Chapter 5

Pure-tone and speech audiometry in patients with Menière’s disease

Introduction

Menière’s disease was first described by Prosper Menière in 1861 as a combination of hearing loss, tinnitus and vertigo [1]. Although the hearing loss may not be the most disabling symptom, most patients describe it as problematic [2]. It is therefore not surprising that many publications on Menière’s disease make statements about the nature and severity of the hearing loss in Menière patients. Some even describe a time course for the hearing loss or all of the symptoms of the disease. According to Beasley and Jones [3], Prosper Menière himself already concluded that the hearing loss was ‘of increasing severity’. This conclusion is also drawn by others and the hearing loss is even used to develop staging methods for the disease [4,5,6]. In many of the aforementioned papers the authors claim that in the early stages of the disease there is a low frequency sensorineural hearing loss that fluctuates in time. In later stages, the hearing loss would increase and the audiogram would become more and more flat. Sometimes a decreased speech discrimination is also mentioned as a common symptom of Menière’s disease [5,6,7]. Although the hearing loss plays an important role in all staging or classification methods described, it remains difficult to compare hearing loss of patients among each other. Most authors indicate that symptoms experienced by individual patients at a given moment may fall in different categories. Furthermore, patients may change categories in an irregular pattern. This implies that a connection between the stage of the disease and the duration is not generally present. Studies on Menière patients in Japan have shown that there is a correlation between average hearing loss and the duration of the disease [8]. In contrast to this a substantial amount of patients has an average hearing loss of less than 21 dB after 10 years [9], and fluctuating hearing losses are found even after 15 years of affection [10]. In 1996 Pou et al. found that the degree of hearing loss and the duration of the disease had their influence on the EcoG results (SP/AP ratio) [11].

The aim of this study was to reinvestigate many of the claims in the literature about hearing loss in Menière patients. We did this on a well defined group of patients under well controlled circumstances. Thus we were able to find support for some claims, and none for many others. This research forms the base for comparison with data from other tests on the same group of patients under the same circumstances.

In this study we obtained audiometric data (pure-tone and speech audiograms), as well as subjective descriptions of hearing loss from 111 patients diagnosed with Menière’s disease. The subjective descriptions were scored according to a questionnaire based on the one developed by Schmidt [12] A computational method was developed to classify the pure tone audiograms as ‘high’ frequency losses, ‘low’ frequency losses, ‘high+low’ frequency losses, ‘flat’ audiograms and ‘other’ audiograms. The average hearing loss, the audiogram shape and the maximum discrimination score on a speech recognition test were related to each other and to the duration of the disease.
Patients and methods

During a three and a half year period (from January 1994 to June 1997) 128 patients suffering from Meniere's disease were extensively investigated according to a diagnostic protocol during a four day stay in the Department of Otorhinolaryngology of the University Hospital Groningen.

