Rhona Hellman and the Munich School of Psychoacoustics

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In the 1980ties we studied at our lab of the Technische Universität München the loudness of tone/noise complexes. Since Rhona Hellman had performed for NASA a large study on this topic, the late Professor Eberhard Zwicker and I invited Rhona in 1985 as a Guest Researcher to our lab. She came to Bavaria with her family and stayed several weeks in Munich. This paper presents some reminiscences of scientific achievements as well as social life.

1 INTRODUCTION

In the 1980ties we studied at the Institute of Electroacoustics of the Technical University Munich the loudness of tone/noise complexes, and we got aware of a large study on that topic which Rhona Hellman[1] had carried out for NASA. Since the head of our lab, the late Professor Zwicker knew Rhona from the 1960ties, when they worked together in the lab of Joe Zwislocki in Syracuse we decided to invite her to our lab to discuss questions of tone/noise complexes and to perform some joint studies.

Rhona accepted our invitation and came with her husband Bill and her son Adrian in the summer of 1985 for several weeks to Munich. This paper recalls some of the questions addressed, solutions proposed, and gives an outlook.

In addition to scientific achievements, also aspects of the social life will be touched.

2 TONE/NOISE COMPLEXES

In the 1980ties Yukiko Yamada from Meiji University, Japan was a guest researcher at the Institute of Electroacoustics of the Technical University Munich, frequently nicknamed the "Zwicker lab". Among other things, she studied together with the present author the loudness of tone/noise complexes (Fastl and Yamada[2]). Since tonal components of technical sounds usually increase their annoyance, the focus was on combinations of broadband noise with a tonal component.

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Figure 1 shows the loudness patterns of some of the sounds studied as measured by an algorithm published in the German standard DIN 45 631. Pink noise with 60 dB overall level (about 45 dB 1/3-oct band level) was combined with a pure tone at 1 kHz and levels of 50, 60, 70, and 80 dB, respectively.

