Bertram Scharf made contributions to numerous topics in the loudness literature. In particular, he brought a great deal of insight into the current understanding of contextual effects in loudness. Some of the contextual effects that he studied include: 1) loudness adaptation, the decline in loudness of the latter portion of a continuous sound, 2) induced loudness reduction, the phenomenon by which a preceding stronger tone reduces the loudness of a weaker tone, 3) temporary loudness shift, a decline in the loudness of weaker sounds due to a physical fatigue of the cochlear amplifier, and 4) loudness enhancement, in which a brief sound is made louder when it follows a stronger sound within a short duration. Context effects serve as complex reminders of the necessity of careful design of any psychoacoustical experiment in which level varies. These effects also result in the breakdown of all loudness models, as virtually all calculations of loudness are performed for sounds without regard for previous stimuli. [supported by NIH-NIDCD.]
INTRODUCTION

Betram Scharf's contributions to psychoacoustics were both numerous and diverse. One notable area that he carefully and thoroughly studied for more than 25 years was contextual effects in loudness. His work in this area inspired many scientists on an international level, especially at the two major institutions at which he worked: the Le Centre National de la Recherche Scientifique (CNRS) in Marseille, France and Northeastern University in Boston, MA, USA — first in his laboratory, and when he retired, in Mary Florentine's laboratory.

There were four major topics in the area of context effects studied by Bertram Scharf: 1) loudness adaptation\textsuperscript{1-11}, 2) induced loudness reduction\textsuperscript{12-16}, 3) temporary loudness shift\textsuperscript{12}, and 4) loudness enhancement\textsuperscript{12, 13}. These contextual effects are extremely important and, in fact, impact every loudness experiment, both in and out of the traditional laboratory\textsuperscript{17, 18}. The effects are not accounted for in loudness modeling, as virtually all calculations of loudness are performed for sounds without regard for previous stimuli. As a result of the magnitude of these effects, loudness models can be off in their estimates by factors of two or more. These four effects are just some of the contextual effects that remain physiologically unexplained and perhaps interdependent\textsuperscript{19}. Each of these effects will be addressed in turn.

1. LOUDNESS ADAPTATION

Loudness adaptation is the decrease in loudness of sounds presented continuously for an extended period of time. Loudness adaptation is more prominent for high-frequency than low-frequency tones and only occurs for sounds presented below about 30 dB SL\textsuperscript{3}. In fact, it is possible for continuous tones at high frequencies and low levels to become completely inaudible over time. In addition, amplitude-modulation eliminates the effect. Canévet, Scharf and Botte\textsuperscript{6} examined the effects of duration and level for tones presented via earphones and loudspeakers, and found average loudness decreases of 65\% under some conditions. In addition, this work examined "induced loudness adaptation," a change in loudness caused by exposure to contralateral tones or increments in a continuous sound. It was later determined that this resulted from a mechanism that was later separately described as loudness recalibration and subsequently, induced loudness reduction. For an early review, see Scharf\textsuperscript{3} and for his most recent review, see Scharf\textsuperscript{20}.

2. INDUCED LOUDNESS REDUCTION

Induced loudness reduction is a phenomenon by which the loudness of a sound (test tone) is reduced when it is preceded by one or more higher intensity sounds (inducer) presented at a nearby frequency\textsuperscript{21}. The effect saturates rapidly and lasts several minutes after exposure\textsuperscript{22}. In the presently published studies, induced loudness reduction tends to primarily reduce the loudnesses of sounds at moderate levels\textsuperscript{14-16, 23-25}. However, there may be some complex tangling of different effects resulting not only from the presence of the inducer, but the repeated presentation of tones across a wide range of levels. Epstein and Gifford\textsuperscript{22} found that the temporal proximity of a baseline test without the presence of an inducer and the follow-up experimental condition with an inducer had an effect on the amount of induced loudness reduction measured.