The diagnostic protocol consisted of routine ENT examination, audiovestibular tests, routine laboratory investigations, measurement of blood pressure, electrocochleography (EcoG), oto-acoustic emission examination and magnetic resonance imaging (MRI) of the temporal bones and the cerebellopontine angle. For 111 patients the diagnosis of Meniere's disease, according to the Definition Menière Groningen was established. The diagnosis of Menière's disease was defined by simultaneous fulfilment of three criteria: cochlear hearing loss of at least 20 dB at one of the pure tone audiogram frequencies, tinnitus and periodic attacks of vertigo (at least two in the past). Patients were excluded when other pathology was found through the diagnostic protocol. A detailed discussion of this definition including the in- and exclusion of patients in the study is also given elsewhere [17]. Of these 111 patients 57 were male (51%) and 54 female (49%), 71 patients (64%) had hearing loss and/or tinnitus in only one ear (unilaterally affected) and 40 patients (36%) had all symptoms in both ears (bilaterally affected). The mean age of the patients was 50 (±11) years, with no significant differences in age between male and female patients or uni- and bilaterally affected patients. The audiometric data contained in the database, consisting of pure tone and speech audiograms (measured with a PB spondaic word list), were used for this study, along with the age of the patients, the duration of the affection and the results of a questionnaire on the (subjective) severity of the symptoms. The duration of the affection was defined as the period between the first appearance of one of the Menière symptoms and the admission into hospital. For bilaterally affected patients this may lead to different durations in the two ears, if vertigo was not the first symptom. Therefore, the duration of the disease was defined as follows: In unilaterally affected patients this was the duration of the affection in their affected ear, in bilaterally affected patients it was the duration of the affection in the ear affected first. The questionnaire on the (subjective) severity of the symptoms tried to classify the hearing loss, the tinnitus, the vertigo and the (possible) fullness in the ear, as perceived by the patient during the last three months before admission. Hearing loss could be characterized as ‘unchanged’, ‘improved’, ‘worsened’ or ‘fluctuating’. Using the duration of the affection, the ears of bilaterally affected patients could be characterized as ‘affected first’ or ‘affected last’, in those cases where a difference in duration was found for the two ears. Also a distinction in ‘most affected’ and ‘least affected’ ears was made for bilaterally affected patients, based on the average hearing loss in the two ears. (The average hearing loss is defined as the average of the hearing thresholds over all six audiogram frequencies.) To characterize the shape of the audiogram in each ear
a classification was introduced taking into account both the curvature and the slope of the audiogram. This leads to five categories for the audiogram shape, capturing all important features of the audiograms seen in our patient group: ‘low’ frequency loss, ‘flat’ audiogram, ‘high’ frequency loss, ‘low+high’ frequency loss, and ‘other’ audiograms, not fitting into one of the previous categories. (These ‘other’ audiograms show a loss that is highest in the mid-frequencies.) Examples of audiograms in these five categories are shown in figure 1.

Figure 1. Pure tone audiogram: five categories; ‘low’, ‘high’, ‘flat’, ‘low+high’, and ‘other’ frequency-losses.
The audiograms shown are the audiogram of individual patients. The procedure used to compute the curvature and slope of an audiogram and the criteria on which the division into the aforementioned categories was based is described in the Appendix. Statistical analysis was performed with mainly parametric but also non parametric tests, regarding the distributions of each parameter analyzed (T-test, Pearson correlation, Pearson Chi-square test, ANOVA). All statistics were done with the SPSS 9.0 program and carefully checked by a professional statistician.

Results

Average audiograms for affected and unaffected ears of unilaterally affected patients are shown in figure 2. It is clear that the hearing thresholds for the affected ears are significantly higher than for unaffected ears (p<0.001 for all frequencies, using a two-tailed T-test).

Figure 2. Average audiograms for affected and unaffected ears for unilaterally affected patients. Standard deviations are represented by small horizontal bars.

Figure 3. Average audiograms for ‘most’ and ‘least’ affected ears of bilaterally affected patients. Standard deviations are represented by small horizontal bars.
Figure 3 shows average audiograms for the ‘most’ and ‘least affected’ ears of bilaterally affected patients. It is clear from this figure that the differences between the two ears are almost as large as for the affected and unaffected ears of unilaterally affected patients (p<0.003 for all frequencies, using a two-tailed T-test). To test whether there was a dependance of the average hearing loss on the duration of the disease, a correlation between these two variables was computed. Although the resulting correlation of $r=0.36$ was significant (Pearson correlation, p<0.001), it is clear from figure 4 that no clear relation between duration and average hearing loss is present in individual cases. The weak correlation found between duration and average hearing loss could be caused, in part or completely, by a relation between the average hearing loss and the age of the patient and a relation between age and duration. However, no significant correlation was found between age and average hearing loss in affected ears. In unaffected ears, on the other hand, there is a relation between age and average hearing loss (Pearson correlation, $r=0.33$, p=0.005), probably in part associated with presbyacusis.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{scatterplot.png}
\caption{Scatterplot: Pearson’s correlation between duration of affection and average hearing loss (affected ears, n=151).}
\end{figure}

The audiogram shapes for affected and unaffected ears are shown in figure 5. In the unaffected ears the ‘flat’ and ‘high’ categories dominate, but in the affected ears we also see a number of ‘low’ and ‘low+high’ audiograms. (The differences between the
two distributions affected versus unaffected ears are significant, Pearson Chi-square test, p=0.006). The distributions for uni- and bilaterally affected ears do not differ significantly (Pearson Chi-square test, p=0.66).

