

USING VARIABILITY IN MASKER LEVEL TO STUDY THE DECISION PROCESS IN FORWARD-MASKED INTENSITY DISCRIMINATION

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Abstract

The decision process in a forward-masked intensity discrimination task was studied by introducing within-trial variability in masker level. In a 2IFC paradigm, the level of the masker presented in interval 1 and interval 2, respectively, was sampled independently from a normal distribution in each trial. Mean and standard deviation of the distribution were varied. Standard level was constant; the level increment was fixed in each block. Correlational analyses revealed different response strategies depending on masker level. With mean masker level equal to standard level, listeners tended to select the interval with the higher masker level, behaving like an energy detector. For mean masker level larger than standard level, three of the four listeners showed a negative correlation between the masker level in a given interval and the probability of responding that the increment had been presented in this very interval. This indicates a strategy of forming a contrast between masker loudness and target tone loudness and voting for the interval in which their difference was smaller. The weight assigned to masker level was larger for the intermediate mean masker level and increased with masker variability.

Non-simultaneous masking produces a rather complex pattern of effects on intensity resolution. Difference limens for a midlevel standard are strongly elevated by an intense forward masker (80-100 dB SPL), relative to the jnd in quiet. However, the effect of the masker on jnd's for standards presented at low and high levels, respectively, is rather small (e.g., Zeng, Turner, & Relkin, 1991), resulting in the *midlevel hump in intensity discrimination*. The mid-level hump is also found for backward maskers and contralaterally presented maskers (e.g., Plack, Carlyon, & Viemeister, 1995), which precludes mechanisms in the auditory periphery as the origin of the effect. In experiments in which the masker-standard level difference was varied while keeping the standard level constant, the jnd elevation caused by a forward masker was larger for *intermediate* than for large masker-standard level differences (*mid-difference hump*; Oberfeld, 2003, in press). These observations are evidence for the *similarity model* proposed by Oberfeld (2003, 2005), which assumes that the masker degrades or biases the memory representations of the target tones (Plack & Viemeister, 1992; Carlyon & Beveridge, 1993), and that the *perceptual similarity* of masker and standard is crucial for the effect. Maskers strongly differing from the standard in at least one dimension (e.g., loudness, duration) are assumed to have only a relatively small effect on the memory representations and thus on intensity resolution, so that the jnd elevation is a non-monotonic function of the masker-standard level difference. The model is compatible with the reduced midlevel humps observed if a masker differing from the standard in duration or spectral content is presented (Schlauch, Lanthier, & Neve, 1997). The mid-level hump can be viewed as a special case of the mid-difference hump because standard level and the masker-standard level difference are correlated if masker level is fixed at, e.g., 90-dB SPL.

The present study for the first time examined not only the effects forward masking on intensity difference limens ("molar psychophysics", Green, 1964), but also assessed the decision process by introducing within-trial variability in masker level and analyzing the trial-by-trial data ("molecular psychophysics", Green, 1964).

For the 2IFC task used, it was assumed that listeners integrate the level of masker and target tone in both of the two observation intervals, and base their decisions on the overall level in each interval. An equivalent description of the expected decision process is that a listener behaves as an energy detector, comparing the output level of a temporal window for the first interval and the output level of a temporal window for the second interval, and voting for the interval where the output level was larger (Plack & Oxenham, 1998). Concerning intensity discrimination in quiet, Jesteadt, Schairer, and Neff (2005) analyzed data from an experiment in which external variability was added by randomly varying pedestal level in each of the two observation intervals. The relation between the level of the tone in the interval containing the standard only and the interval containing the standard-plus-increment, respectively, and performance was compatible with the pattern an energy detector would produce.

The above assumptions result in the hypothesis that the binary response (“Increment in interval 1” or “Increment in interval 2”) be correlated with the within-trial difference in masker level. For example, listeners should tend to respond “Increment in interval 2” if the masker presented in the second interval is higher in level than the masker in interval 1. In line with the predictions of the similarity model, a second hypothesis was that the effect of the masker levels presented in a given trial on the response be smaller in conditions where the masker was found to cause only a small deterioration in performance.

