were fundamentally different from those evoked by a real sound, we proposed that tinnitus originates in the brain.

To identify potential drugs to treat tinnitus, we developed rat behavioral models of tinnitus. Like humans, rats exposed to high intensity noise developed tinnitus; in some cases, the tinnitus was transient while in others it was persistent. Humans develop tinnitus after taking high doses of aspirin (salicylate). Rats treated with high doses of salicylate reliably developed behavioral evidence of tinnitus. Memantine and scopolamine have been proposed as treatments for tinnitus, but neither drug suppressed salicylate-induced tinnitus. However, tinnitus was completely suppressed by a potassium channel modulator. We evaluated the neural correlates of salicylate-induced tinnitus along the auditory pathway. High doses of salicylate suppressed otoacoustic emissions and the compound action potential from the auditory nerve. Despite the fact that salicylate suppressed the neural output from the cochlea, it caused a large increase in the sound-evoked activity in the auditory cortex. That is, the auditory cortex became hyperactive after salicylate-induced hearing loss, a possible neural correlate of hyperacusis or sound intolerance; however, salicylate caused a significant decrease in spontaneous activity. These results suggest that the central auditory system becomes hyperactive following cochlear damage. This hyperactivity may be due to a loss of centrally mediated inhibition.

Richard Salvi, PhD, is a professor and director with the University at Buffalo.

Imaging Brain Function in People with Tinnitus

By Jennifer Melcher

We focused on recent imaging and evoked potential data demonstrating abnormally elevated responses to sound in people with tinnitus. Some of the response elevations are related to the hyperacusis that often accompanies tinnitus. Others are related to tinnitus per se. The subjects for our studies are patients with tinnitus of various suspected etiologies and with a variety of perceptual characteristics. The subjects have clinically normal hearing thresholds but have threshold loss at frequencies above the standard clinical range, suggesting damage to the auditory periphery that may have been instrumental in the development of tinnitus. Our studies examine brain activity using functional magnetic resonance imaging (fMRI) and the auditory brainstem response (ABR). Sound-evoked activity measured with these two techniques is compared between tinnitus subjects and threshold- and age-matched subjects without tinnitus.

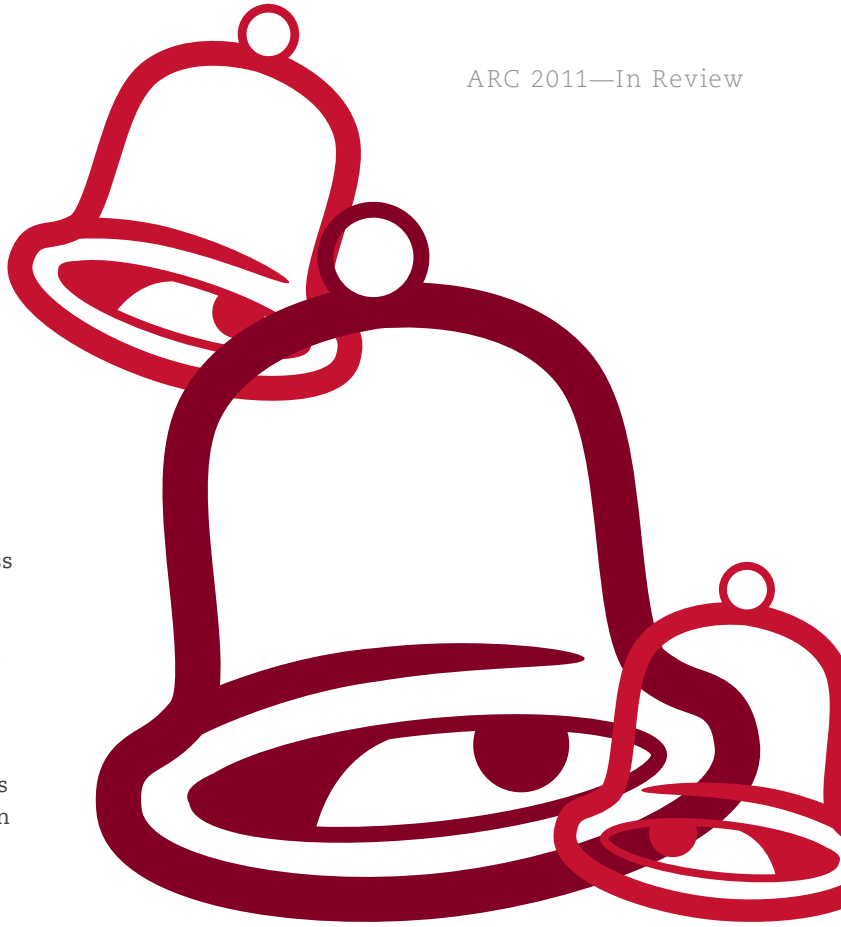
Our fMRI data show elevated responses to sound in the inferior colliculi that occur with hyperacusis, while the ABR data show an elevated ratio of wave V to wave I amplitude related to tinnitus. At the level of the cerebral cortex, the primary auditory cortex shows elevated responses to sound related to both hyperacusis and tinnitus. We hypothesize that the tinnitus-related elevations may occur as a result of over-attention to the auditory domain. Overall, the results are consistent with theories that tinnitus and hyperacusis arise from hyperactivity within the central auditory system.

Jennifer Melcher, PhD, is associate professor at Harvard Medical School and Massachusetts Eye and Ear Infirmary.

