Partial loudness of a signal for different masker types using categorical loudness scaling

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Introduction

Categorical loudness scaling (ISO 16832, [1]) is a fast standardized procedure to measure loudness over a large level range. The procedure was primarily standardized for the usage in audiology to measure the audible range of a listener. For this purpose, loudness functions are measured for narrowband signals as a function of the centre frequency using verbal (and often intermediate non-verbal) categories. In the present study, this procedure is used to measure the partial loudness, i.e., the loudness growth functions for masked signals. The target signal is a pure tone embedded in two different masker types: (i) amplitude modulated and (ii) unmodulated broadband noise. These two masker types differ in their ability to mask the signal, being less effective in the case of the modulated masker (e.g., [2], [3], for a review). Carlyon and co-authors [4] referred to this difference as modulated-unmodulated difference (MUD). The present study investigates how the masker type influences the supra-threshold perception. Data from a loudness matching experiment of Verhey and Heise [5] indicated that the MUD reduces with level. Verhey and Heise hypothesized that the effect of the reduced masking for the modulated masker is equivalent to a condition where the unmodulated masker is reduced in level by the magnitude of the MUD. The present study tests this hypothesis by measuring loudness functions for the two masking conditions and for an unmodulated condition with a masker level redued by the MUD. To assess the accuracy of the categorical loudness scaling the results are compared to loudness matching data for the tone embedded either in the modulated or in the equal-level unmodulated masker within the same listeners.

Methods

Apparatuses and Stimuli

Stimuli were generated digitally at a sampling rate of 44.1 kHz. A standard personal computer controlled the stimulus generation and presentation and recorded the results. Stimuli were D/A converted and amplified by a Fireface 400, and presented via Sennheiser HD 650 headphones. Listeners were seated in a sound-insulated booth and the sound was presented diotically.

The target signal was a 986-Hz pure tone. The signal duration was 600 ms including 50-ms raised-cosine ramps at signal on- and offset. The target signal was temporally centred in the masking noise. The masker duration was 700 ms also including 50-ms raised-cosine ramps at on- and offset and had a lower cut-off frequency of 250 Hz and an upper cut-off frequency of 4000 Hz. The masker was either an unmodulated or an irregularly rectangularly modulated noise with a mean modulation frequency of 40 Hz and a jitter of 10%, and was generated as in, e.g., [6]. Examples of the masker waveforms (in grey) for the two noise types with an added signal (in black) are shown in Figure 1.

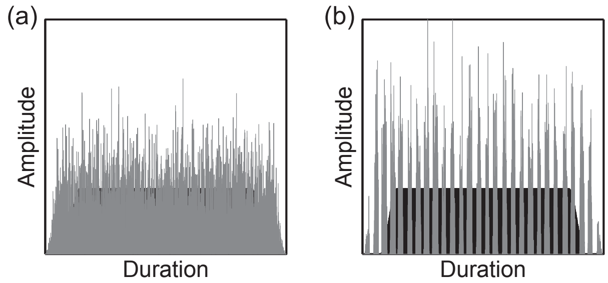

Figure 1: Time waveforms for the masker (grey) and the signal (black) for two masker types: (a) unmodulated masker and (b) modulated masker.

Listeners

Twentyfour listeners (17 female, 7 male) participated in the experiments. The age ranged from 18 to 33 years. All listeners showed a normal audiogram in the relevant frequency range, i.e., threshold were 15 dB HL or lower for all audiometric frequencies between 250 and 4000 Hz.

Procedure

The experiment was performed in two steps. In the first step, the masked threshold of the tone was measured for both masking conditions. A three-alternative, forced-choice (3-AFC) procedure with adaptive signal-level adjustment (1-up 2-down) was used to determine the thresholds [7]. The tonal target signal was added to one of these intervals. This signal interval was randomly selected for each trial. Listeners had to indicate which of the intervals contained the signal. The procedure was repeated three times for each condition and the average of these estimates was taken as the final estimate of the threshold.

In the second step, the perception of the masked tone at supra-threshold levels was measured using a loudness-matching procedure and categorical loudness scaling. The loudness-matching procedure was essentially the same as used in [5]. In contrast to that study the level of the masking noise was 55 dB sound pressure level

(SPL) and the tone level in the reference interval (i.e. the interval with the fixed-level tone) was 5, 10, 15, 20 or 25 dB above individual masked threshold for the respective masking condition.

In addition to the loudness matching experiments, loudness was measured with an adaptive loudness scaling procedure as described in [8] which is in accordance with the standard for categorical loudness scaling ISO 16832 [1]. The procedure consists of two phases. In the first phase, the individual dynamic range for the masked tone is determined. The levels of the following second phase are uniformly distributed over the individual dynamic range which has been estimated in the first phase. Seven named and four unnamed loudness categories were used as in the example of ISO 16832 [1]. Listeners had to assign each presented stimulus to one of the given categories.

For the derivation of the loudness functions, the categories were linearly transformed to numerical values (categorical units, CU) from 0 (inaudible) to 50 (extremely loud). A model loudness function was fitted to the individual data as described in [8]. The levels corresponding to the loudness values in CU were derived from the individual loudness functions and the median was determined. The loudness function for the group of listeners was then determined by fitting a loudness function to the median data as suggested in [1].

Categorical loudness scaling data were obtained for three masking conditions. In addition to the two masking conditions used in the matching experiments, loudness was also measured for a tone masked by an unmodulated masker with a level that was reduced by the magnitude of the individual masking release (reduced-level condition). For each of the three masker conditions, the data were obtained separately, i.e. the tracks were not interleaved. In total, each listener performed three categorical scaling experiments and two matching experiments.

