Available online at www.sciencedirect.com
ScienceDirect
Hearing Research 239 (2008) 126–140
Hearing Research
www.elsevier.com/locate/heares

Research paper

The effect of noise-induced sloping high-frequency hearing loss on the gap-response in the inferior colliculus and auditory cortex of guinea pigs

Shan-Kai Yin [a], Yan-Mei Feng [a], Zheng-Nong Chen [a], Jian Wang [a,b,*]

[a] *The Affiliated Sixth People's Hospital, Otorhinolaryngology Institute, Shanghai Jiao Tong University, Shanghai 200233, China*
[b] *School of Human Communication Disorder, Dalhousie University, Halifax, Canada B3H 1R2*

Received 20 November 2007; received in revised form 11 January 2008; accepted 7 February 2008
Available online 15 February 2008

Abstract

Gap detection has been used as an evaluation tool for temporal processing in subjects with sensorineural hearing loss (SNHL). However, the results from other reports are varied making it difficult to clearly define the impact of SNHL on the temporal processing ability of the auditory system. Specifically, we do not know if and how a high-frequency hearing loss impacts, presumably through off-channel interaction, the temporal processing in low-frequency channels where hearing sensitivity is virtually normal. In this experiment, gap-evoked responses in a low-frequency band (0.5–8 kHz) were recorded in the inferior colliculus (IC) and auditory cortex (AC) of guinea pigs through implanted electrodes, before and after a slopping high-frequency hearing loss, which was induced by over-stimulation using a 12-kHz-tone. The results showed that the gap thresholds in the low-frequency region increased gradually and became significantly higher 8 weeks after the induced high-frequency hearing loss. In addition, the response latency was slightly increased in the IC but this was not true for the AC. These results strongly indicate that a high-frequency hearing loss exerted an off-channel impact on temporal processing in the low-frequency region of the auditory system.

Keywords: Gap-evoked response; High-frequency hearing loss; Acoustic over-stimulation; Inferior colliculus; Auditory cortex; Guinea pig

1. Introduction

Sensorineural hearing loss (SNHL) impacts the lives of more than 10% of the general population and more than 25% of those over 65 (Rahko and Hakkinen, 1979), mainly by reducing their ability to understand speech. In addition to the loss of audibility in the frequency region where damage to the auditory peripheral (the cochlea) exists, signal conduction and processing are also distorted in the central auditory system (Moore, 1996; Syka, 2002). Poor supra-threshold processing and coding errors have also been recognized in both intensity and frequency processing and more recently in temporal processing.

Gap detection, modulation detection and forward masking are three major methods for evaluating auditory temporal resolution. These can be tested in both behavioral experiments and objective observations. Gap detection evaluates the ability to detect a silent gap or a great drop of signal intensity embedded in an otherwise continuous or consistent stimulus. This test has been widely used for evaluating the impact of hearing loss on the temporal resolution of the auditory system in a quite few studies in both animals (e.g., Rybalko and Syka, 2005; Salvi and Arehole, 1985; Wang et al., 2006) and human subjects (e.g., Rupp et al., 2002, 2004). However, the role of SNHL on temporal resolution is far from conclusive, largely due to technical issues which have been summarized by Moore (1996).

* Corresponding author. Address: The Affiliated Sixth People's Hospital, Otorhinolaryngology Institute, Shanghai Jiao Tong University, Shanghai 200233, China. Tel.: +86 21 64834143.
E-mail address: jian.wang@dal.ca (J. Wang).

0378-5955/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.heares.2008.02.002

More specifically, we do not know if a high-frequency SNHL impacts the temporal resolution of low-frequency channels where the auditory sensitivity is virtually normal. If this is the case, the change in temporal processing of the low-frequency channels should occur through an off-channel effect (more likely involves central auditory plasticity), in addition to the distorted input from auditory peripheral. In most of the previous studies, however, the SNHL spread to the low-frequency region where the temporal processing was evaluated, even though it was biased to high-frequency regions in some studies (e.g., Irwin et al., 1981; Moore, 1993). Moreover, the effect of aging was not clearly separated from the effect of the hearing loss in most of the previous studies. Therefore, it is not clear if there is an off-channel impact caused by a high-frequency hearing loss on the temporal resolution of low-frequency channels where hearing thresholds would be normal. Such an off-channel impact on temporal processing is both theoretically possible and practically important. The off-channel effect of cochlear lesions on signal processing has been evident in both intensity and frequency coding (e.g., Florentine et al., 1993; Nelson and Freyman, 1986; Schroder et al., 1994; Simon and Yund, 1993; Wang et al., 1996), but has not been studied in temporal processing.

