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Temporal Weighting of Loudness: Effects of a Fade In

(Zeitliche Gewichtung der Lautheit von graduell eingeblendetem Rauschen)

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Introduction

If listeners evaluate the overall loudness of a longer sound fluctuating in level, the initial and final portions of the stimulus receive greater weight than its temporal center [1]. If all temporal segments provide the same amount of information, an ideal listener would weight the level information provided by each segment uniformly [2]. Pedersen and Ellermeier [3] found that some listeners used an approximately optimal set of weights if trial-by-trial feedback was provided.

In everyday life, we frequently encounter sounds gradually increasing in intensity, as for example a car approaching on the road. The present experiment studied the temporal weights used in evaluating overall loudness of a level fluctuating sound that contained a *fade in.* The stimulus consisted of ten 100-ms wide-band-noise segments. The levels of the first few segments were attenuated relative to the level of the final segments. We expected weights for the softer segments constituting the fade in to be smaller than for the unattenuated segments, although all segments still provide the same information. A *fast fade in* condition (3-segment fade in) and *slow fade in* condition (6-segment fade in) were studied in the experiment. The two conditions were presented randomly interleaved in order to find out whether listeners adapt their weights on a trial-by-trial basis.

Additionally, intensity difference limens were measured for a 300-ms wide band noise burst and a 'fade in' noise stimulus consisting of three 100-ms noise segments, with the level of the first and the second segment attenuated by 10 and 5 dB, respectively, relative to the level of the third segment. The ideal weights described above rely on the assumption that listeners' intensity resolution for the two types of stimuli is identical.

Method

Stimuli and Apparatus

The stimuli consisted of ten 100-ms wide-band-noise segments. A MATLAB program was used for digital stimulus generation and experimental control. Stimuli were generated via two channels of an RME ADI/S D/A converter (f_S = 44.1 kHz, 24-bit resolution), attenuated by two TDT PA5 programmable attenuators, buffered by a TDT HB7 headphone buffer, and presented diotically via Sennheiser HDA 200 headphones. The attenuator setting remained constant throughout the experiment, all level changes were generated digitally. The experiment was conducted in a single-walled IAC sound proof chamber.

Listeners

Five listeners aged 21-41 years (M = 27.2) participated in the experiment. All reported normal hearing. Only two listeners (BH and KD) had experience in comparable psychoacoustic tasks. All listeners except BH and KD were unaware of the hypotheses under test.

Procedure

Estimation of perceptual weights

The sound pressure levels of the ten segments were initially independently drawn from a normal distribution with μ = 60 dB SPL and σ = 2 dB. In the slow fade-in condition, the first six segments were then attenuated by subtracting 15, 12.5, 10, 7.5, 5 and 2.5 dB, respectively. In the fast fade-in condition, the first three segments were attenuated by subtracting 15, 10 and 5 dB. Additionally, in the fast fade-in condition 2.5 dB were subtracted from all ten segments in order to equalize the overall mean in the fast fade-in and slow-fade in condition to around 55 dB SPL. Each of the so constructed stimuli was then randomly chosen to be a "loud" or "soft" trial. $\Delta L/2$ = 0.5 dB was added to each of the ten segments in a "loud" trial and subtracted in a "soft" trial, resulting in a mean difference of ΔL = 1 dB between "loud" and "soft". Figure 1 (middle lower panel) shows a schematic depiction of a trial with slow fade-in (left) and fast fade-in (right). The stimuli were presented in a 1I, 2AFC procedure. The listeners' task was to decide if they had just heard a "soft" or "loud" noise. After some training (with trial-by-trial feedback), each listener completed 2000 trials in 40 blocks, thus 1000 trials in the slow fade-in and fast fade-in condition, respectively. The two conditions were presented randomly interleaved in each block of 50 trials. Feedback (percentage of correct responses) was provided after each block only.

Data analysis

The resulting data were analyzed to determine the relative perceptual weight with which each of the temporal segments contributed to the decision of the listener. Logistic regression (PROC LOGISTIC, SAS 8.01) was used to estimate the weights out of 1000 binary responses obtained in each condition. The binary responses served as the dependent variable, the sound pressure levels of the ten temporal segments served as the independent variables. The regression coefficients were taken as weight estimates. The resulting weights were normalized such that the sum of the absolute values was unity.

