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Session 1aPP: In Memory of Bertram Scharf: Five Decades of Contributions to Auditory Perception

1aPP8. Inspiration from Bertram Scharf's work

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In 1990, Bertram Scharf and I discussed about me doing a post doc in his laboratory. The opportunity to work with Bertram did not materialize, but his work in loudness, efferents, and attention has been a continuing inspiration not only for my own research but also for auditory perception, physiology and audio engineering in general. For example, a Google Scholar search of "Bertram Scharf" on January 3, 2013 produced 1526 citations for his top 10 papers, with 6 on loudness and critical bands, 2 on efferents and 2 on attention. Here I highlight several recent studies that have been inspired by Scharf's work. The first study showed significant loudness adaptation in patients with auditory neuropathy, particularly those with otoferlin deficits. This result directly supports Scharf's proposition that simple loudness adaptation is due to limited excitation in the sensory process, which in this case can be pinned down to transmitter release and replenishment in the hair cell and nerve synapse. The second study extended Scharf's theoretical work in efferents and attention to improving feedback control in cochlear implant users and tinnitus sufferers. This line of work could help improve cochlear implant speech performance and reduce internal gain to alleviate tinnitus.

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INTRODUCTION

Bert Scharf's work in loudness, efferent function and attention has been a continuing inspiration for auditory perception, physiology and audio engineering. For example, a Google Scholar search of "Bertram Scharf" produced 1526 citations for his top 10 most cited papers, with 6 on loudness and critical bands, 2 on efferents and 2 on attention (Table 1).

TABLE 1. Top 10 cited papers by Bertram Scharf, retrieved on January 2, 2013 (http://scholar.google.com).

Title	Author and Journal	Citations
1. Critical bands	B Scharf - Foundations of modern auditory theory, 1970 - Academic Press, New York	415
2. A model of loudness summation	E Zwicker, B Scharf - Psychological review, 1965	241
3. Loudness	B Scharf - Handbook of Perception, Volume IV. Hearing, 1978 - Academic Press, New York	165
4. Frequency selectivity in normally-hearing and hearing-impaired observers	M Florentine, S Buus, B Scharf, E Zwicker - Journal of Speech and Hearing Research, 1980	135
5. On the role of the olivocochlear bundle in hearing: 16 case studies	B Scharf, J Magnan, A Chays - Hearing research, 1997	117
6. Focused auditory attention and frequency selectivity	B Scharf, S Quigley, C Aoki, N Peachey, A Reeves- Perception & Psychophysics, 1987	109
7. Loudness adaptation	B Scharf - Hearing research and theory, 1983 - Academic Press New York	94
8. Effective attenuation of signals in noise under focused attention	H Dai, B Scharf, S Buus - The Journal of the Acoustical Society of America, 1991	90
9. On the role of the olivocochlear 10. bundle in hearing: a case study	B Scharf, J Magnan, L Collet, E Ulmer, A Chays - Hearing research, 1994	82
10. Audition II: Loudness, pitch, localization, aural distortion, pathology	B Scharf, AJM Houtsma - Handbook of perception and human performance,1986 - J. Wiley & Sons, New York	78

STUDIES INSPIRED BY SCHARF

Here I highlight several recent studies that have been directly influenced by Bert Scharf's work. The first project showed significant loudness adaptation in patients with auditory neuropathy, particularly those with synaptic transmission deficits. This result directly supports Scharf's proposition that simple loudness adaptation is due to limited excitation in the sensory process, which in this case can be pinned down to transmitter release and replenishment in the hair cell and nerve synapse. The second project extended Scharf's theoretical work in efferents and attention to improving feedback control in cochlear implant users and tinnitus sufferers.

Loudness Adaptation

I first met Bert on August 1, 1989 when he came to Syracuse University to give an invited talk about loudness adaptation. I took detailed notes as required by Joe Zwislocki, the host of his talk and the teacher of my psychophysics course. I learned from Bert's talk that the auditory system does not adapt to sound except for two conditions. The first exception is that normal-hearing listeners can adapt to low-level, high-frequency sounds, a process termed simple loudness adaptation. The second exception is that some hearing-impaired listeners, such as those with an acoustic tumor, can totally adapt to a constant sound. Bert also talked about induced adaptation, the directional and contextual effects, as well as methods used to measure and quantify adaptation. He didn't believe attention plays any significant role, nor did he believe that simple decrease in discharge rate is the neural code. Instead he advocated for a spatially-constant but temporally-variant mechanism: "sensory systems adapt to steady, prolonged stimulation that is concentrated on a constant set of receptor units. Fluctuations in the level of stimulation reduce or eliminate adaptation. Fluctuations may be in the stimulus or in the sensory organ" (Scharf, 1983 P.51).

