The American Journal of Otology
18:S17–S18 © 1997, The American Journal of Otology, Inc.

Optical Imaging of Cat Auditory Cortical Organization After Electrical Stimulation of a Multichannel Cochlear Implant: Differential Effects of Acute and Chronic Stimulation

*H. R. Dinse, †G. Reuter, †S. M. Cords, *B. Godde, *T. Hilger, and †T. Lenarz

**Institut für Neuroinformatik, Theoretische Biologie, Ruhr-Univ. Bochum, and †Med. Hochschule, Exp. HNO, Hannover, Germany*

Objective: To study the effects of electrical stimulation on cortical activation patterns.
Materials and Methods: Optical imaging of auditory cortex in cats that are acutely and chronically electrically stimulated with cochlear implants.
Results: Chronic electrical stimulation results in expansion of cortical territory and overlap.
Conclusion: Effects of chronic electrical stimulation are comparable to use-dependent cortical plastic reorganization. **Key Words:** Cochlear implant—Cortical activation patterns.
Am J Otol **18**(suppl):S17–S18, 1997.

Prosthetic management with electrical cochlear implant stimulation devices is increasingly used to treat prenatal or postnatal damage of sensorineural origin. However, the effects of such electrical stimulation on cortical activation patterns are poorly understood. It is a key feature of cortical organization in each sensory domain to contain topographically ordered representational maps of the outside world. For the auditory cortex, a cochleotopic arrangement was described based on extensive microelectrode mapping experiments (1).

In recent years, new technologies have been developed that allow the simultaneous assessment of two-dimensional activity distributions. They are based on differences of light absorption of the oxygenated and deoxygenated microcirculation (2). Such optical imaging techniques offer unique advantages in exploring higher brain functions, including the neural basis of sensory processing and plastic adaptive mechanisms. We used optical imaging of intrinsic signals to address the question of the effects of electrical cochlear stimulation on the topography of cat auditory cortex in acutely deafened, neonatally deafened, and neonatally deafened and persistently stimulated animals.

Supported in part by DFG Neurovision Ey 17-3 and BMFT 01VJ 9005.

Address correspondence and reprint requests to Dr. Hubert R. Dinse, Institut fur Neuroinformatik, Theoretische Biologie, Ruhr-Universität. Bochum RUB, D-44780 Bochum, Germany.

MATERIALS AND METHODS

To study the effects of electrical stimulation of several frequency sites on the topography of the auditory cortex, we implanted multichannel electrodes into the scala tympani of neonatally and acutely deafened anesthetized cats (3). As a rule, four pairs could be inserted into the scala tympani. For optical measurements, we used a Lightstar II imaging and acquisition system (LaVision) with a 2-mHz A/D converter and a Peltier-cooled, slow-scan, 12-bit digital CCD camera. The cortex was illuminated with a 546-nm light source. Images were computed by subtracting a stimulus from a non-stimulus condition (4). Recordings of local field potential maps using glass microelectrodes in the same individual animals were used to provide electrophysiologic controls (4,5).

RESULTS

Acutely deafened animals that had had a normal hearing experience lasting several months served as controls in this study of the effects of electrical stimulation of various electrode pairs on activation pattern in the auditory cortex. Each pair evoked circumscribed zones of activity and systematic variation of the stimulation pairs and thus of the cochlear frequency sites revealed a systematic shift of the response areas indicating preservation of cochleotopic selectivity.

In experiments using neonatally deafened cats that had never experienced hearing and that were recorded between 6 and 12 months of age, we were able to confirm these findings; however, cochleotopy appeared less sharp and profound. In addition, reliability and stability of responses was less robust. The results indicate that also in