Method

Stimuli and Apparatus

The standard and the masker were 30-ms, 1-kHz pure tones. A 2I, 2AFC procedure was used. In one of the two observation intervals (randomly selected), an increment was added in-phase to the standard. Standard level was 25 dB SPL. Listeners were tested in quiet and with a forward masker presented in both intervals. In each trial, the sound pressure level of the masker presented in interval 1 and interval 2, respectively, was sampled independently from a normal distribution. Mean masker level was 25, 55, or 85 dB SPL. The standard deviation (SD) was 0 dB (fixed masker level), 2 dB, or 6 dB. Masker level was limited to a range of ± 2.5 SDs. The silent interval between masker offset and standard onset was 100 ms. The interval between the offset of the first target tone and the onset of the second target tone was 650 ms.

All stimuli were generated digitally, played back via one channel of an RME ADI/S D/A converter ($f_s = 44.1$ kHz, 24-bit resolution), attenuated (TDT PA5), buffered (TDT HB7), and presented to the right ear via Sennheiser HDA 200 headphones.

Procedure

Listeners participated in two training sessions, followed by three sessions in which intensity difference limens (DLs) were measured using a 2IFC, adaptive procedure with a 3-down, 1-up tracking rule. These DLs were used to select individual increments for the main experiment.

In the main experiment, a level increment (ΔL) was added to the standard in one of the two observation intervals (selected randomly). Listeners indicated the interval containing the louder target tone. They were instructed to ignore the maskers. Based on the DLs obtained in the adaptive procedure, a level increment was selected individually for each Mean Masker Level \times SD combination that would correspond to percent correct in the range from 70% to 85%. It was not possible for all listeners to find a single increment resulting in the targeted performance level for all conditions. The resulting

variation in increment level across conditions presents a potential problem for the analyses of the trial-by-trial data. Therefore, additional trials presenting the standard in both observation intervals (i.e., no-increment trials) were included in each block (Green, 1964), except for the in-quiet condition. The no-increment condition allowed for direct comparisons between correlations observed in the different mean masker level and masker level SD conditions, without having to worry about potential effects of increment level.

Only one Mean Masker Level \times SD combination was presented in each block. A block comprised 35 trials with the level increment presented in interval 1, the increment presented in interval 2, and without increment, respectively. Visual trial-by-trial feedback was provided, except following a no-increment trial. For each combination of mean masker level and masker level SD, six blocks of 105 trials were run in separate sessions, resulting in a total of 210 trials per condition (Mean Masker Level \times SD \times Increment Position).

Listeners

Four normally hearing students at the Universität Mainz participated in the experiment voluntarily (3 women, 1 man, age 19-24 years). They were naïve with respect to the hypotheses under test. Only listener KD had previous experience in an intensity discrimination task.

Results and Discussion

Effect of Mean Masker Level and Masker Variability on Intensity Resolution

The data were analyzed in terms of a signal detection theory (SDT) model assuming equal-variance Gaussian distributions. The no-increment trials (standard presented in both intervals) were excluded from the analysis. As the level increment was not constant across all listeners and conditions, it was not possible to analyze performance in terms of d' directly. Instead, the level increment corresponding to $d' = 1.641$ (the performance level targeted by a 3-down, 1-up, adaptive procedure) was estimated for each block. In the first step, resolution-per-dB was computed as $\delta' = d'/\Delta L$. The level increment corresponding to $d' = 1.641$ was then computed as $\Delta L_{DL} = 1.641/\delta'$. The upper panels in Fig. 1 show the individual estimates of the level increment corresponding to $d' = 1.641$ as a function of mean masker level and masker level variance. Compared to previous results (Oberfeld, 2003, in press), the effect of the masker was surprisingly small, except for listener LE. For listeners KD and LE, the effect of the intermediate masker was slightly larger than the effect of the intense masker. This *mid-difference hump* pattern (Fig. 2, panel A) was also observed in previous experiments using an adaptive procedure (Oberfeld, 2003, in press). For the conditions with fixed masker level ($SD = 0$ dB), a repeated measures ANOVA indicated no significant effect of mean masker level, $F(3, 9) = 2.71$. There was a marginally significant quadratic trend, however, $F(1, 3) = 9.45$, $p = .054$, compatible with the observation of a mid-difference hump.