Results and Discussion

Figure 2 shows averaged masked thresholds (stars) together with the three measured loudness functions. The masked thresholds are 36 dB for the unmodulated condition and 28 dB for the amplitude modulated condition, i.e. the MUD was 8 dB. This MUD is considerably smaller than the 15 dB found in [6]. This is presumably due to the different set of listeners.

In agreement with the difference in thresholds, the loudness function for the modulated masker (solid line) starts at a lower level than for the unmodulated condition (dashed thick line) with the same level. The difference at 0 CU (inaudible) is 9 dB, i.e. almost the same as obtained in the theshold experiment. However, the absolute levels are about 7 dB lower. This difference in absolute threshold values could originate from the limitations in the fitting procedure of the loudness function and other procedual differences.

All loudness functions of the masked signals are steeper than for an unmasked narrowband signal centred at 1 kHz as reported in [8] or [9]. This is in agreement with previous studies on loudness of masked tones using different procedures (see [10] and [11]). The lower portion of the loudness function in the modulated condition is shallower than in the unmodulated condition with the same masker level, resulting in larger level differences at low levels than at medium and high levels. The loudness function of the unmodulated condition with the reduced masker level (55 dB - MUD) is very similar to the loudness function for the modulated condition at almost all levels. The maximum difference of about 3 dB was observed at 0 CU. Since the same threshold would be expected in these two conditions, this can be taken as another evidence of the limited accuracy of the threshold as derived from categorical loudness scaling data.

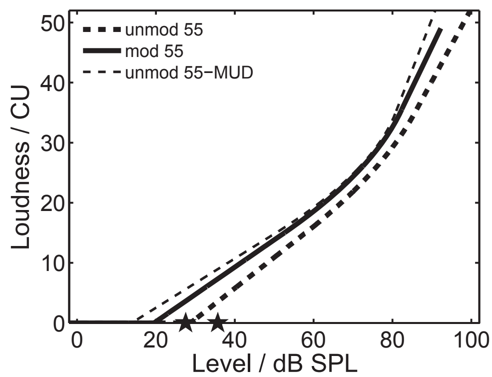

Figure 2: Median loudness growth functions for the listeners participating in the experiments are shown for the two masker types at a level of 55 dB (unmodulated masker with a dashed line and modulated masker with a black solid line). The loudness function for the unmodulated masker with a lower level (55 dB minus MUD) is shown by a thinner dashed line. The averaged masked thresholds are shown as black stars.

In order to compare the scaling data to the maching data, a different representation is required where the level of the tone in the modulated condition is plotted as a function of the level of the tone in the unmodulated condition (Figure 3). The data representation is essentially the same as in [5]. The left panel shows the data in dB SPL and the right panel shows the data relative to the threshold. The star indicates the thresholds for the modulated and unmodulated condition. In the left panel the star is located below the diagonal reflecting the masking release. For the loudness matching data, the data points are in general below the diagonal. The results show that the advantage due to the lower threshold in the presence of the modulated masker decreases with increasing signal level. This implies that the loudness of the signal embedded in the modulated masker grows more slowly than that of the signal masked by the unodulated masker. At a sound pressure level of the tone corresponding to about 25 dB above the threshold of the tone masked by the unmodulated 55-dB masker there is no longer a MUD. This is in agreement with previous studies comparing the loudness of a tone in a masking-release condition to that of a tone in a baseline condition ([12] and [5]). When the data are plotted relative to masked threshold (right panel of Figure 3) the data points are close to the diagonal at low levels above threshold, whereas, at higher levels, the level of the tone above threshold in the modulated masking condition is higher than that of the tone in the unmodulated condition. For levels close to threshold, the data points are slightly below the diagonal. This nonmonotonic effect was unexpected and may be related to the different cues used in the two masker paradigms resulting in different psychometric functions.

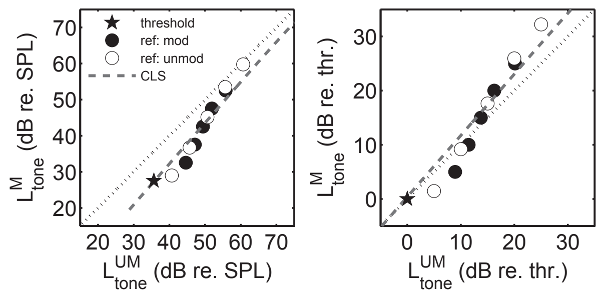

Figure 3: Median data of matching an scaling experiment. Left panel: data expressed in dB SPL. Right panel: data expressed in dB relative to the measured masked threshold. Symbols show the results of the matching experiment: open symbols indicate results for a reference with an unmodulated masker and filled symbols indicate level for a reference with the modulated masker. The star represents the measured threshold of the tone in the corresponding masker and the dashed line shows the results of the scaling experiments with the same maskers.

The dashed line in Figure 3 indicates levels at equal loudness derived from the scaling data shown in Figure 2. Although there are some differences in the exact shape of the function, the results are similar to those of the matching experiment. The decrease of the effect of masking release is, however, much less pronounced than in the matching data and there is a residual MUD even at high levels. In addition, the curve does not show the nonmonotonic behaviour which is observed in the matching data.

Summary and Conclusions

The present study investigated to what extent categorical loudness scaling can be used to measure the loudness of masked signals. Modulated and unmodulated maskers were used resulting in different masked thresholds. Previous studies showed that this difference in threshold is preserved at suprathreshold levels. In this study, a similar result was found using categorical loudness scaling. The comparison to matching data within the same subjects indicate that not all aspects of suprathreshold perception are assessed by categorical loudness scaling. Thus, categorical loudness scaling is a fast procedure to measure suprathreshold perception over a wide level range while matching provides a more detailed characterisation how perception changes above threshold.

References

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