![Figure 5. Bar chart: Distributions of audiogram shapes for affected (n=151) and unaffected ears (n=71). The five categories; ‘low’, ‘high’, ‘flat’, ‘low+high’, and ‘other’ frequency-losses are represented as shown in the legends of the chart.](image)

To see whether there is a relation between the audiogram shape and the duration of the disease, the duration was divided into four classes, based on quartiles of the distribution. Figure 6 shows the distributions of audiogram shapes in the four classes. It is clear from this picture that no relation between audiogram shape and duration of the affection was present (p=0.46, Pearson Chi-square test).

Figure 7 shows the relation between the audiogram shape and the average hearing loss (also divided into classes based on quartiles). It should be noted here that the group of ears with an average hearing loss 27.5 dB contains a relatively large number of flat audiograms. This is due to the fact that all other audiogram shapes necessitate hearing losses in low -, mid - or high frequencies, leading to and average hearing loss exceeding 27.5 dB. The other three classes clearly show a gradual transition from the ‘low+high’ and ‘low’ audiogram shapes to the ‘flat’ audiograms. Using a Pearson Chi-square test, the differences turn out to be statistically significant (p=0.002). If the ears with a hearing loss below 27.5 dB are left out of the analysis, the significance of this transition increases (Pearson Chi-square test, p=0.001).
Figure 6. Bar chart: Distributions of audiogram shapes for affected ears (n=151) versus duration of disease. Duration is divided into four classes. The five audiogram-categories; ‘low’, ‘high’, ‘flat’, ‘low+high’, and ‘other’ frequency-losses are represented as shown in the legends of the chart. The number of ears per subgroup are listed in the blank boxes.

Figure 7. Bar chart: Distributions of audiogram shapes for affected ears (n=151) versus average hearing loss. Average hearing loss is divided into four classes. The five audiogram-categories; ‘low’, ‘high’, ‘flat’, ‘low+high’, and ‘other’ frequency-losses are represented as shown in the legends of the chart. The number of ears per subgroup are listed in the blank boxes.
The question could now be raised whether there is a relation between the audiogram shape and the classification of the hearing loss during the three months before intake, as given by the patients in the questionnaire. This question can not be answered straightforward. The fact that some of the categories contain a very small amount of ears, or even no ears at all (such as the category ‘low+high’ with ‘improved’ hearing), prohibits the direct use of a Pearson Chi-square test. Reclassification of the description of the hearing loss given on the questionnaire into ‘changed’ and ‘unchanged’, substantially reduces this problem. A Pearson Chi-square test can now be performed reliably, but reveals no significant relationship (p=0.47). Because it is argued by many authors that a fluctuating hearing loss is a sign of active Menière, the ‘fluctuating’ category was compared to the ‘unchanged’. Figure 8 shows that among the ‘fluctuating’ hearing losses there are more ‘low’ audiograms and less ‘high’, whereas the percentages of other audiograms are relatively similar in both groups. The differences are only weakly significant (Pearson Chi-square test, p=0.046).

Speech audiometry
The speech reception threshold (SRT) shift was larger in affected ears (33.8 dB) than in unaffected ears (9.8 dB), as could be expected on the basis of the difference in average hearing loss. This also explains the difference in maximum speech discrimination (82.5% in affected ears and 98.0% in unaffected ears).
Table 1. Correlation of average hearing loss, duration of the affection, SRT-shift and maximum speech discrimination for affected ears of unilaterally affected patients (uni aff), unaffected ears of unilaterally affected patients ('uni unaff'), most affected ears of bilaterally affected patients (bi most) and least affected ears of bilaterally affected patients (bi least).

<table>
<thead>
<tr>
<th></th>
<th>duration of affection (years)</th>
<th>average hearing loss (dB)</th>
<th>maximum speech discrimination (%)</th>
<th>speech reception threshold shift (dB)</th>
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<tr>
<td>Uni aff</td>
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<tr>
<td>duration of affection (years)</td>
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<td>maximum speech discrimination (%)</td>
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<td>-0.812**</td>
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<td>speech reception threshold shift (dB)</td>
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<tr>
<td>Uni unaff</td>
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<tr>
<td>duration of affection (years)</td>
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<tr>
<td>average hearing loss (dB)</td>
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<td>0.891**</td>
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<td>maximum speech discrimination (%)</td>
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<td>speech reception threshold shift (dB)</td>
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<td>Bi least aff</td>
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<tr>
<td>duration of affection (years)</td>
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<td>maximum speech discrimination (%)</td>
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<td>-0.670**</td>
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<td>Bi most aff</td>
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<tr>
<td>duration of affection (years)</td>
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<td>-0.258</td>
<td>0.323*</td>
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<td>0.905**</td>
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** Pearson correlation is significant at the 0.01 level (2-tailed)
* Pearson correlation is significant at the 0.05 level (2-tailed)

