Psychoacoustics in Audiology: applications for diagnosis and treatment of hearing disorders

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Introduction

One of the most important domains of applied psychoacoustic is the area of audiology. A wide variety of applications of psychoacoustical methods are employed to assess auditory dysfunctions as well as to achieve a satisfying fit of hearing aids (HA) or cochlear implants (CI).

In the following, two topics will be highlighted: (1) loudness scaling by means of a line length paradigm and (2) psychophysical measurements of pitch perception in cochlear implant subjects.

Loudness scaling revisited

The rating of perceived loudness is frequently in use in clinical audiology to control the adjustment and fitting of hearing aids or cochlear implants. There are a variety of methods applied to assess individual loudness functions. The “Würzburger Hörfeld” method is characterised by the application of seven verbal categories, which are attached aside a touch sensitive strip on a tray (Figure 1 left). Although many subjects feel comfortable with this verbalization, several constraints have to be regarded:

- the position and distance between verbal categories is chosen arbitrarily and the slope and the characteristics of the measured individual loudness function is influenced by this labelling
- Subjects are inclined to give their ratings at the position of the labels

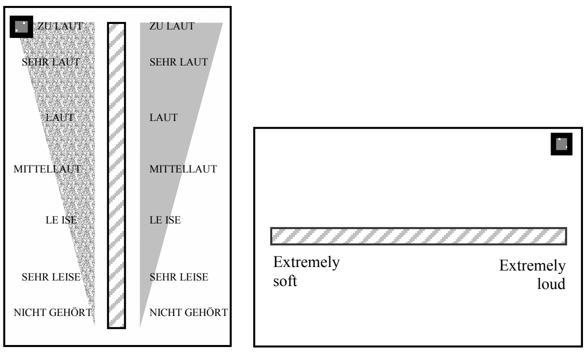

Figure 1: Tray with touch sensitive input. Left: Verbal categories attached (Würzburger Hörfeld), Right: minimal and maximal endpoints (line length scaling).

The line length paradigm applies only to categories, namely “extremely soft” and “extremely loud” at the beginning and the end of the touch sensitive input field (Figure 1, right). A study with normal hearing (Dissertation Kopf [1]) and with hearing impaired subjects (Dissertation Hiltenperger [2]) demonstrated, that the ratings of the subject were distributed more equally without peaks and the loudness functions derived with the line length paradigm were less dependent from frequency.

Correspondence of frequency to place with intracochlear electrodes

The correspondence of frequency to place of highest excitation on the basilar membrane has been investigated for a variety of species and functions to describes this mapping were published for example by Greenberg. Multichannel cochlear implants employ direct electrical stimulation of either dendrites or spiral ganglion cells of the auditory nerve. It is obvious, that the mechanisms in normal acoustic stimulation and electrical stimulation are different. Therefore it seems questionable if place/frequency maps derived from normal hearing are applicable for determining the pitch which is elicited by electrical stimulation.

Since more and more cochlear implant candidates with substantial residual hearing on either the implanted or the opposite ear were elected to receive a CI in our ENT department, it was possible to investigate the electric place/frequency map by means of a binaural pitch adjustment task in this special patient group.

Subjects and method

Six subjects received the Combi 40+ 12 channel implant (Med-El, Innsbruck). Due the comparably large electrode array, a stimulation of neural structures near the apex is possible with this device. Therefore it was expected, that low pitch sensations could be elicited and a comparison with low frequency acoustic residual hearing on the contralateral ear was possible. A customized research interface was utilized to deliver the electrical stimuli direct to the implant. Electrical stimuli were 500 ms biphasic pulse trains with a rate of 800 pps and a pulse duration of 26.6 µs. Pure tones with a rise/fall time of 25 ms were digitally generated and applied at the ear with residual hearing by means of a D/A converter, amplifier and a HDA 200 audiometric headphone. Electrical as well as acoustical stimuli were presented at comfortable loudness level, which was measured prior to the beginning of the experiment.

Six apically located electrodes were utilized as reference stimuli. The acoustic comparison stimulus was presented with 10 different initial frequencies from 125 to 1000 Hz with one repetition. In total, 20 adjustments for each test electrode were given. Electrical and acoustical stimuli werde presented alternating between implanted ear and headphone ear with a pause duration of 500 ms. The subjects adjusted the frequency of the acoustical stimulus by means of a rotary knob. The end of the run was indicated by pressing a stop button.