For the data obtained under forward masking, jnd's tended to be larger with random variation in masker level than with fixed masker level (Fig. 2, panel A). However, a repeated measures ANOVA with the factors Mean Masker Level and SD showed no significant effect of masker level SD ($F[2, 6] = 3.23$).

A potential explanation for the small effect on intensity resolution is the use of a fixed increment rather than an adaptive procedure (cf. Carlyon & Beveridge, 1993).

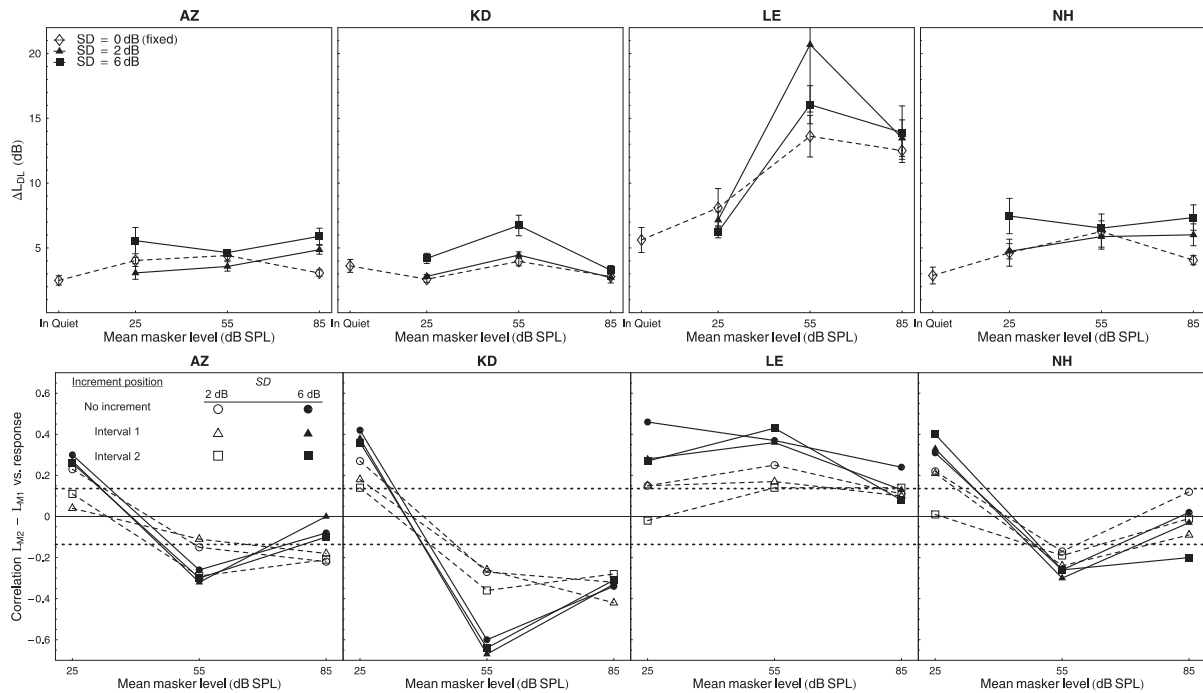


Fig. 1: Upper row: Individual level increments (ΔL_{DL}) corresponding to $d' = 1.641$ as a function of mean masker level. Open diamonds: $SD = 0$ dB (fixed masker level). Triangles: $SD = 2$ dB. Boxes: $SD = 6$ dB. Error bars show ± 1 SEM of the six estimates per data point. Lower row: Individual point-biserial correlations of the difference between masker level in interval 2 and masker level in interval 1 ($L_{M2} - L_{M1}$) with the binary response of the listener (1 or 2, indicating that he or she detected the increment in interval 1 or interval 2, respectively). Open symbols: $SD = 2$ dB. Filled symbols: $SD = 6$ dB. Circles: no increment. Triangles: increment in interval 1. Boxes: increment in interval 2. Correlation coefficients above or below the dotted horizontal lines, respectively, are significantly different from zero ($p < .05$).

