Intensity Discrimination and Loudness in Forward Masking: The Effect of Masker Level

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Introduction

If a brief sound is presented in close temporal proximity to another tone (e.g., a forward masker), both intensity resolution and perceived intensity (loudness) are altered by the masker.

Zeng, Turner, and Relkin [1] first reported the "midlevel hump" in non-simultaneously masked intensity discrimination. In the presence of an intense forward masker (90-100 dB SPL), just-noticable differences (jnd's) were considerably elevated at intermediate standard levels (40-60 dB SPL). At low and high standard levels, however, jnd's remained approximately as small as in quiet. As to loudness, the presence of an intense tone preceding or following a target tone causes the perceived intensity of the target tone to be larger than in quiet ("loudness enhancement", e.g., [2]). Conditioners presented at a level below target tone level result in a reduction of perceived intensity ("loudness decrement").

Previous models proposed for the midlevel hump in intensity discrimination (the recovery-rate model [1], and the referential-encoding hypothesis [3,4]) can not explain similarity effects reported in [5] and [6]. Moreover, the effects of various parameters on both phenomena are very similar (cf. [4]), and jnd's and loudness enhancement have been found to be correlated [7,8]. These findings suggest a common process, or a causal link between the phenomena [4]. The models mentioned above can not account for loudness enhancement, however. In the present paper, I suggest an alternative model and present data from two experiments designed to test the model.

Model

I propose that the effects of non-simultaneous masking can be understood by a two-level model that

1. combines the "mergence hypothesis" [2] (which can explain loudness enhancement) and the "loudness enhancement hypothesis" [4] (which assumes a causal link between enhancement and jnd elevation)
2. extends the mergence hypothesis by introducing a similarity effect.

The mergence hypothesis assumes that a listener ‚integrates' the perceived intensities of masker and standard, resulting in loudness matches reflecting a weighted average between masker and standard loudness. However, such model predicts enhancement to increase monotonically with the level difference between masker and standard, which contradicts the finding of a midlevel hump in loudness enhancement [7,8]. In the new model, a **similarity effect** is included. It is assumed that less integration will occur if the tones are perceptually different (e.g., in spectral content, duration, or intensity). This idea is compatible with previous studies demonstrating, e.g., that the midlevel hump is most pronounced if masker and standard are of the same duration [5]. Now, for a 90-dB SPL masker and a 90-dB SPL standard, the weighted average between the two perceived intensities is just as large as the loudness of each interactor presented alone (*no enhancement*). A 30-dB SPL standard and a 90-dB SPL masker are perceptually too different for pronounced integration to occur (*nearly no enhancement*). A 60-dB SPL standard and a 90-dB SPL masker, however, are sufficiently similar perceptually for their loudness to be integrated (*pronounced enhancement*). Obviously, such similarity effect would result in a midlevel hump in loudness enhancement. In a second step, the new model can predict jnd's: according to the loudness-enhancement hypothesis, enhancement causes jnd elevation by introducing variability in perceived intensity. Consequently, the model predicts the two effects to be correlated.

The model can be tested by independently varying masker level and standard level and measuring jnd's and loudness matches. Unlike previous models, the new model predicts jnd's and loudness enhancement to be **non-monotonic functions** of the masker-standard level difference at each standard level.

Experiment 1: Jnd's

Stimuli

The standard was presented at 25 dB SPL, 55 dB SPL, and 85 dB SPL, respectively. The level difference between masker and standard ($L_M - L_S$) was varied between −60 and +60 dB in 15 dB steps. Masker level ranged between 10 dB SPL and 100 dB SPL. Standard and masker were 1-kHz pure tones with a steady-state duration of 20 ms. They were gated on an off with 5-ms $\cos^2$-ramps and presented monaurally to the right ear via Sennheiser HDA200 headphones.

Procedure

A 2I, 2AFC adaptive procedure (2-down, 1-up; [9]) was used to measure jnd's ($\Delta L_{DL} = 10 \cdot \log[1 + \Delta I/I]$). Standard and standard plus increment were presented in two observation intervals in random order. In forward masked trials, a masker was presented in both intervals (ISI = 100 ms). Listeners selected the interval containing the increment. Visual feedback was provided after each trial. Step size was 5 dB for the first four reversals, and 2 dB for the remaining 8 reversals. The jnd was computed as the arithmetic mean of the increments presented at the last 8 reversals. At least three runs were obtained for each data point.

Listeners

Five listeners participated in the experiment. One of them (DO) was the author; the others were paid an hourly wage. All had less than 10 dB HL thresholds in the frequency range between 125 Hz and 6000 Hz. All listeners also took part in Experiment 2, with the exception of AS who completed Experiment 1 only due to lack of time. Instead of her, listener AL participated in Experiment 2.