Auditory systems appear to be able to integrate information from all parallel frequency channels to improve temporal resolution. This integration is demonstrated by the fact that gap-detection thresholds will decrease as the bandwidth of gap markers increase. On the other hand, gap-detection thresholds in hearing impaired subjects have been repeatedly found to be elevated when broadband signals were used as gap markers (Buus and Florentine, 1985; Buus et al., 1984; Salvi and Arehole, 1985). This apparent reduction in temporal resolution is largely due to the loss of audibility in high-frequency regions. However, it is not entirely clear whether the temporal resolution in the residual channels will change if there is no loss of sensitivity in these channels. Some studies claimed that there was no difference in the gap detection between normal and hearing-impaired subjects when a sinusoidal signal (Bacon and Moore, 1987; Glasberg and Moore, 1989; Moore and Glasberg, 1988) or a narrow band noise (Lister et al., 2000) was used as gap marker. However, for stimuli that contain slow random fluctuations in amplitude, such as narrow band noises, subjects with SNHL often perform more poorly in tasks such as gap detection even when the stimuli are well above threshold and all fall within the audible frequency range (Bacon and Moore, 1987; Buus and Florentine, 1985; Florentine and Buus, 1984; Glasberg et al., 1987). As pointed out by Moore (1996), one of the reasons for the uncertainty about the consequence of SNHL on gap-detection threshold is due to the variation in the platform or the sound level on which gap detection is compared. Comparison at the same sound pressure level (SPL) or sensation level (SL) often produced different results (Fitzgibbons and Wightman, 1982; Florentine and Buus, 1984; Glasberg and Moore, 1989; Glasberg et al., 1987; Moore and Glasberg, 1988; Moore et al., 1993, 1989; Tyler et al., 1982).

Fully understanding the impact of high-frequency hearing loss on the temporal acuity in the low-frequency region with normal sensitivity is practically important because sloping high-frequency hearing loss is the most common configuration of SNHL, especially in age-related SNHL cases. However, to the best of our knowledge, only one paper published so far has evaluated the temporal resolution in low-frequency regions after restrictive high-frequency hearing loss (Fitzgibbons and Gordon-Salant, 1987). Unfortunately, the authors did not discriminate the effect of hearing loss from aging in this study.

Given the difficulty in controlling age, configuration and etiology of hearing loss in human subject recruitment, we though it would be beneficial to address this issue in a well-controlled animal experiment. In the present study, we produced relatively consistent high-frequency hearing loss by using noise over-stimulation. Next, we evaluated the gap-responses in the low-frequency region after a high-frequency hearing loss. The goal of this study was to explore the potential off-channel impact of the hearing loss on gap-detection threshold. The evaluation of gap-responses was performed in the region where the hearing threshold was virtually normal; thereby the issue of using SPL versus SL was avoided.

2. Materials and methods

2.1. Grouping and schedule

In total, 28 healthy albino guinea pigs aged 3–6 months were used in this experiment. Otoscopy examination was performed to exclude ceruminal impaction and middle ear infection. Out of the 28 guinea pigs, 4 were used for evaluating the cochlear lesion in scanning electronic microscopy (SEM) and 24 were used for chronological observation of evoked responses. The 24 animals were randomly attributed into two groups: 16 in an experimental group and 8 in a control group. All of these 24 animals were implanted with metal electrodes unilaterally in both the inferior colliculus (IC) and auditory cortex (AC). A control recording of all evoked responses was performed two weeks after the surgery. The animals in the experimental group were then exposed continuously to a 12-kHz pure tone at 110 dB SPL for 30 h. The whole set of evoked responses were re-tested at 3 days, and then 1, 2, 3, 4, 6 and 8 weeks after the exposure. The recording was done in the control group at the exact same time line as the experimental group. After the final electrophysiological measurement, an electrolytic lesion was performed through the implanted electrode in both IC and AC and the tip location of the electrodes was confirmed by the examination of brain slices. The cochleae from the animals in the experimental group were harvested to evaluate the cochlear lesion. Since we did not see adequate hair cell loss corresponding to the hearing loss shown in the functional test,