Correlational Analyses of the Trial-by-Trial Data

The effect of forward masking on the decision process was studied using correlational analyses (cf. Richards & Zhu, 1994). In the first analysis, point-biserial correlations were computed between the trial-by-trial difference in masker level for the two intervals ($L_{M2} - L_{M1}$) and the binary response (1 or 2, for the increment present in interval 1 or interval 2). As discussed above, an energy detector would select the interval containing the higher overall level. Therefore, a *positive* correlation between $L_{M2} - L_{M1}$ and the response was expected. All listeners showed this pattern for mean masker level equal to standard level (25 dB SPL; Fig. 1, lower panels). All correlation coefficients were significantly different from 0 ($p < .05$) with a masker level SD of 6 dB. With the 2-dB SD, 8 of the 12 coefficients significantly differed from 0.

The data obtained with mean masker level larger than standard level indicated a decision strategy not compatible with an energy detector, except for listener LE, who showed positive correlations between $L_{M2} - L_{M1}$ and the response at all masker levels. For the remaining listeners, 28 of the 36 correlation coefficients were significantly *smaller* than 0 at the 55-dB SPL and the 85-dB SPL mean masker level (Fig. 1, lower panels). A negative correlation between the difference in masker level and the response means that the listeners tended to vote for the interval containing the *softer* masker. Such a behavior is compatible with a decision strategy of comparing masker loudness and target tone loudness in each of the two intervals, and voting for the interval in which this difference in loudness was smaller.

The data were analyzed via a repeated measures ANOVA with the factors mean masker level, SD, and increment position.