Results

Fig. 1 shows the individual data. For masker levels smaller than standard level ($L_M - L_S \leq 0$), forward masked jnd's were approximately as small as in quiet. As the level difference increased, jnd's were elevated at each standard level. At a standard level of 25 dB SPL, there was clear evidence for a **perceptual-distance effect** for all but one listener (BS). The maximum jnd's were observed at level differences of 15 to 45 dB. With further increases in level differ-

ence, jnd's became smaller again, resulting in non-monotonic functions. At a standard level of 55 dB SPL, only YS showed a decrease in jnd elevation at the largest level difference. In accordance with previous findings, jnd's were not elevated for 85-dB SPL standards combined with 85-dB SPL maskers. There was a jnd increase at a level difference of 15 dB, however. If one compares the jnd's obtained with 85-dB SPL maskers at the different standard levels, it is obvious that a 'midlevel hump' was present for all listeners but BS.

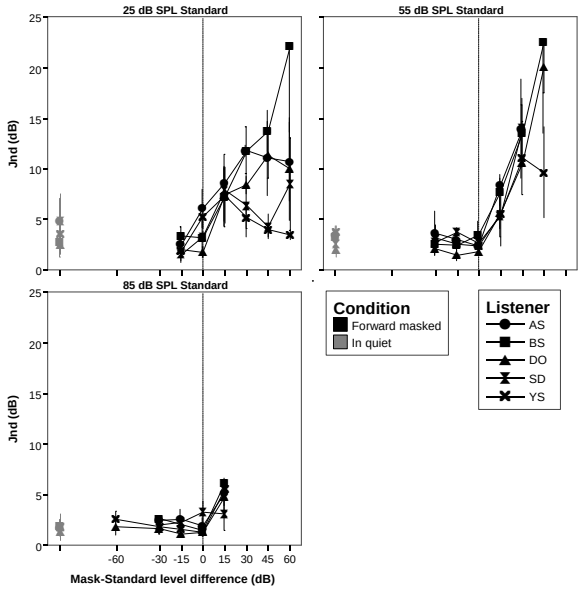

Fig. 1: Jnd's as a function of the level difference between masker and standard. Each panel shows data for one standard level. Errorbars show plus/minus one standard deviation.

Experiment 2: Loudness Matches

Stimuli

The same stimuli as in Experiment 1 were used.

Procedure

The standard was always presented in the first interval, followed by a comparison tone after an ISI of 650 ms. In forward-masked trials, a masker was presented in interval 1 only (ISI = 100 ms). Listeners responded whether the test tone in interval 1 (the standard), or the test tone in interval 2 (the comparison tone) had been louder. Comparison tone level was adjusted in two randomly interleaved tracks [10]. The upper track (2-down, 1-up rule) tracked the 70.7% point on the psychometric function. In the lower track, a 2-up, 1-down rule was used to track the 29.3% point. Step size was 5 dB until the fourth reversal, and 2 dB for the remaining 8 reversals. No feedback was provided. In each run, the arithmetic mean of the level differences between comparison tone and standard at the last 8 reversals were computed for the upper and for the lower track. The arithmetic mean of these two values was taken as the loudness match. At least three runs were obtained for each data point.

Results

Fig. 2 shows individual loudness matches (as defined above). Positive loudness-match values denote loudness enhancement. As expected, there was loudness decrement if masker level was smaller than standard level. As $L_M - L_S$ increased above 0 dB, an increasing amount of loudness enhancement was observed. Again, the maximum amount of enhancement was present for level differences between 15 and 45 dB. At larger level differences, loudness enhancement decreased again, resulting in a non-monotonic function. This pattern was observed both at 25 dB SPL and 55 dB SPL standard level. Loudness enhancement and decrement were more pronounced at 55 dB SPL, however. Unexpectedly, intense maskers produced loudness decrement in four cases.

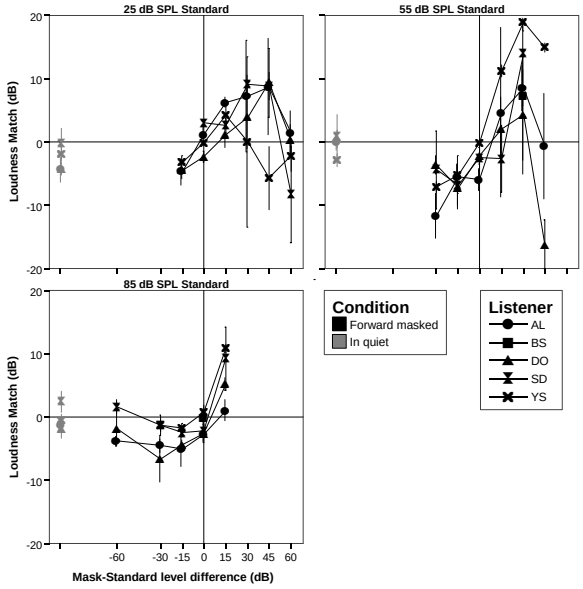

Fig. 2: Loudness matches as a function of the level difference between masker and standard.

Summary

The non-monotonic functions observed in both experiments are evidence supporting the new model that predicts jnd's and enhancement to increase with masker-standard level difference up to a point where the perceptual distance between masker loudness and standard loudness becomes sufficiently large for integration to decrease and the effects to become smaller again. The differences between the jnd functions at 25 dB SPL and 55 dB SPL standard level were not predicted by the model, however. It also remains unclear why intense maskers produced loudness decrement in some cases.

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