000	5.1	5.0	0.7	5.4	4.4	yes
4000	6.1	5.1	0.1	6.0	6.0	yes
6000	6.0	6.7	2.9	6.7	3.1	no
8000	9.7	8.1	3.9	8.5	5.9	yes
9000	6.7	8.9	1.7	7.5	5.0	yes
10000	6.3	7.9	-0.7	6.9	7.0	yes
11200	6.1	9.2	3.4	10.7	2.7	no
12500	9.4	11.8	1.3	6.9	8.1	yes
14000	5.9	11.7	-1.7	10.0	7.6	yes
16000	1.1	16.2	-8.9	10.1	10.0	yes
mean:	**7.3**	**7.3**	**2.2**	**7.3**	**5.1**	

Table 4: Averaged levels with standard deviation in dB HL (mean) for 17 frequencies in Hz. Delta is the difference of mean for both groups. The last column (sign.) shows. the significance of the results. In the last row is the total mean of each column calculated. Left ear.

3 years and 3 months after the first field study we retested 43 pupils of the former first grade. The test procedure at the retests had some amendments.

First of all the pre-audiometry was left out as a learning stage since the pupils were familiar with an audiometry. Meanwhile a new developed audiometry software was in use which contained an interesting feature: the complete course of the audiometry could be stored as a XML stream to hard disk. By means of an implemented replay function each audiometry test could be examined afterwards. The same audiometry course could be represented also by means of SVG vector graphics as a course of time in a usual Web browser. All actions of the audiometrist and the reactions of the test subject are presented with time stamp. This made possible to assess the quality of the real measuring course in detail. In use of this new feature a couple of audiograms were discarded and the pupils retested with improved results. For the retest sessions we used only 3 Maico MA 53 audiometers with notebooks. All stations were connected via W-LAN.

Making the two testings comparable, the pupils who had been excluded at the first test were at the second excluded again. The number of the evaluated pupils went down from 43 to 35. This is approximately a third of numbers in each group compared with the first study. For this the variation of the age is considerably less. The age of the first grade pupils hesitated between 6.3 and 7.3 years and had an average of 6.8 years. Of course the retest group had the same fluctuation since they were the same children. Their mean age amounted to 10.1 years. The age difference of the two groups is 3.3 years and nearly half a year more than the difference at the first research groups.

When we compare the values and the shape of the curves in the test retest situation with that in the first research, we see a quite similar course, edges included. The left ear shows with 5.1 dB HL averaged differences a higher improvement of the sensitivity than the right ear with 3.7 dB HL. Due to the smaller number in each group the differences in the average values between the age groups are not all significant.

3.3 Gender

If we compare the hearing threshold of girls with that of boys we notice that boys hear better than girls from 125 Hz to 3 kHz and with the exception of 125 Hz are these differences significant. From 4 kHz to 10 kHz the differences are very small. From 11,2 kHz up to 16 kHz are the levels of girls better. The thresholds at 16 kHz (left ear) are significantly better. At the 125 Hz tone the attenuation of the HDA 200 ear phone is lowest and environmental noise has most likely the chance to disturb the measurement. Therefore the difference is smaller but the variance higher. To give an overview to this results we will limit the presentation to the right ear and combine the particular frequencies to 4 frequency bands. The “low” band consists of the 3 frequencies from 125 Hz to 500 Hz, the “middle” band of 4 frequencies from 750 Hz to 2 kHz, the “high” band also of 4 frequencies from 3 kHz to 8 kHz and the “extra” band of 6 frequencies from 9 kHz to 16 kHz. The total band is not an equal average of all 17 levels but an equal average of the 4 bands. This will reduce the overweight of the extra band as already mentioned.

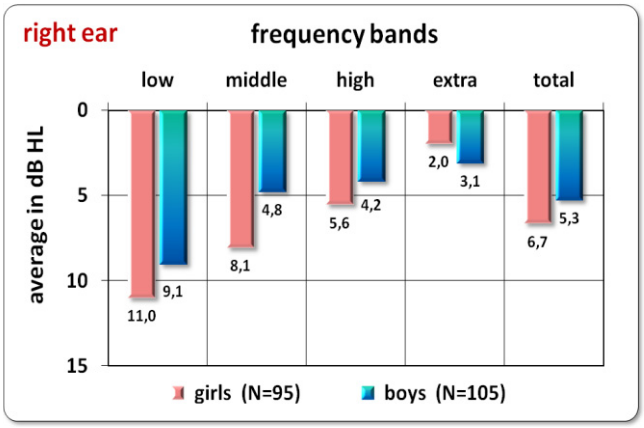

Fig. 5 Contrast between girls and boys in 4 frequency bands. At “low”, “middle” and “total” the differences are significant – right ear

Fig. 5 shows that boys will have a better hearing sensitivity at the 3 lower bands, but the girls at the highest. The average of all differences in the hearing levels between girls and boys amounts to 1 dB HL. This is not very much but nevertheless will be surprising and contrary to other studies [8]. Especially when we consider that boys have much more frequently to do with toy pistols, china crackers and other noisy toys than girls. In addition to that the girls are a little older than the boys in the present paper. The average age of girls was 9.1 years compared to 8.7 years of the boys. After all findings in this paper the girls should rather hear a little better than the boys. But they do not.