Bert's idea on the "constant set of receptor units" has been greatly expanded as significant adaptation occurs in cochlear-, brainstem-, and midbrain-implant subjects (Tang *et al.*, 2006; Lim *et al.*, 2008). Recently we also made a surprising finding that severe frequency-independent loudness adaptation (Fig. 1) occurs in a subset of auditory neuropathy subjects with deficient synaptic transmission (Starr *et al.*, 1998; Roux *et al.*, 2006). This finding is surprising because previous studies showed essentially normal auditory processing in these subjects when their body temperature was normal. Perhaps continuous stimulation and higher than normal body temperature can both disrupt the transmission process from inner hair cells to the auditory nerve fibers. The new finding reinforce the idea that loudness adaptation can be due to limited excitation at any level from the cochlea to the brain.

We have also started to test Scharf's idea on the role of temporal fluctuations in loudness adaptation. Our preliminary data showed that amplitude modulation, indeed, can reduce loudness adaptation to a high-frequency pure tone.

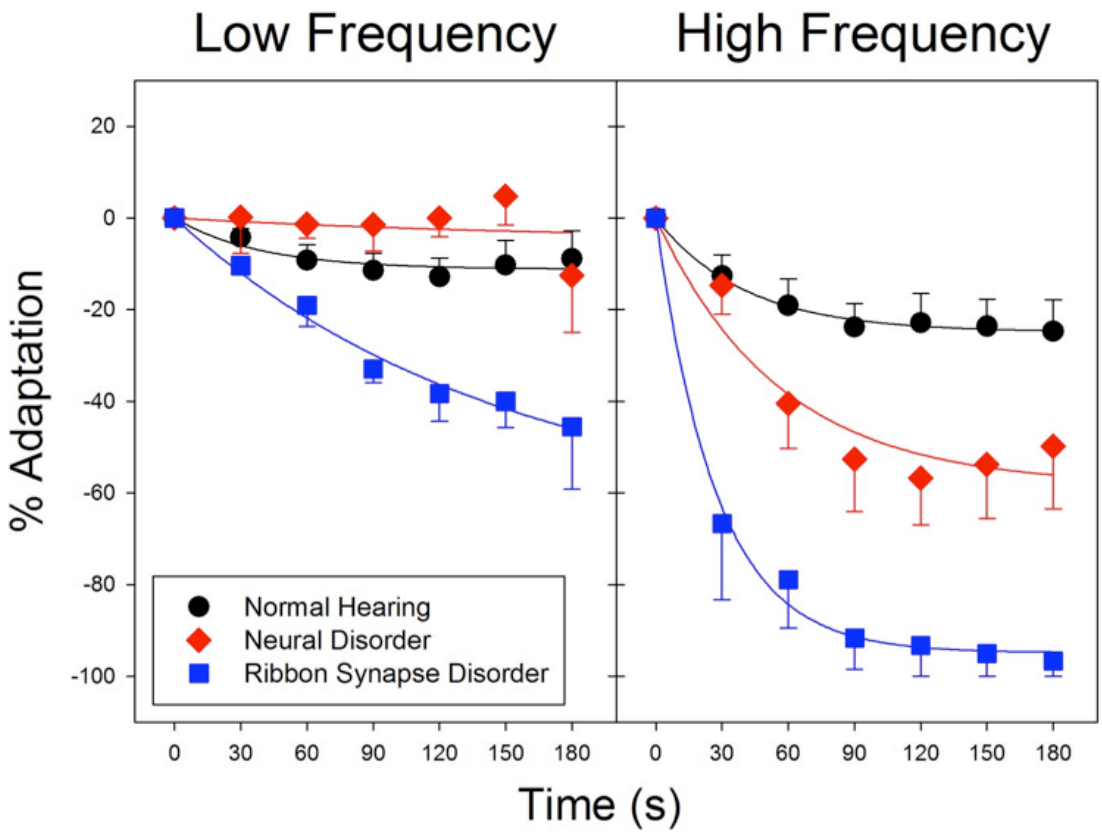
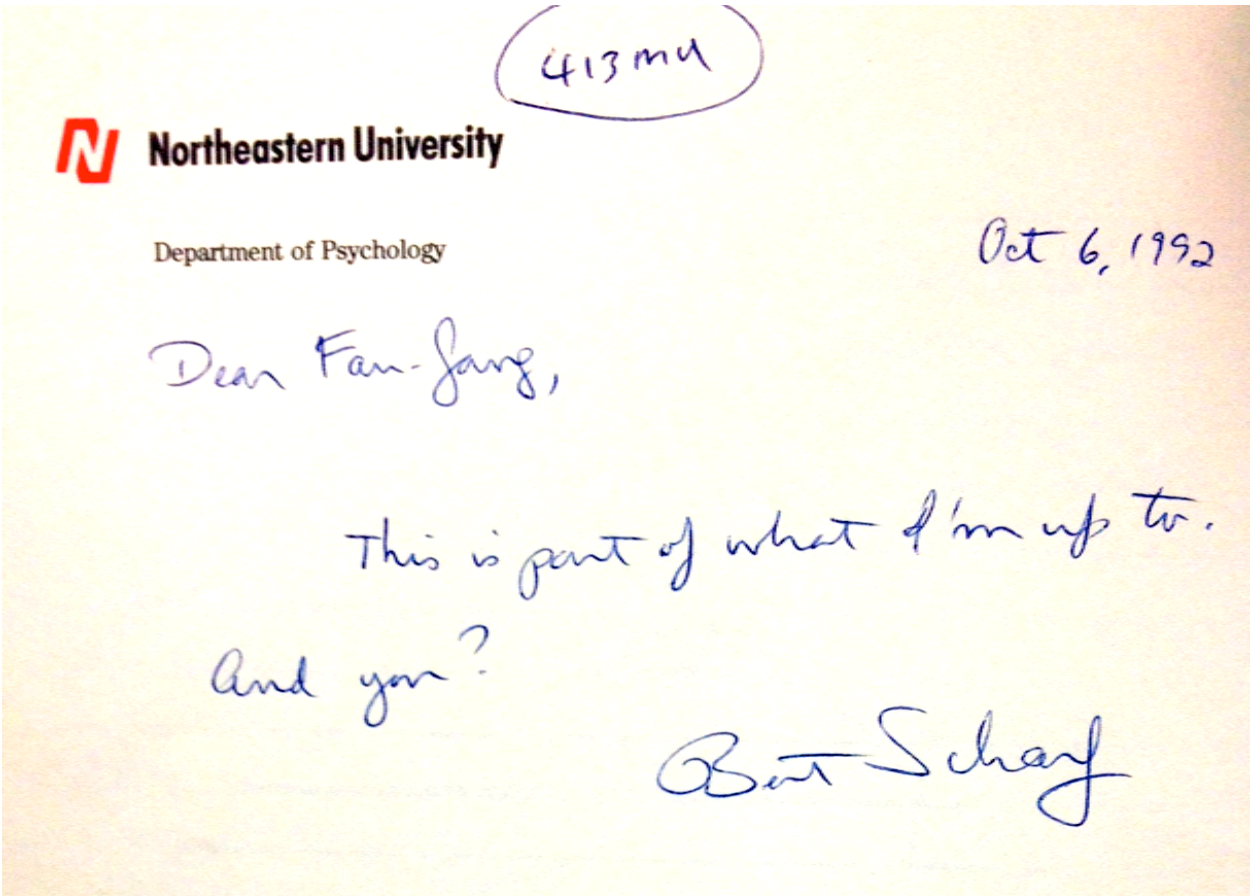