Hyperacusis

By Craig Formby

We discussed current research and scientific progress in the understanding of a significant secondary condition to tinnitus, namely, hyperacusis. Hyperacusis is a reduced tolerance to the loudness of sounds in relation to that normally judged to be tolerable by a typical listener. Hyperacusis may or may



not be associated with measurable hearing loss and has been reported as a coexisting condition with tinnitus in approximately 85–90 percent of patients who report this sound tolerance problem. It manifests audiologically as a collapse of the loudness discomfort levels (LDLs) upon the audiometric thresholds, leading to a reduced auditory dynamic range. Hyperacusis tends to be a bilateral condition, uniformly affecting loudness judgments across all frequencies of the audiogram more or less equally. Phenomenologically, hyperacusis is consistent with an abnormal increase or resetting of the overall gain within the central auditory pathways, resulting in an inordinately high level of auditory activation. The associated physical symptoms may be pain, fullness, and/or pressure within the ears in response to sound. Hyperacusis is related to the physical properties of the sound simulation alone, rather than to the context or emotional meaning associated with the stimulation. Thus, if corresponding limbic and autonomic nervous system activation occurs (as is believed to be the case in related conditions of misophonia or phonophobia), then this activation is considered to be secondary to the primary hyperacusis problem.

Experimental evidence for the adaptive plasticity of the gain control process was presented. Ostensibly, this process is mediated by central neuronal mechanisms that regulate the supra-threshold sensitivity of the auditory system. The gain process was shown to be responsive to long-term changes in the background sound levels to which normal-hearing listeners are exposed. In turn, chronic systematic changes in the levels of their background exposures were shown to give rise to predictable increases or decreases in the perceived loudness of sounds. Clinical examples of these plastic effects on loudness perception also were described for patients who were treated for their tinnitus and hyperacusis conditions by tinnitus retraining therapy (TRT). TRT, which combines directive counseling and sound therapy in a structured treatment protocol, typically leads to progressively elevated LDLs and sizeable increases in the patients' dynamic ranges (for loudness) over the course of treatment (at least when sound therapy is provided by low-level, bilateral noise generators). These significant secondary treatment effects have subsequently been studied in a randomized controlled clinical trial. The study sample for the trial included previously unsuccessful hearing-aid users who, before treatment, were limited by their hyperacusis conditions and/or diminished dynamic ranges to amplified sound. The treatment effects for the full TRT protocol (counseling combined with sound therapy), in terms of increased LDLs and dynamic

range expansion, were markedly superior to partial treatment effects achieved for either counseling alone or sound therapy alone. Moreover, evidence was presented that the full treatment effects were clinically beneficial for improving both word recognition performance and hearing aid benefit. Thus, principles of TRT appear to offer great promise for improving hearing aid benefit among hearing-impaired listeners with diminished sound tolerance and, in turn, for reducing their reliance on compression and related signal processing strategies to achieve successful aided listening.

Recommended readings are listed below for those interested in learning more about hyperacusis and some of the topics covered in this presentation.

Craig Formby, PhD, is a distinguished graduate research professor with the University of Alabama.

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Recommended Reading

Baguley DM, Andersson G. (2007) *Hyperacusis: Mechanisms, Diagnosis, and Therapies*. San Diego: Plural.

Formby C, ed. (2007) Hyperacusis and related sound tolerance complaints: differential diagnosis, treatment effects, and models. *Semin Hear* 28(4).

Formby C, Gold SL. (2002) Modification of loudness discomfort level: evidence for adaptive chronic auditory gain and its clinical relevance. *Semin Hear* 23(1):21–34.

Formby C, Sherlock LP, Gold SL. (2003) Adaptive plasticity of loudness induced by chronic attenuation and enhancement of the acoustic background. *J Acoust Soc Am* 114:55–58.

Hazell, JWP, Sheldrake JB. (1992) Hyperacusis and tinnitus. In: Aran JM, Dauman R, eds. *Fourth International Tinnitus Seminar*. Amsterdam, The Netherlands: Kugler, 249–253.

Jastreboff PJ, Hazell WP. (2004) *Tinnitus Retraining Therapy: Implementing the Neurophysiological Model*. New York: Cambridge University Press.

Tinnitus: Psychological Distress and Treatment

By Laurence McKenna

Tinnitus is one of the most prevalent symptoms to affect humanity. Not everyone with tinnitus suffers as a consequence. This represents one of the biggest challenges in understanding and treating tinnitus. An intuitive response is to suggest that variations in the psycho-physical characteristic of tinnitus must account for why some people suffer and others do not. To date, however, the evidence does not support this explanation. A psychological model suggests that distress arises when a person makes overly negative interpretations of tinnitus. In other words the person's view of tinnitus is colored by "all or nothing," "catastrophic," or similar thinking. Such thinking leads to an increase in the person's stress arousal and to emotional distress. This in turn leads to selective attention and monitoring of tinnitus. The person therefore becomes more aware of tinnitus and this feeds their overly negative thinking. The perception of threat associated with tinnitus also leads the person to act in ways that he or she believes will limit the impact of tinnitus; very often this prevents the person from discovering that his or her interpretation of tinnitus is overly negative. There is now considerable evidence to support the component parts of this understanding of tinnitus. The vicious circles involved maintain the person's distress. Habituation is slowed and the person may even