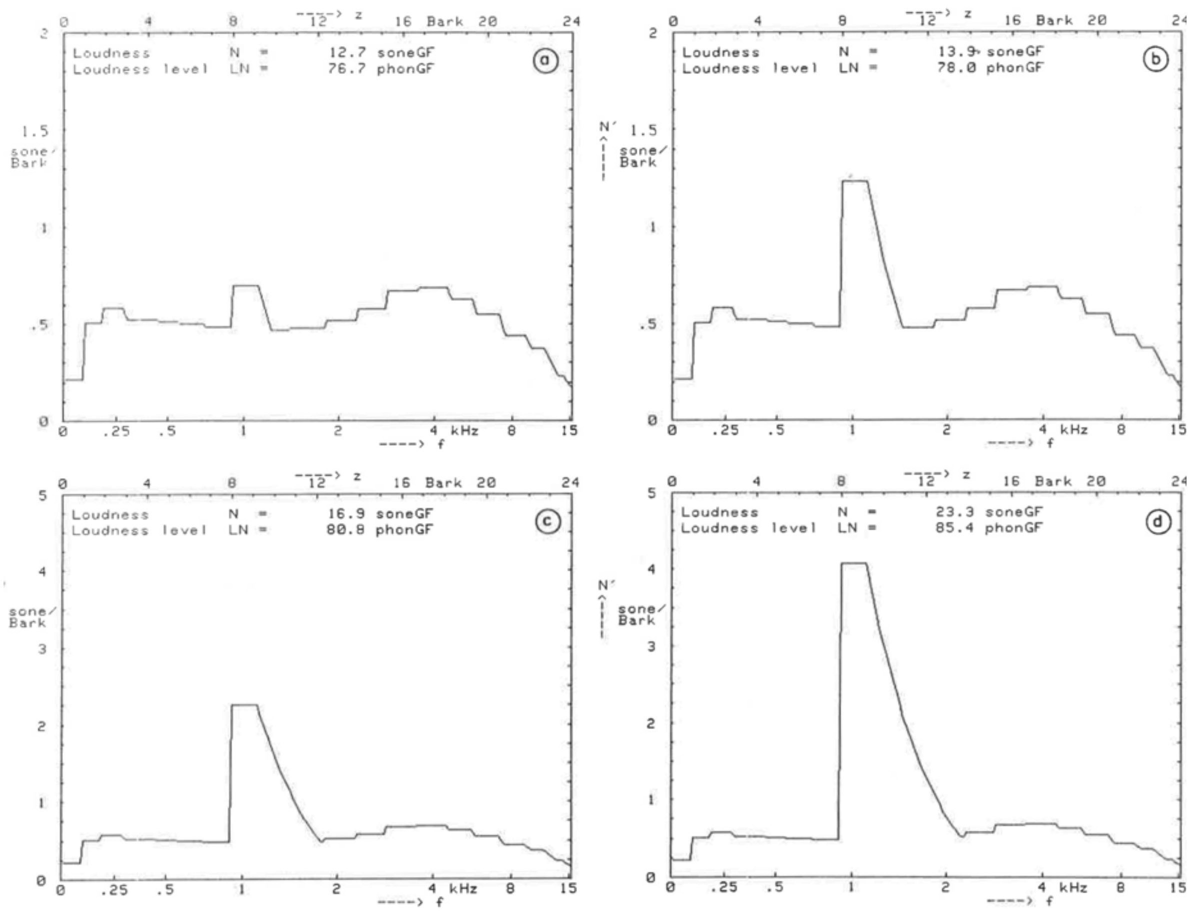

Fig. 1 - Loudness patterns of tone/noise complexes. Pink noise with 60 dB overall level plus a 1 kHz-tone with a level of (a) 50 dB, (b) 60 dB, (c) 70 dB, and (d) 80 dB (after Fastl and Yamada[2]).

In the data displayed in figure 1, with increasing level, the tonal component clearly dominates the loudness pattern. The relative areas corresponding to the tonal component vs. the broadband component can be taken as an indication of the tone content (Fastl and Zwicker[3]).

The results displayed in figure 2 illustrate that (overall) loudness increases with the SPL of a 1 kHz-tone, added to pink noise of 60 dB. This holds true for both, German (a) and Japanese (b) subjects.

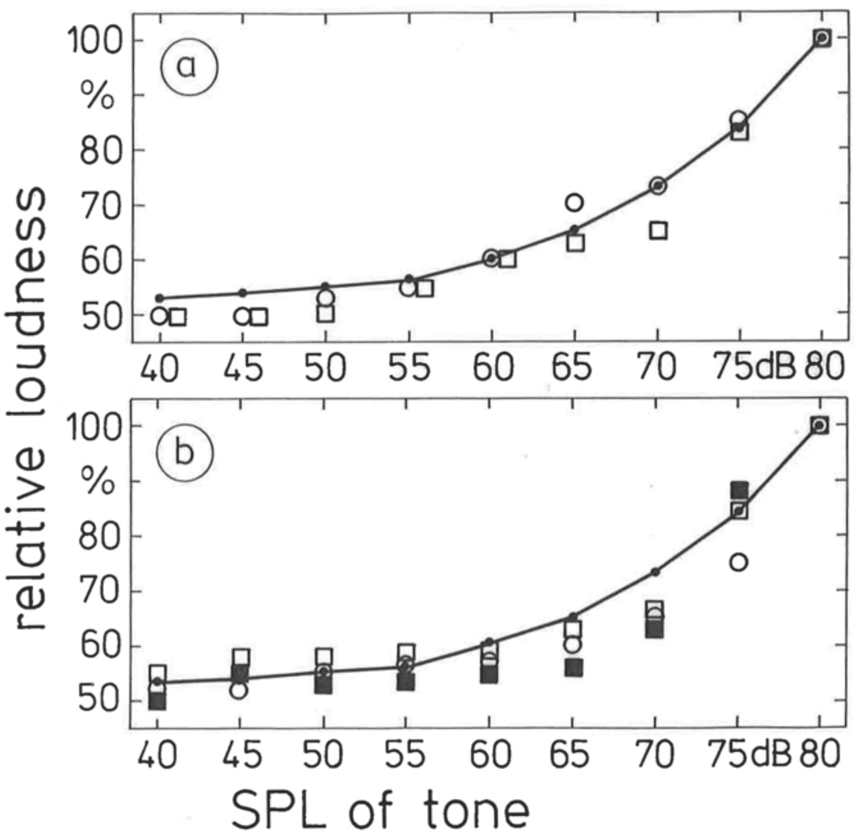

Fig. 2 - Loudness of broadband noise with a tonal component. Symbols: subjective evaluations by German (a) or Japanese subjects (b).
Curve: calculated loudness according to DIN 45 631 (after Fastl and Yamada[2]).