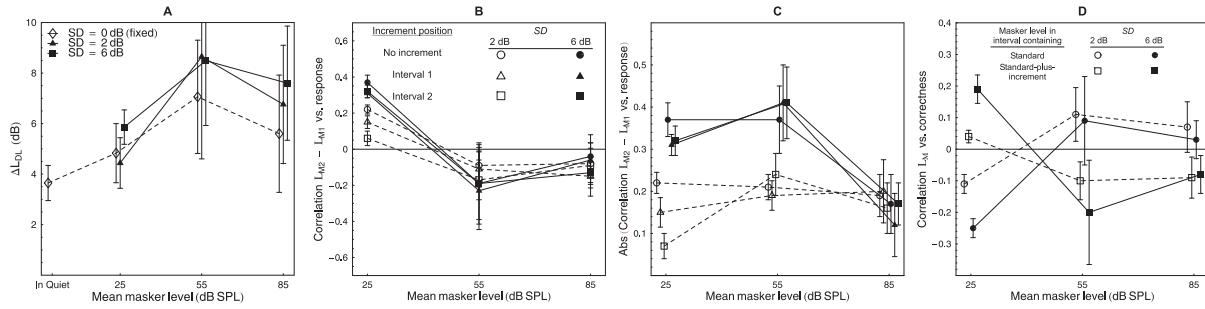


Fig. 2: Panel A: Mean level increments (ΔL_{DL}) corresponding to $d' = 1.641$ as a function of mean masker level. Open diamonds: $SD = 0$ dB (fixed masker level). Triangles: $SD = 2$ dB. Boxes: $SD = 6$ dB. Panel B: Mean point-biserial correlations of the difference between masker level in interval 2 and masker level in interval 1 ($L_{M2} - L_{M1}$) with the binary response. Open symbols: $SD = 2$ dB. Filled symbols: $SD = 6$ dB. Circles: no increment. Triangles: increment in interval 1. Boxes: increment in interval 2. Panel C: Mean *absolute* values of the point-biserial correlations between $L_{M2} - L_{M1}$ and the binary response. Same format as panel B. Panel D: Mean point-biserial correlations between masker level and the correctness of the response as a function of mean masker level. Circles: masker level in the interval containing the standard. Boxes: masker level in the interval containing the standard-plus-increment. Open symbols: $SD = 2$ dB. Filled symbols: $SD = 6$ dB. Error bars show ± 1 SEM of the four individual means.

The effect of mean masker level was significant, $F(2, 6) = 5.65, p = .072, \tilde{\epsilon} = .67$, confirming the observation of different decision strategies for mean masker level equal to or greater than standard level, respectively (Fig. 2, panel B). To examine the importance of the difference in masker level for the decision (i.e., the strength of the association independent of the sign of the correlation), the same type of ANOVA was conducted for the *absolute values* of the correlation coefficients. As predicted by the similarity model, the influence of the difference in masker level on the response was strongest for the 55 dB SPL mean masker level, $F(2, 6) = 7.96, p = .046, \tilde{\epsilon} = 0.66$ (Fig. 2, panel C). It was larger at a masker level SD of 6 dB, $F(1, 3) = 14.53, p = .032$, except for the 85 dB SPL mean masker level (significant Mean Masker Level \times SD interaction, $F[2, 6] = 11.90, p = .015, \tilde{\epsilon} = 0.80$). The effect of increment position was not significant, $F(1, 3) = 1.15$.

For a forward-masked detection task, Jesteadt et al. (2005) found that the level of the masker in the interval containing the signal was negatively related to performance, while the level of the masker in the non-signal interval had only a very small effect on the correctness of the response. Performance of an energy detector would be equally affected by the masker level in the two intervals, albeit in opposite directions. For the present experiment, this raised the question as to whether the relation between masker level in the two types of interval and performance differed depending on the decision strategy. It seemed conceivable that at the smallest mean masker level, masker level in both intervals was correlated with the correctness of the response, because the decision process was compatible with energy detection. At the larger masker levels, however, was performance determined mainly by masker level in the interval containing the increment, due to the different decision strategy observed? To answer this question, correlations of the correctness of the response (false or correct) on individual trials with masker level in the interval containing the standard, M_S , and masker level in the interval containing the standard-plus-increment, M_{S+I} , were computed separately. At a mean masker level of 25 dB SPL, all correlation coefficients for the relation between M_{S+I} and the correctness of the response were positive. In contrast, all correlation coefficients for the relation between M_S and the correctness of the response were negative (Fig. 2, panel D shows the mean data). This is the pattern expected for an energy detector. For the two larger mean masker levels, the opposite relations were found for all listeners except LE (e.g., *negative* correlation between M_{S+I} and the correctness of the response). To test whether the strength of the association between masker level and correctness differed between

the standard interval and the standard-plus-increment interval, the *absolute values* of the correlations coefficients were analyzed in a repeated measures ANOVA with the factors mean masker level, *SD*, and interval. There was no significant effect of interval, $F(1, 3) = 0.11$, showing that the correctness of the response was equally influenced by masker level in both intervals.

Summary

The decision process in a forward-masked intensity discrimination task was studied by introducing within-trial variability in masker level. Correlations of the trial-by-trial difference between masker level in interval 2 and masker level in interval 1 with the binary response indicated different decision strategies for different masker-standard level combinations. The influence of masker level on the decision was stronger at the intermediate mean masker level, where previous experiments found the largest effect on DLs. Masker level in the interval containing the standard as well as in the interval containing the standard-plus-increment affected the correctness of the response, contrary to what Jesteadt et al. (2005) found for a forward-masked detection task. Studying the decision process seems a promising tool for a better understanding of intensity discrimination under non-simultaneous masking.

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