FIGURE 1. Loudness adaptation to low- (left panel) and high-frequency (right panel) pure tones in normal-hearing listeners (black circles) and auditory-neuropathy patients with either neural disorder (red diamonds) or ribbon-synapse disorder (blue squares). The y-axis is normalized to each individual listener's comfortable loudness level, with 0% representing no adaptation (=the pure tone stays at the same comfortable level as a function of time) and -100% representing total adaptation (=inaudible). Figure adapted from Wynne et al. (2013).

Closed-Loop Cochlear Implants and Tinnitus Models

Although my opportunity to do a post-doc with Bert didn't materialize, Bert and I have maintained close collegial contact, especially in studying the role of efferents in human auditory perception. On October 6, 1992, Bert sent a note (Fig. 2), along with his presentation on a case study, which later became an influential paper in human efferent function (Scharf *et al.*, 1994). Bert's work stimulated my interest in this area so I started to test dizzy patients with vestibular neurectomy at the House Ear Institute. We had many exchanges throughout the course of this project. In particular, Bert signed his extensive and critical review, which greatly improved both presentation and data interpretation of our study (Zeng *et al.*, 2000).



413 MU

Northeastern University

Department of Psychology

Oct 6, 1992

Dear Fan-Gang,

This is part of what I'm up to.

And you?

Bert Scharf

FIGURE 2. A personal note from Bert Scharf on his work in efferent function.

These interactions with Bert have continued to influence on my research. One current area of my research is to understand the effects of auditory feedback, from the olivocochlear bundle to the abundant central feedback loop, on auditory processing. For example, in cochlear-implant listeners, the efferent feedback loop is most likely damaged, contributing to the difficulty of understanding speech in noise. We are converting the cochlear implant from a simple stimulator to a neural activity recorder so that the missing feedback loop in current cochlear implants can be closed (Mc Laughlin *et al.*, 2012).

Another example of Bert's influence on my research is his idea that the auditory system is not static, e.g., the dynamic shaping of the auditory filter by attention (Scharf *et al.*, 1987; Dai *et al.*, 1991) or loudness recalibration by the efferent system (Nieder *et al.*, 2003). I have recently applied this dynamic processing idea to tinnitus and hyperacusis, in which loudness is not simple addition of sound energy but a dynamic process that includes nonlinear interactions between external sound and internal noise and automatic gain control (Zeng, 2012).

I am sure that Bert would love to hear that his inspiring ideas could help improve cochlear implant speech performance and reduce internal gain to alleviate tinnitus.

ACKNOWLEDGMENTS

I thank Mary Florentine and Huanping Dai for their invitation to participate in this special session honoring Bert Scharf, a great scientist and colleague whose work has impacted not only my own career but also our fundamental understanding of auditory processes and applications.

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