Results

The individual frequency adjustments showed a comparably large range of scatter. The average standard deviation for the adjustments were as high as 20% related to the average frequency adjustment. With increased test electrode number (which means electrodes more basal) the adjustments do increase as well (Figure 2). Four out of six subjects showed no significant difference of their adjustments between E1 and E2. The difference was larger between E2 and E3, where 5 out of six subjects showed significant differences (student-t-test, $p < 0.05$). The subjects also showed differences in terms of the absolute adjustments. Some subjects adjusted comparably low frequencies.

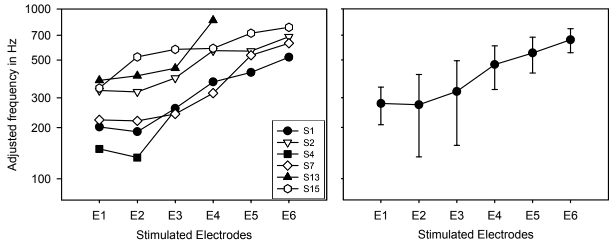

Figure 2: Pitch comparison between electrical and acoustical stimulation. Left: individual adjustments of six subjects. Right: Median and 50% range for 4 subjects (S4 and S13 excluded)

The median and 50% quartile range is displayed in figure 2 right. The median adjustment shows no clear difference between E1 and E2. Between E2 and E6 the average frequency adjustments increased up to 678 Hz.

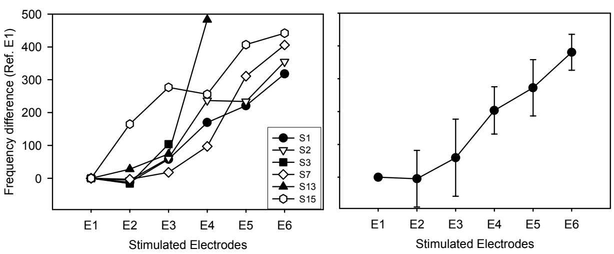

Figure 3: Pitch comparison between electrical and acoustical stimulation related to individual adjustment of E1. Left: individual adjustments of six subjects. Right: Median and 50% range for 4 subjects (S4 and S13 excluded)

Due to the between subject differences of the pitch adjustments – presumably caused by individual differences of insertion depth – error ranges are quite large for the averaged results. A calculation of the frequency difference in relation to the adjustment of E1 was conducted to eliminate individual insertion depth differences (Figure 3). With one exception, the subjects show resembling frequency adjustment differences. The frequency of E1 and E2 were adjusted nearly equal. A linear regression between the adjustments from E2 to E6 shows a clear correlation ($R^2 = 0.98$). The slope is 98 Hz/electrode which is approximately 40 Hz/mm and shallower than in normal hearing (70 Hz/mm).

Discussion

To illustrate the adjusted frequency to electrode place correspondence, figure 4 displays a X-Ray scan combined with the average adjustments (left) and the acoustic frequency place map according to Otte et al. on the right side for subject S4. There is a clear mismatch between the adjusted frequency and this map. Although the results should be considered carefully, because a severe to profound hearing loss will distort the reproduction and perception of pure tones in an unpredictable manner, there seems to be enough evidence to question the application of frequency/place maps derived from normal hearing to electrical stimulation.

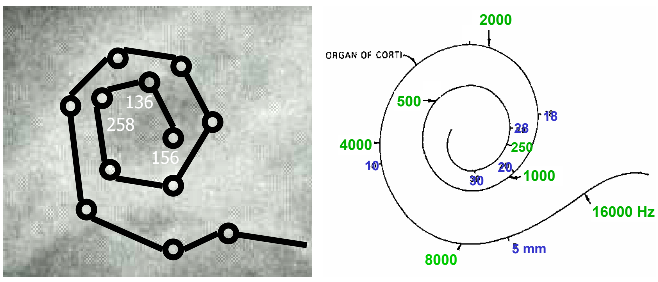

Figure 4: X-ray scan with electrical frequency place map for subject S4, (left). Right: Frequency place map according to Otte et al. (1978) for normal hearing.

Conclusion

- At or above the second turn of the cochlea, different electrode places elicit nearly the same pitch perception.
- The results do agree with histological studies, where at the apex of the cochlea no spiral ganglion cells were present.
- Frequency place maps derived from normal hearing seem to be not appropriate for electrical stimulation by means of multichannel intracochlear electrodes.

Acknowledgements

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References

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[2] Hiltensperger, C. (2004) Untersuchung der Lautstärkeempfindung Schwerhöriger mit der "Methode der Linienlänge", Dissertation Ludwig-Maximilians-Universität München.