The data displayed in figure 2 indicate that the loudness of tone/noise complexes is evaluated in a rather similar way by German or Japanese subjects. Generally, the subjective loudness evaluations can be approximated by loudness calculations according to DIN 45 631.

Since Rhona Hellman had done the large NASA study on the influence of tonal components on loudness, we wanted to discuss our results with her and to get a feeling about loudness evaluations by subjects from the USA. However, before delving into joint work, we wanted that Rhona and her family get settled in Munich.

3 RHONA IN BAVARIA

3.1 Social life

During Rhona's stay in Munich, also Sonoko Kuwano from Osaka University, Japan was a Guest Researcher in the Zwicker lab. In addition to hard work, we had also very enjoyable periods of social life. The following photos are snapshots from an excursion to the Bavarian Alps.

Fig .3 - In the Bavarian Alps near the source of the river Isar which eventually traverses Munich.
Eberhard Zwicker, Rhona Hellman, Christa Fastl

Fig .4 - In the marvellous garden of the Zwicker family.
Hugo Fastl, Christa Fastl, Rhona Hellman, Eberhard Zwicker

Fig .5 - In the cosy home of the Zwicker family.
Seiichiro Namba, Rhona Hellman, Hugo Fastl, Eberhard Zwicker, Sonoko Kuwano, Erika Maria Zwicker, Christa Fastl

3.2 Preparations for joint work

Rhona Hellman had used for much of her work TDH headphones. Since this transducer attenuates low and high frequencies considerably, we had proposed a free-field equalizer (Fastl and Zwicker[4]). Together with Rhona we discussed the possible magnitude of loudness reduction since the headphone acts like a filter on broadband sounds.

Figure 6 enables a comparison of the loudness patterns for pink noise of 60 dB overall level when presented in free field conditions or over TDH 49 headphones without equalizer.

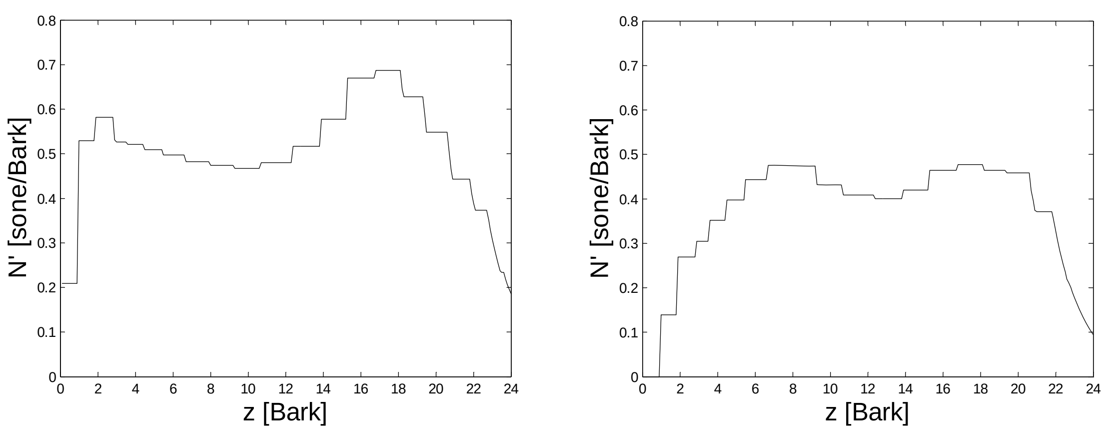

Fig .6 - Loudness patterns for pink noise of 60 dB overall level when presented in free field conditions (left) or over TDH 49 headphones without equalizer (right).

The results displayed in figure 6 clearly reveal that the loudness pattern for presentation of pink noise over TDH 49 headphones is rather different from the loudness pattern for free field conditions. The overall loudness is reduced from about 12 to about 9 sone, i.e. by some 25 %. Since such differences cannot be neglected in precise loudness measurements and calculations, henceforth, in all her publications Rhona took account of the frequency response of the electroacoustic transducer used.

4 RESULTS OF RHONA'S WORK IN MUNICH AND BEYOND

4.1 Minus 6 dB(A) but twice as loud

One of the most startling results of Rhona's work in Munich is the inverse behavior of A-weighted level and loudness (Hellman and Zwicker[5]): despite a *decrease* in level by 6 dB(A), the loudness does not decrease, but *increases* by about a factor of two! This astonishing result is achieved as follows: On the one hand, an overall A-weighted level of 77 dB(A) is obtained by a combination of 77.2 dB pink noise plus 70 dB pure tone at 1 kHz. On the other hand, a 6 dB(A) higher level of 83 dB(A) is obtained by 47 dB pink noise plus 83 dB pure tone. Nevertheless, the sound with 83 dB(A) produces only half the loudness of the sound with 77 dB(A)!

