Comment on 'Temporal modulation transfer functions in patients with cochlear implants [J. Acoust.Soc.Am.91, 2156-2164 (1992)]

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Comment on "Temporal modulation transfer functions in patients with cochlear implants" [J. Acoust. Soc. Am. 91, 2156–2164 (1992)]

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Shannon [J. Acoust. Soc. Am. 91, 2156–2164 (1992)] reports a strong decrease of modulation detection thresholds with cochlear implant patients for an increase of the stimulus level. His conclusion that this result differs from the findings for acoustical stimulation in normal-hearing subjects needs some clarification. His statement about acoustic stimulation is based on modulation detection measurements for *noise* carriers, where, indeed, thresholds in normal-hearing subjects are nearly independent of level, at least for carrier levels of more than 20 dB SL. For *sinusoidal* carriers, however, the modulation detection thresholds decrease with increasing carrier levels over the entire hearing range, similar to his findings with implant listeners.

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INTRODUCTION

In a recent publication, Shannon (1992) reports a series of measurements related to modulation detection in cochlear implant patients. One of the experimental parameters was the stimulation level of the carrier signal. The results in his Fig. 4 indicate that sensitivity increases over the full range of stimulation levels that covers about 20 dB for electrical stimulation. Modulation thresholds, expressed as $20 \log m$ (where m is the modulation index), vary from -5 to -10 dB at low levels to -40 dB at the highest levels. In the discussion Shannon compares this result to findings obtained with acoustical stimulation in normal-hearing subjects. Referring to the studies of Viemeister (1979) and Bacon and Viemeister (1985), he concludes that the level dependence is quite different for the two modes of stimulation. Although this conclusion is correct, given the results in the cited studies, the comparison is not appropriate and probably misleading. The implant data were obtained with sinusoidal carriers, while Viemeister (1979) and Bacon and Viemeister (1985) measured the level dependence with a noise carrier. This experimental difference would, as such, not cause any problem, if, for acoustic stimulation, level effects in modulation detection thresholds were the same for sinusoidal and noise carriers. I want to point out with this comment that the level dependence for these two types of carriers is *not the same*, as is well documented in a number of studies.

I. LEVEL EFFECTS ON MODULATION DETECTION THRESHOLDS FOR SINUSOIDAL CARRIERS

Modulation detection thresholds for sinusoidal carriers as a function of stimulus level have been obtained in a number of studies (Riesz, 1928; Zwicker, 1952; Zwicker and Kaiser, 1952; Zwicker, 1953; Goldstein, 1967; Maiwald, 1967; Long and Cullen, 1985; Zwicker and Graf, 1987; Schorer, 1989). All these studies revealed a monotonic decrease of the modulation detection thresholds with increas-

ing level, with one exception: For a high carrier frequency of 10 kHz, Long and Cullen found a relative maximum in modulation detection thresholds at an intermediate level.

Since, unfortunately, a major part of the above-mentioned studies has been published in German, I will, for these studies, summarize some of the relevant results. The figure numbers refer to the figures in the original publications. Throughout this comment, modulation detection thresholds will be expressed as $20 \log m$, where m is the modulation index. A part of these results have also been included in the recent book by Zwicker and Fastl (1990).

Zwicker (1952) measured what nowadays would be called modulation transfer functions for sinusoidal carriers of 250 Hz, 1 kHz, and 4 kHz at a variety of carrier levels. In all conditions, the modulation thresholds decreased with increasing levels.

Zwicker and Kaiser (1952) showed that modulation thresholds for a 4-Hz modulation can be determined in the whole frequency range between 50 Hz and 16 kHz. If curves of equal modulation thresholds are plotted in a frequency-level diagram, the picture is quite similar to a plot of equal loudness contours (Fig. 6). A level increase of 10 to 15 dB leads to a decrease in the modulation threshold of 3 dB.

A subsequent study by Zwicker (1953) revealed that modulation thresholds as low as -36 dB can be measured at high levels for carrier frequencies between 400 Hz and 7 kHz (Fig. 1). By adding an (unmodulated) sinusoidal or noise masker, modulation thresholds could be raised. For carrier levels of at least 30 dB above the masked threshold, no influence of the masking sound on the modulation threshold was observed (Figs. 4, 7, 8, and 11).

Maiwald (1967) compared directly the level dependence of modulation detection thresholds for a 1-kHz sinusoid and a narrowband noise (bandwidth 127 Hz) centered at 1 kHz. Modulation thresholds for the sinusoids dropped from $m = -20$ dB at a carrier level of 20 dB to $m = -40$ dB at a level of 100 dB (Fig. 12). For the same level range, modulation thresholds for the noise carrier decreased only

from $m = -10.5$ dB to $m = -14$ dB (Fig. 16).

The study of Zwicker and Graf (1987) mainly reproduced the findings from Zwicker (1953) with a larger number of subjects and the authors concluded that a masking noise affects modulation thresholds only for a level range up to 25 dB above the masked threshold of the (unmodulated) carrier.

Schorer (1989), finally, combined the results from several studies for a modulation frequency of 4 Hz and his own data (Fig. 6). The monotonic decrease in modulation detection threshold with level could be described by an analytic relation that yields a reduction in m by 2.5 dB (a factor of 1.33) for a level increase of 10 dB.

II. SUMMARY

In summary, all results with acoustic stimulation and sinusoidal carriers in normal-hearing subjects show a level dependence very similar to the one described by Shannon. Thus, the similarity between acoustic and electric stimulation with respect to the processing of temporal cues might be even closer than suggested by Shannon. He concluded that this similarity implies the usefulness of temporal cues for implant listeners. I would add the conclusion that experiments with electrical stimulation are of high relevance for our understanding of modulation detection in the (healthy) auditory system, since they have one major advantage over acoustic stimulation: Electrical stimuli do not undergo the mechanical filtering in the inner ear, and therefore, results

from such experiments reveal directly the contribution of *neural* stages on, e.g., the modulation transfer function.

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