These differences were statistically significant (p<0.001 for both, using a T-test). A Pearson Correlation test was performed, including average hearing loss, duration of the affection, SRT-shift and maximum speech discrimination. To check for possible differences between groups of patients, the population was divided into: affected ears of unilaterally affected patients ("uni aff"), unaffected ears of unilaterally affected
patients (‘uni unaff’), most affected ears of bilaterally affected patients (‘bi most’) and least affected ears of bilaterally affected patients (‘bi least’). The results are shown in table 1. As could be expected, strong correlations were found between SRT-shift, maximum speech discrimination and the average hearing loss in all groups (table 1). Furthermore, significant correlations were found between the duration of the affection and the audiometric data in the least affected ears of bilaterally affected patients (in unaffected ears the duration of the affection is not defined).

Figure 9. Scatterplot: Maximum speech discrimination (%) versus average hearing loss for four subgroups; unilaterally affected (uni aff), unilaterally unaffected (uni unaff), bilaterally ‘most’ affected (bi most) and bilaterally ‘least’ affected ears (bi least). The line indicates the values below which the discrimination should be considered disproportionately poor9.

A more detailed relation for the four different groups of ears between maximum speech discrimination and average hearing loss is shown in figure 9. In each groups the speech discrimination is (almost) 100% for hearing losses up to 40 dB. For larger losses (mainly found in the groups ‘uni affected’ and ‘bi most affected’), the discrimination decreases with increasing hearing loss. Especially in the group of affected ears of unilaterally affected patients a very wide distribution of discrimination scores can be seen for hearing losses between 50 dB and 80 dB. Patients with a 65 dB
average hearing loss can have a speech discrimination score of 95% (almost normal),
down to 15% (almost none).
The question could be raised whether (part of) this wide distribution could be
explained by differences in audiogram shape. The correlation r=0.79 between speech
discrimination and average hearing loss for all affected ears implies that 62.4% of the
variance in speech discrimination can be accounted for by the variance in average
hearing loss (Pearson Chi Square). Addition of the audiogram shape as a factor of
possible influence gave an improvement of only 0.4% of explained variance.
(ANOVA: dependant variable= max. speech disc., predictors: (constant), av. hearing
loss, aud. shape, F=124.8, p<0.001, r^2=0.628). Therefore it was be concluded that the
audiogram shape did not have any significant additional effect on speech
discrimination.

Discussion

The classification of audiogram shapes used in this paper is not unique. Different
classifications are possible. The number of categories could be expanded to include
also ski-slope audiograms, peak audiograms, etc. Also a reduction of the number of
categories to only ‘flat’, ‘high’ frequency and ‘low’ frequency losses would be
possible. The choice was made to take the smallest number of categories that would
still allow us to describe the characteristics of audiogram shapes seen most in our group
of Menière patients and those described in literature. This resulted in the five
categories described in the methods section. The computational algorithm described in
the Appendix allows us to classify the audiogram shapes in an objective manner.
Nevertheless, the choice of parameter values was based on a comparison with a
subjective classification of a number of audiograms.
The outcome that the hearing loss in affected ears was larger than in unaffected ears (at
all audiograms frequencies) is hardly surprising. It is, however, peculiar that a similar
difference is seen between ‘most’ and ‘least’ affected ears in bilaterally affected
patients. A comparison of this outcome with data in literature is difficult, because a
comparison between uni- and bilaterally affected patients is rarely made. Previous
analysis of our patient group suggested that uni- and bilateral affection might be two
different entities [17]. In this study the only indication of a difference between these
two groups is the fact that significant correlations are found between audiometric data
(average hearing loss, SRT-shift and maximum speech discrimination) and the duration
of the affection in the ears of bilaterally affected patients (most markedly in the ‘least’
affected ears of this group).
There is no difference in audiogram shape between affected ears of uni- and bilaterally
affected patients. The difference with the unaffected ears is mainly that there are more
‘low+high’ and ‘low’ frequency losses among the affected ears (27%, against 5.6% in
unaffected ears). The percentage of ‘flat’ audiograms is larger among the unaffected ears (51%, against 35% in affected ears). This is partly due to the fact that a substantial amount of unaffected ears have no hearing loss at all (66% has an average hearing loss < 20dB).