The solution of the paradox is found in the corresponding loudness patterns, similar to the patterns displayed in figure 1: The pink noise with 77.2 dB produces in the loudness patterns a larger area and hence a larger loudness than the 83 dB pure tone.

4.2 Same dB(A) but different loudness

At InterNoise 1987 Hellman and Zwicker[6] presented data that sounds with (almost) the same A-weighted SPL, i.e. 90.9 and 91.4 dB(A) can differ in loudness by a factor of 2.1. Depending on the combinations of broadband noise plus tone, with increasing sound pressure level, a non-monotonic increase in loudness with clear dips is found. The non-monotonic behavior established in the psychoacoustic experiments is also reflected in instrumental measurements of loudness.

4.3 Two tone/noise complexes

At InterNoise 1989 Hellman and Zwicker[7] reported data for combinations of broadband noise with two tones. With the frequency separation of the two tones, loudness increases. However, when noise is added, the loudness increase is much less than for tones in quiet without background noise. A similar behavior is also observed for instrumental loudness measurements. For a spacing of the two tones of only 25 Hz, Hellman and Zwicker recommend to use percentile loudness for the instrumental evaluations.

4.4 ANSI S 3.4-2005

Rhona was very instrumental in implementing ANSI S3.4-2005. Her paper in Acoustics Today (Hellman[8]) clearly advocates the advantages of this standard compared to older versions. Nevertheless, she faithfully traces the developments from early work by Fletcher and Munson[9], S.S. Stevens[10] as well as Zwicker[11]. The list of references explicitly shows that over a span of more than 40 years Rhona herself contributed a wealth of data relevant for the understanding of loudness perception.

5 OUTLOOK

Despite the fact that ANSI S3.4-2007 these days best describes the loudness of pure tones as standardized in ISO 226 (2003) there still seems to be room for improvement. One example can be illustrated by means of figure 7: Concerning the loudness of pink noise, according to more recent data by Schlittenlacher et al.[12] the predictions by ANSI S3.4-2007 (upper dashed curve) frequently seem not to be in line with subjective evaluations (circles).

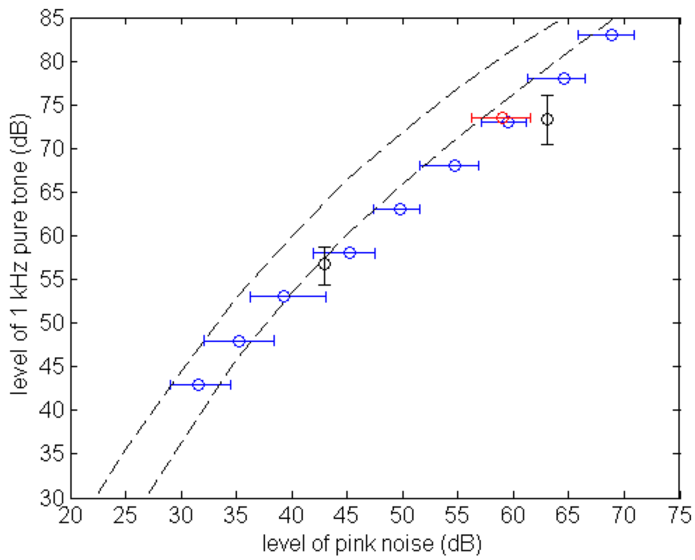

Fig. 7 - Loudness comparisons of a 1 kHz pure tone and pink noise. Level of 1 kHz-tone as a function of the level for pink noise at same loudness.
Circles: subjective evaluations (medians and inter-quartile ranges). Upper dashed curve: values predicted by ANSI S3.4-2007. (after Schlittenlacher et al.[12]).

Of course, ANSI S3.4-2007 predicts that a broadband sound like pink noise needs less (overall) level than a pure tone to elicit the same loudness. However, in comparison to the subjective data, the predicted level difference between narrow band and broadband sounds at same loudness seems to be somewhat too large.

In summary, this author feels that it is the legacy of Rhona Hellman to continue studies on loudness as she did all her lifetime in order to eventually arrive at loudness calculation procedures in line with loudness perception.

5 ACKNOWLEDGEMENTS

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