As a result of the constant, fluctuating nature of the amount of loudness reduction and the inclusion of tones across a wide range of levels in a typical loudness experiment, induced loudness reduction is a cause of discrepancies between estimates of loudness performed by listeners at the beginning of an experiment and at the end of an experiment. In fact, because moderate levels are most affected, induced loudness reduction alters the entire shape of the loudness function\textsuperscript{26}.

Figure 1 shows the results of an experiment in which a comparison tone level was adjusted by the listener to match a fixed test tone in conditions with (experimental) and without (baseline) an inducer preceding. The comparison tone level in the original baseline condition minus the level in the experimental condition is the amount of induced loudness reduction. Each panel shows results for a different inducer condition. Even very low-level inducers resulted in reduction of loudness for tones at levels below the inducer level. In some cases, inducers resulted in increases in loudness for sounds above the inducer level. These findings are consistent with some of the
otherwise unexplained attention and enhancement work done by Bertram Scharf\textsuperscript{12, 13, 27}. The detangling and modeling of the types of context effects in loudness is complex and remains very incomplete. There is still some question about whether loudness enhancement and induced loudness reduction might be related or simply be forms of identical physiological processes\textsuperscript{13, 25}.

![Graphs showing ILR (dB) vs Test Tone Level (dB SPL) for different Inducer Levels](image-url)

FIGURE 1. The amount of induced loudness reduction as a function of test-tone level for inducers presented at six different levels.

### 3. TEMPORARY LOUDNESS SHIFT

Exposure to high-level sounds, particularly for an extended period of time, causes a reduction in loudness, known as loudness fatigue or temporary loudness shift. Temporary loudness shift can affect sounds ranging from threshold to very high levels. Because of the dangers of repeated exposure to high-level sounds, this has been studied in limited form\textsuperscript{4, 28-33}. Temporary threshold shift, which is the more commonly measured clinical metric, increases rapidly with changes in exposure duration and level. It is not clear that loudness fatigues by the same amount as threshold shifts. Bertram Scharf with some of his colleagues, have hypothesized that loudness fatigue and temporary threshold shift result from two different, but correlated mechanisms\textsuperscript{9, 34}. Loudness fatigue is typically present when threshold shift occurs.
4. LOUDNESS ENHANCEMENT

Loudness enhancement is a context effect in which the loudness of a sound (target) is increased by a higher level sound that immediately precedes it. The preceding sound and the target must be presented at similar frequencies and the preceding sound must be presented less than 500 ms prior to the target in order for the effect to occur. There is some debate regarding the degree to which loudness enhancement is intertwined with induced loudness reduction (see Scharf, Buus and Nieder13).

THE IMPORTANCE OF CONTEXT EFFECTS

It has been predicted that the area of context effects is prime for new discoveries, and it is highly likely that the study of context over the next quarter of a century will help bridge the gap between the laboratory and the real world18, 35. Context effects are one of the major missing pieces for applying laboratory findings to ecological listening scenarios. In daily environments, people's expectations are based on their perceived listening situations. For example, an outdoor experiment measured the loudness of noise transmitted through three barriers (acoustic tile, a slat fence, and hemlock) and no barrier. When blindfolded, listeners judged loudness to be the same across all four conditions. When listeners could see the barriers, there were sizable differences in loudness estimates36. Context effects abound. It is well known that the loudness of conversational speech can remain constant even when physical distance from the speaker changes (i.e., loudness constancy37) and when a listener switches between listening with one ear and two ears (i.e., binaural loudness constancy38, 39). For more examples of the cognitive effects of context on loudness judgments, see Fastl and Florentine18.

CONCLUSIONS

Bertram Scharf helped provide insight into some of the most complex contextual effects seen in loudness measurements. Context remains one of the great unconquered areas in loudness modeling, despite data indicating that loudness can change by more than a factor of two as a result of context. As such, all loudness models inadequately describe the loudness of sound in any condition in which the auditory system has previously been exposed to sounds that are at or nearby in frequency across a wide range of levels. Bertram Scharf's work helped provide the data and the theoretical frameworks for reconsidering the simple model's assignment of a loudness value to a sound without regard for what had been previously presented.

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