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PURE TONE INTENSITY DISCRIMINATION AND DYNAMIC RANGE ADAPTATION

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ABSTRACT

Electrophysiological animal studies have shown that in response to a noise fluctuating in level, neurons adapt their dynamic range according to the level distribution. This Dynamic Range Adaptation (DRA) shifts the neurons' input-output growth function towards the most probable levels. The present study investigates the effect of context on intensity discrimination, in search of a perceptual correlate of DRA. Nine normal-hearing participants took part. Intensity difference limens (DLs) were measured for 2-kHz, 50-ms pure tones at 55- and 75-dB SPL, embedded in sequences of 50-ms narrowband non-simultaneous noise with a Gaussian level distribution centered around 55- or 75-dB SPL. The hypothesis was that DRA should yield lower DLs for matched tone and context levels than for unmatched levels. The results showed a significant interaction between tone level and context level but not consistent with DRA: DLs remained larger for the loud than for the soft context for both tone levels. Possible explanations include (i) the use of different stimuli compared to the animal studies, (ii) the presence of off-frequency listening which may lower DLs when the tone level is higher than the context level, and (iii) differences in absolute thresholds between context levels, which may affect DLs more than DRA.

Keywords: *psychoacoustics, dynamic range, intensity discrimination*

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1. INTRODUCTION

The response function of individual neurons is known to depend on stimulus statistics and, in particular, on the recent stimulus history [1]. Several studies [2–6] performed measurements with a continuous noise called context, and showed a shift of the dynamic range of neurons dependent on the context mean level. The context level changed every 50 ms, following a distribution consisting of a high-probability region (HPR), a 10-12 dB range with a high presentation probability, and a low-probability region with all the remaining tested levels. Depending on the HPR's mean level, the horizontal shift of the rate-level function (RLF) places its steepest part near the most probable levels, leading to an increased difference between the spike rates obtained for two nearly probable levels, and thus to the improvement of the coding of HPR levels. This phenomenon is called dynamic range adaptation (DRA).
It was observed in small mammals : first in the inferior colliculus of guinea pigs [2, 3], then in the auditory nerve of cats [4, 5] and in the auditory cortex of marmosets [6]. The effects observed were smaller in the auditory nerve than in the inferior colliculus [4], so it appears that DRA may be enhanced throughout the auditory pathways. Wen *et al* [5] focused on the time course of DRA at the level of the auditory nerve. For an increase in HPR, the mean time needed for the shift caused by DRA to happen was of 211 ms, and for a decrease, 262 ms. In general, the range of time constants were comprised between 100 and 400 ms.
Several psychophysical tasks have used similar stimulus paradigms to study the effects of the level distribution on loudness discrimination or amplitude modulation detection. However, their results have not been consistent with DRA. For example, Herrmann *et al* [7] investigated the effect of experimental context on cortical responses, and on modulation detection in a group of human subjects. They

concluded from electroencephalography recordings that some DRA is observable in the human auditory cortex, but for the modulation detection task, performance was better for levels that had a low probability of presentation than for levels in the high probability region. However in this study, the stimuli were separated by silences longer than the time constant of DRA observed by Dean *et al* [2] and Wen *et al* [4] (100-ms signals every 500 ms).
No perceptual correlate of DRA has thus been observed in humans yet. Here we hypothesize that a consequence of DRA on intensity discrimination tasks should be a lower discrimination threshold when test tones have a similar level as the context compared to when they have different levels. The goal of this experiment is to study the differences in intensity discrimination performance for different level configurations, using a narrowband context with a fluctuating level and pure tone standards.

2. INTENSITY DISCRIMINATION IN A NARROWBAND CONTEXT

2.1 Material and methods

The main experiment was an intensity discrimination task of short pure tones presented in different contexts, using matched and mismatched levels for context and test tones.
Discrimination thresholds were obtained with an interleaved 2I-2AFC, 2-down, 1-up adaptive protocol in six conditions. There were two standard levels (55- and 75-dB SPL, respectively labeled soft and loud), which were tested in silence, and in two different mean context levels (55- and 75-dB SPL).
The context was a continuous narrowband noise (1880-2120 Hz) played continuously throughout the procedure, except it stopped during the test signals' presentation. The context was divided in 50-ms "epochs", with 5-ms onset and offset half-Hanning windows for smoothing. The context level changed every 50 ms (every epoch), following a Gaussian distribution centered around its mean level, with a standard deviation of 3 dB. The distribution was truncated so the levels were bounded to $\pm$ 10 dB around the mean level.
The test signals (standards) were 2-kHz pure tones, of duration 50 ms, with 5-ms onset and offset half-Hanning windows for smoothing. The same 500 ms of context were played before both test intervals.
Nine normal-hearing participants took part (thresholds below 20 dB HL between 125 and 8000 Hz). All subjects completed a preliminary experiment testing their detection thresholds in the loud context (results not shown). Only subjects with a threshold at least 10 dB lower than the lower standard level were selected. This ensures that all standards were presented at least at 10 dB SL in the loud context.
The hypothesis formulated based on the physiological data from the literature was as follows : discrimination thresholds for test tones and context matched in levels are expected to be lower than for mismatched levels. The mean level of the context being close to the steepest part of the neurons' response function, the representation of small intensity differences should be enhanced in the matched level condition, so discrimination thresholds should be lower.