The lack of correlation between the audiometric data and the duration of the disease in the affected ears of the unilaterally affected patients is not unexpected. Previous studies on this group of patients (unpublished) have shown little or no correlation between subjective or objective measures of the severity of the disease and the duration. A study performed by Watanabe et al. in Japan showed a (weakly) significant correlation between hearing loss and duration [9]. Unfortunately these results can not be directly compared to the correlations we found for the bilaterally affected patients, because bilaterally affected patients were excluded by Watanabe et al.

A significant correlation was found between audiogram shape and the average hearing loss in the affected ears. In accordance with the descriptions generally given about the course of Menière’s disease, the audiogram becomes more and more flat as the hearing loss increases. This ‘flattening’ could be partly due to the upper limit of 120 dB used in standard audiometry. Therefore, a hearing loss of 120 dB on average can only have a ‘flat’ shape. However, 95% of all affected ears have an average hearing loss below 75 dB, where ‘flattening’ due to the upper limit of 120 dB can not be expected to play a significant role.

Unfortunately a direct relation between the audiometric data and the subjective complaints about the hearing loss could not be found. Although a weakly significant difference was found between the groups of ‘fluctuating’ and ‘unchanged’ hearing losses, this can hardly be regarded as support for the hypothesis that low-frequency hearing losses are ‘fluctuating’ and flat losses remain stable, as suggested in literature. The number of patients in this study may have been somewhat small to find significant differences. Also, it is possible that audiogram shape and average hearing loss are not directly related to the subjective complaints. One might expect the audiometric data to depend on the stage or severity of the disease and the subjective complaints (during the three months before intake) may not give a clear indication of this stage or severity.

In 1982 Paparella et al. described so called ‘peak audiograms’, found in a substantial number of their Menière patients [7]. They reported that 42% of Menière patients have a threshold at one of the audiogram frequencies which is at least 10 dB better than at the adjacent octave frequencies. In most cases where such a peak audiogram is found, the peak will be found at 2 kHz (71%). In normal hearing adults and non-Menière patients the percentage of peak audiograms is 7% and 6.25% respectively. In our patient group we found 15 out 151 affected ears to have a peak audiogram (10%), of which 11 had the peak at 2 kHz (73%). In the 71 unaffected ears only 1 peak audiogram could be found (1.4%), which was not at 2 kHz. This difference between affected and unaffected ears was weakly significant (p=0.02), but in comparison with the numbers given by Paparella et al., we would have to conclude that the affected ears
in our patient group do not differ from a group of normal hearing subjects or non-Menière patients. The correlation found between pure-tone and speech audiometry is hardly surprising. A direct relation was already described by Fletcher for calculating the speech reception threshold from the pure-tone audiogram [13].

Figure 10. Scatterplot: Speech Reception Threshold Shift (dB) versus hearing loss for speech according to Fletcher (dB), defined in 1950 (all ears).

Figure 10 shows the SRT shifts calculated with his method and those measured. A high correlation ($r=0.899$, $p<0.001$) is evident. There are no indications in this figure of relatively poor speech reception by Menière patients, as mentioned in some studies [5,6,7]. However, it is shown that in individual cases the Fletcher index deviates substantially from the real SRT shift. This indicates that, in contrast to non-Menière patients, these patients have no, or weak correspondence between their pure-tone and speech audiogram. The maximum discrimination found in this study also does not give an indication of reduced speech reception. The line in figure 9 indicates the values below which the discrimination should be considered disproportionately poor [10]. Only five ears fall below this line and they are in the range of very low discrimination scores, where the results are no longer very reliable. We must therefore conclude that we have not found any indication of reduced speech discrimination in Menière patients. (That is, reduced in respect to what could be expected on the basis of the pure-tone loss.) Figure 9 could be divided into two parts. The ears with an average hearing loss below 40 dB show almost undisturbed maximum discrimination. The
spread in this region is small. Above 40 dB, however, the spread increases dramatically and discrimination ranges from undisturbed to severely impaired. The fact that the boundary between these regions is found around a hearing loss of 40 dB could be considered as an indication that there is some connection with inner and outer hair cell loss. Many studies report that outer hair cells are most easily damaged and total destruction of these cells results in an amplification loss of around 40 dB [14,15]. Perhaps correlation studies with e.g. EcoG or OAE data from this same group of patients may provide us with more information in this area [16].