3.4 Pre-audiometry

The result of the pre-audiometry in comparison with the later hearing test also shall be summarized briefly. First of all must be noticed that the environmental conditions at the pre-audiometry were a little more unfavourable than at the audiometry where we had the highest possible requirement for silence. The measurement of tympanometry took place in the same room as the pre-audiometry and therefore it was a little more noise. It was not the major goal to get excellent data for analyzing differences between two measurements but to give the children an explanation of the test procedure and the experience to recognize pure tones at the hearing threshold. The testing of the lowest frequency 125 Hz was not performed.

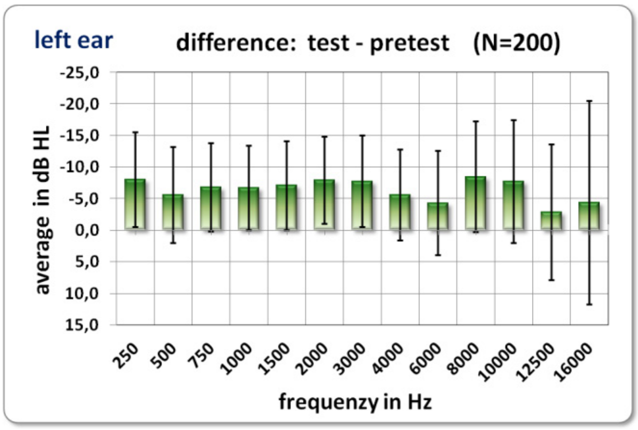

Fig. 6 Differences between audiogram and pre-audiogram mit standard deviation. Negative levels show an improvement – left ear.

Because of the great standard deviation it can be seen that a couple of pupils did not improve their test results but deteriorated it. The whole group however show an improvement of the average differences at all test frequencies. The differences are even bigger than at the other group comparisons in chapter 3.1 and 3.2. The average improvement amounts to 6.4 dB HL over all test frequencies. However, environmental conditions at the pre-audiometry do not allow any too far-reaching conclusions from this result. Anyway the trend goes into the direction improvement [5]. A preliminary testing is a good exercise for the audiometry and leads in the predominant cases to an improvement in the test results.

4 Discussion

Children still are in the process of growing and many object features and capabilities are not developed fully but still in progress. Therefore it is not surprising that the hearing sense seems to follow this pattern. A part of the improvements can be explained with the neuronal gestation which is just getting on by use and exercise of the senses. By example children who grow up in remote and quiet areas of China are hearing as a group worse than children in Central Europe (not each individual) [9]. They have less acoustic stimulations to train their hearing sense but much more noise induced hearing loss caused by heavy impulse noise. They use many opportunities at festivals to bang with handmade and industrial produced fire-crackers near their ears. In the present study we did not consider to compare data from Chinese children in detail because the comparable age groups were too small and the disturbance variables too various.

The worse hearing of children especially at deep frequencies in the opposite of adults certainly has structural components partly. The cochlea, the tympanic membrane and the ossicular chain are build in the final shape and quantity and underlie only marginal growth after birth. This structures have to work together in a certain way from the first day of life on. More variable is the middle ear volume filled with air. The mastoid cavity needs air to be developed complete. From birth to the adolescent age the volume of this cavity grows to a multiple. The volume stiffness of the middle ear is one important component for the transfer function of the middle ear. A greater volume will lead to a smaller stiffness and this improves the transduction of deep frequencies [10]. The development of the mastoid cells has an effect in the same direction when the greater surface of the mastoid cells will ease the thermal exchange. In a pure cavity the compression and decompression happens adiabatically when the changes are quick. With thermal exchange we get a more isotherm process and a further decrease of the volume stiffness up to factor 1.4 [11]. The transfer function of the middle ear will be shifted to lower frequencies. As a consequence of this the hearing sensitivity for extreme high frequencies decreases. Boys in general are a little bigger than girls at the same age and the volumes of their heads too. Considering that we are able to explain the difference between girls and boys in the threshold course. In adults we find the same differences between female and male.

Burén et al. [8] found a decreasing of hearing sensitivity in the extra high frequencies (14 kHz and 16 kHz) in children older than 10 years. He tested in 3 age groups: 10, 14 and 18 years. Haapaniemi published a study of school children in Finland [9] where he presented improvements of the hearing threshold up to 8 kHz in 3 age groups: 7, 10 and 14 years. Frequencies above 8 kHz he did not regard. The tendency in his results is the same as in the present paper except the better hearing of his girls. He also found signify-cant better hearing in the left ear but did not tell what ear was measured first. Maybe the normal procedure: to start with the right ear, leads to an improvement at the left ear as a consequence of learning effects. Axelsson [5] had in his retests distinct (averaged) improvements without exceptions compared with the first test.

5 Conclusion

The results of the field study with a remarkable improvement of the hearing threshold at children with rising age could be confirmed by a long term study with a sub group of the children at a retest 3 years later. Some reasons for this improvement was discussed as growth, gestation and training. Maybe we have a combination of this and more influences. It is not trivial to estimate the quantum of each factor. The growth of the structures, gestation of neuronal structures, training of the senses and the gain of personal experiences happens simultaneously and can't be separated.

The sense of hearing is a wonderful gift and can give much joy with the gladdening experience of the music for example. But it is also sensitive for damages as we have seen in many cases. To shield the ears totally against sound as a consequence of this danger will lead to deprivation [10]. Hearing will be learned and trained than it will reach the full capability.

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