2.2 Results

Intensity discrimination thresholds are presented for each standard level as a function of context type (figures 1 and 2). The data were analyzed in a two-ways repeated-measures (rm) ANOVA with factors context level and standard level. Both effects are significant (respectively : $F_{1,8}$ = 272.309, p<1e-6 ; $F_{2,16}$ = 89.604, p<1e-8), as well as their interaction ($F_{2,16}$ = 56.551, p<1e-7). Additional one-way rmANOVA were performed for each standard level, as well as Bonferroni pairwise comparisons.
For the soft standard (figure 1), the results and pairwise comparisons are consistent with the hypothesis : thresholds are significantly higher when the context level is different from the standard level (p<1e-5), and higher in the loud context than in silence (p<1e-4).
However for the loud standard (figure 2) there is no difference between context conditions, even though there is a significant effect of context level (one-way rmANOVA on context level for the 75-dB SPL standard, $F_{2,16}$ = 5.80, p = 0.013).

3. DISCUSSION

Our results are only partially consistent with an effect of dynamic range adaptation. Although we did find an interaction between context and standard levels, there was no significant difference in discrimination thresholds between context levels for the loud standard level. There may be several possible explanations for that :
1. Intensity discrimination may rely on other cues than the slope of the rate-level function, so this task may not be adequate to reveal a perceptual correlate of DRA.
2. Contrary to animal experiments which used broadband

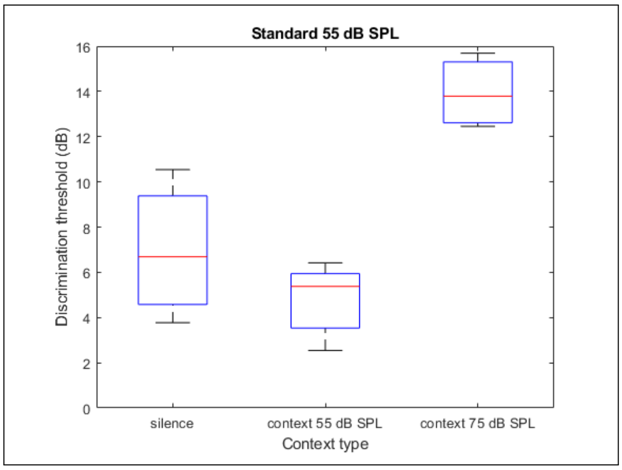

Figure 1. Discrimination thresholds for the soft 55-dB SPL standard, plotted against context type (including silence). The median is presented as a red bar, with the first and third quartile limiting the blue box around it. Whiskers are including all non-outlier values (more than 3 times the interquartile value away from the first or third quartile) that do not fall into the box. The loud (75-dB SPL) context produces significantly higher thresholds than the soft (55-dB SPL) one and the silence.

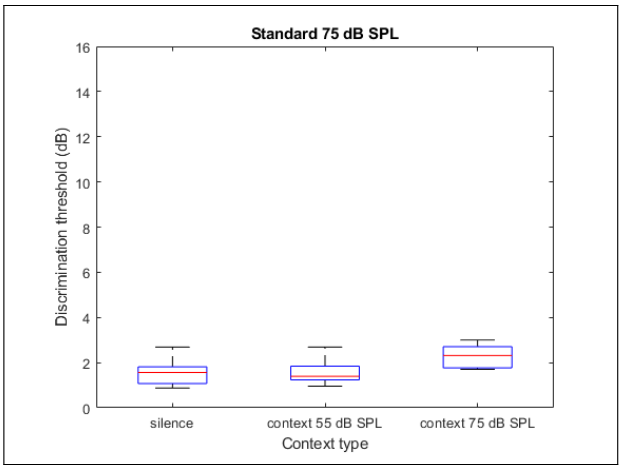

Figure 2. Discrimination thresholds for the loud 75-dB SPL standard, as in figure 1. No significant difference appears between conditions.

signals, we used narrowband signals meaning that the levels at the output of auditory filters are much higher in our case. Maybe DRA is not as efficient at these high levels. One solution would be to perform a similar task using broadband signals. Consequences of DRA on perception might be easier to observe when stimulating larger neural populations.
3. Maybe DRA has an effect in our task but additional processes mask its effect for the loud standard. For example, it is possible that for the low context level, there is some off-frequency listening : as the loud standard is presented at a significantly higher level than the soft context, its excitation pattern is probably broader than that of the context. That may make discrimination thresholds lower than they would really be if subjects were listening only to a restricted frequency range where the context is effective (i.e. around 2000Hz). One solution to test this is to add a notched noise to suppress any clues arising from the spread of excitation.
4. A last possibility is that performance is worse than expected in the loud context-loud standard condition. Absolute thresholds increase with context level (tested in preliminary experiments, results not shown), and studies [8, 9] have shown that discrimination thresholds in dB SL follow the near-miss to Weber's law. As a consequence, an increase in context level can be expected to result in an increase in thresholds : the task with context would be equivalent to a quiet condition but with a softer standard level, yielding higher discrimination thresholds. It is what we observe in figure 1 for the soft standard. However for the loud standard, in figure 2, it is not the case : the lower SL in the loud context does not significantly increase the thresholds, even though a small tendency is observable. It is possible that the higher standard level is simply less affected by the context since it is played at a higher SL than the soft standard in all conditions.

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