Loudness Perception in Listeners with Sensorineural Hearing Impairment

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Stefan Launer
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Erstreferent: Prof. Dr. Dr. Birger Kollmeier
Korreferent: Prof. Dr. Volker Mellert
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Abstract

People suffering from a cochlear hearing loss show different performance than normal in several different auditory functions. In this study loudness perception in the hearing impaired is investigated. The perceptual consequences of cochlear hearing loss with respect to loudness perception are raised absolute threshold, loudness recruitment, reduced loudness summation and reduced frequency selectivity. Probably two components contribute to the alterations in cochlear processing of sounds due to cochlear damage. One component is due to the loss of active processes, yielding less compressive processing in the cochlea ("compression loss"). The second component accounts for the reduced sensitivity of the inner ear, causing solely a frequency–dependent attenuation ("sensitivity loss"). Raised threshold represents a consequence of the latter component, while loudness recruitment, reduced loudness summation and reduced frequency selectivity probably reflect some of the perceptual consequences of the former component. The aim of this thesis is to test these assumptions by measuring and modeling loudness perception and its relation to other auditory functions.

Loudness scaling experiments were performed with normal–hearing subjects, employing magnitude estimation, restricted magnitude estimation and a categorical scale with many categories using a narrowband noise as stimulus. The results obtained with these three methods are very similar. Specifically, all measured loudness functions exhibit a curved shape and a steeper increase near threshold than at mid and high levels when plotted on a logarithmic scale. A less curved loudness function is observed for measurements employing a categorical scale with 11 categories. Since this method exhibits also a practical advantage, it is used throughout this study.

Next, the relation between audiometric threshold shift and slope of loudness function is investigated. Therefore, the loudness functions of 67 sensorineural hearing–impaired subjects measured using the categorical scale with 11 categories are analysed. It is shown that on average the slope of the loudness function increases with increasing hearing loss but a large intersubject variability is observed even for subjects suffering from a similar amount of hearing loss. Among the different explanations the most appealing is that the variability might be due to different contributions of the two different components of sensorineural hearing impairment. Furthermore, categorical scaling is applied to investigate the influence of signal bandwidth on perceived loudness. Categorical scaling is performed with 9 normal–hearing and 14 sensorineural hearing–impaired subjects employing bandfiltered noises with bandwidths ranging from 1–6 critical bands. For normal–hearing listeners, perceived loudness increases with increasing bandwidth in the same way as expected from the literature ("loudness summation"). In the hearing impaired, loudness summation is strongly reduced. This finding could either be explained by increased auditory filter bandwidths or reduced compressive processing in the impaired cochlea or a combination of both. Finally, two extensions of Zwicker's loudness model are applied to model the measured loudness curves of hearing–impaired listeners. Reduced frequency selectivity is modeled in both approaches by the dependence of "normal" auditory filters on level. Thus, it is assumed that the auditory filter bandwidth of the hearing impaired is the same as that of normal–hearing subjects at the same sound pressure level (dB SPL) but differs when compared at the same sensation level (dB SL). In the first approach, hearing impairment is modeled by an inaudible, internal noise. It is assumed that hearing impairment resembles a masking condition in normal–hearing subjects. Thus, raised absolute threshold and recruitment are taken into account by one single component ("one–component approach"). In the second approach, both factors, raised threshold and recruitment, are taken into account separately ("two–component approach"). Raised threshold is achieved by a frequency–dependent attenuation while loudness recruitment is modeled by increasing the exponent in the power law, which relates specific loudness to excitation patterns. In this approach it is assumed that the exponent reflects the compressive processing in the cochlea. This is motivated by the physiological evidence that the compression loss is probably largely independent of the sensitivity loss. The one–component approach describes the data on average quite well but fails to predict individual data correctly. Adjusting further parameters does not improve the predictions in this approach. The two–component approach correctly describes the data, if the exponent of the power law is adjusted to the individual data obtained with narrowband stimuli. Moreover, this approach also predicts the loudness functions obtained with broadband stimuli correctly. Hence, the physiologically motivated two–component approach appears to model different aspects of cochlear hearing loss in a more realistic way than the one-component approach.

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