Conclusions

Affected ears of patients suffering from Menière’s disease (according to the Definition Menière Groningen) show reduced hearing, both in pure-tone and in speech audiometry [17]. A classification method was devised to determine audiogram shape in an objective manner. The results of this method indicate that affected ears more frequently show ‘low’ or ‘low+high’ hearing losses. The shape of the hearing loss does not depend on the duration of the affection. In combination with the fact that the average hearing loss does not correlate with the duration of the disease this leads to the conclusion that, if a classification of the hearing loss in Menière’s disease is possible, such a classification can not be connected to the duration. This conclusion is further supported by the fact that no relation is found between the duration of the disease and the classification of the hearing loss over the three months before intake, as given by the patients in the questionnaire. A relation between the (objective) audiometric data and the (subjective) classification of the hearing loss by the patient seems to be present, but is not very strong. Correlations between pure-tone and speech audiometry are present as in non-Menière ears, and no indications are found of reduced speech discrimination relative to the expectation based on pure-tone loss. The audiogram shape does not appear to play any additional role in speech discrimination (in addition to the influence of the average pure-tone loss).
This research forms the base for comparison with data from other tests on the same group of patients under the same circumstances.

References

1 Menière P: Mémoire sur des lésions de l’oreille interne donnant lieu a des symptomes de congestion cérébrale apoplectiforme. (A report on lesions of the inner ear giving rise to symptoms of cerebral congestion of apoplectic type.) Gazette Médicale de Paris 1861;16:597-601.


**Appendix**

Pure tone audiograms consist of threshold values for each of the six standard audiogram frequencies (250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz and 8000 Hz). In order to reduce the amount of data we chose to characterize each audiogram using only two numbers: the average hearing loss and the audiogram shape. The average hearing loss is defined as the average of all thresholds, and computation of this value is straightforward. The shape of an audiogram may be intuitively clear, but in order to obtain an objective classification a precise definition was required. First the low frequency -, mid frequency - and high frequency hearing losses \( L_1 \), \( L_2 \) and \( L_3 \) were computed as: \( L_1 = \frac{\text{threshold at 250 Hz} + \text{threshold at 500 Hz}}{2} \), \( L_2 = \frac{\text{threshold at 1 kHz} + \text{threshold at 2 kHz}}{2} \) and \( L_3 = \frac{\text{threshold at 4 kHz} + \text{threshold at 8 kHz}}{2} \). The curvature \( k \) of the audiogram was then defined as:

\[
k = \frac{|L_1 + 2L_2 - L_3|}{(20\% |L_3 - L_1|)}
\]

Based on the value of \( k \), the audiograms are divided into two groups: ‘curved’ audiograms, with \( k > 0.8 \); and ‘straight’ audiograms, with \( k < 0.8 \). The ‘straight’ audiograms are subdivided into: ‘low’ frequency losses, with \( L_3 - L_1 < -10 \); ‘high’ frequency losses, with \( L_3 - L_1 > 10 \); and ‘flat’ losses with \(-10 < L_3 - L_1 < 10\). The curved audiograms are subdivided into: ‘low+high’ frequency losses, with \( L_2 < \frac{L_1 + L_3}{2} \); and ‘other’ losses. In order to check the categorisation, all audiograms were visualized and the classification compared with intuitively given descriptions. Audiograms that would not be classified as ‘low’, ‘flat’, ‘high’ or ‘high+low’ (but not necessarily ‘mid’ frequency losses), could be placed in the ‘other’ category manually. However, this turned out not to be necessary. (Therefore the ‘other’ category only contains ‘mid’ frequency hearing losses.) This finally leads to the five categories of hearing loss: ‘low’, ‘flat’, ‘high’, ‘high+low’ and ‘other’, examples of which are shown in figure 1.