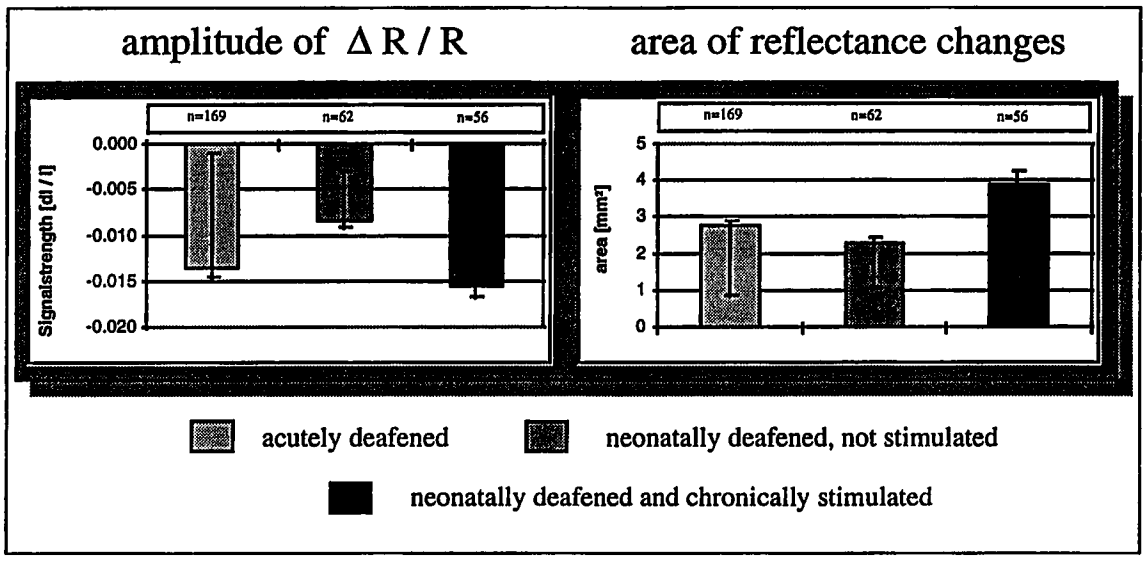

FIG. 1. Similarities and differences obtained for acutely deafened animals, neonatally deafened animals, and neonatally deafened animals receiving chronic stimulation. n, number of maps measured under various conditions; both SD and SEM are shown.

neonatally deafened animals the auditory cortex can be activated in a coarse topographic fashion, at least.

In the neonatally deaf animals that received chronic stimulation, the situation was somewhat different. Chronic stimulation was accomplished with the continuous interleaved sampler strategy applied for 12 weeks, 5 days a week, 5 hours a day, starting when the cats were 10 weeks old. The response areas corresponding to the chronic-stimulation electrode configurations were broader and showed less variability than the response areas evoked by the other electrode configurations, indicating expansion of cortical territory typical of cortical reorganizational plasticity.

To provide a more detailed analysis, Figure 1 summarizes the similarities and differences obtained for acutely deafened, neonatally deafened, and neonatally deafened animals receiving chronic stimulation. As for signal strength, we found the smallest signal amplitudes in neonatally deafened but not stimulated animals ($p < 0.0005$ compared with the other two groups). There were also significant differences between the acutely deafened animals and those receiving chronic stimulation, which showed the largest amplitudes ($p < 0.05$). Another difference was found for the size of the area that showed reflectance changes expressed as mm^2 cortex. Chronic stimulation resulted in large areas of reflectance changes ($p < 0.0005$ compared with nonstimulated animals), but acutely deafened animals also had significantly larger areas of reflectance changes than neonatally deafened animals ($p < 0.05$). Combined, these quantitative comparisons indicates that optical imaging can reveal differences for the three stimulation conditions tested.

CONCLUSION

We can demonstrate that electrical stimulation with a multichannel cochlear implant device generates activity throughout the auditory pathway, including the cortical auditory cortex, that leads to cochleotopic patterns in the corresponding frequency areas of auditory cortex that are compatible with known activity maps following acoustic stimulation. These maps were measured by means of optical imaging techniques that provide a fine spatial resolution together with the advantage of repeated measurements that allow assessment of parameter dependencies of these maps.

After chronic stimulation, we found large and highly overlapping areas of reflectance changes. Enlargement of representational maps and topographic overlap are a typical signature of use-dependent cortical plastic reorganization. The adaptational consequences of long-term stimulation and the type of evoked representational activity patterns are of considerable importance for our understanding of the function and possible mechanisms underlying the implant-mediated sound perception. Specifically, plastic adaptational properties of cortical neurons may provide the substrate involved in mediating the highly variable improvement of open speech understanding with practice that is often observed in patients with hearing aids.

REFERENCES

1. Merzenich MM, Knight PL, Roth GL. Representation of cochlea within primary auditory cortex in the cat. *J Neurophysiol* 1975;38: 231–249.
2. Frostig RD, Lieke EE, Ts'o DY, et al. Cortical functional architecture and local coupling between neuronal activity and the microcirculation revealed by in vivo high-resolution optical imaging of intrinsic signals. *Proc Natl Acad Sci U S A* 1990;87:6082–6.
3. Dinse HR, Godde B, Hilger T, et al. Optical imaging of cat auditory cortical organization following acute electrical stimulation of a multi-channel cochlear implant. *Internal report.* Bochum: Institut für Neuroinformatik, 1996;96-04:1–15.
4. Godde B, Hilger T, von Seelen W, et al. Optical imaging of rat somatosensory cortex reveals representational overlap as topographic principle. *Neuroreport* 1995;7:24–8.
5. Hilger T, Berkefeld T, Godde B, et al. Relation between optical imaging maps and spiking and non-spiking point-spread functions recorded in supragranular and granular laminae in rat somatosensory cortex. *Soc Neurosci Abstr* 1996;22:538–4.