Difference limens

Difference limens were obtained for a 300-ms wide band noise and a noise stimulus consisting of three 100-ms noise segments. The level of the first and the second segment were attenuated by 10 and 5 dB, respectively, relative to the level of the third segment. No random level fluctuation was applied. An absolute identification task (1I, 2AFC) combined with a 3-down, 1-up adaptive procedure was used. In each track, the grand mean level of the 300-ms noise was μ = 50 dB SPL. The grand mean level of the 3-segment noise was also 50 dB SPL. In each trial, either a soft (mean level $\mu_S = \mu - \Delta L/2$) or a loud noise (mean level $\mu_L = \mu + \Delta L/2$) was presented.

The listener's task was to indicate on a response pad whether the softer or the louder noise had been presented.

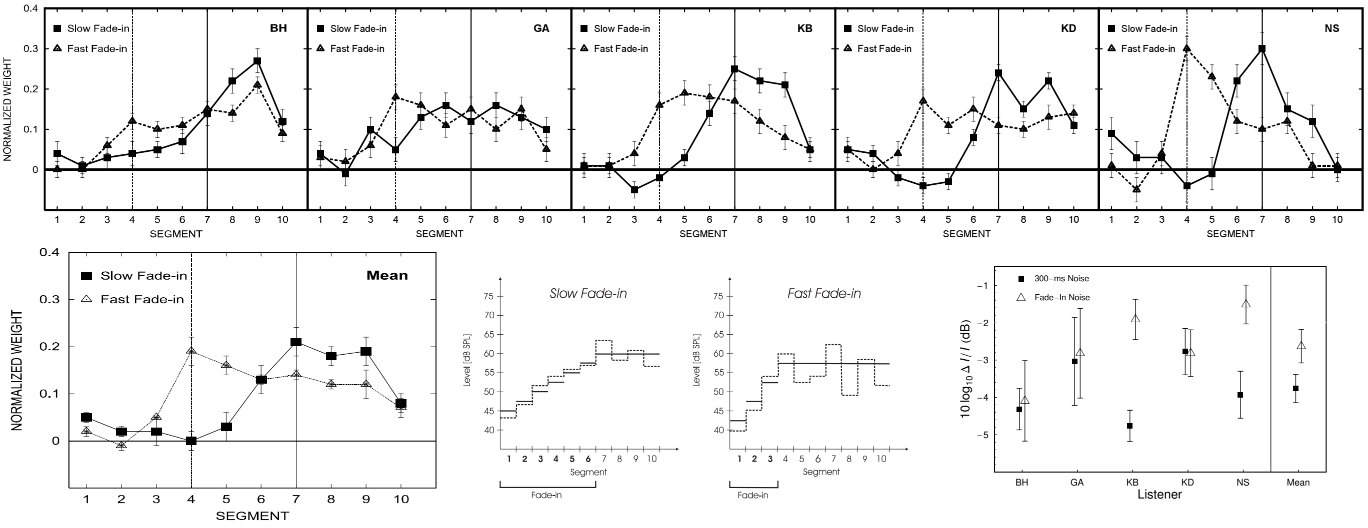

Fig. 1: *Upper panel*: Normalized relative perceptual weights assigned to the 10 segments. Squares: slow fade in. Triangles: fast fade in. Panels represent listeners. Vertical lines indicate the first unattenuated segment. Error Bars show ± 1 Standard Error of the weight estimates. *Left lower panel*: Mean normalized perceptual weights assigned to the 10 segments. Error Bars show ± 1 SEM. *Middle lower panel*: Schematic representation of a trial in the slow fade-in condition (left) and the fast fade-in condition (right). Thick lines represent grand mean segment levels, dotted lines show the random fluctuation. *Right lower panel*: Individual and mean difference limens (10 $\log_{10}\Delta I/I$). Squares: 300-ms noise burst. Triangles: Fade-In Noise. Error Bars show ± 1 SEM.

The sound pressure level difference between the softer and the louder noise (ΔL) was decreased after three consecutive correct responses and increased after every incorrect response. The adaptive procedure adjusted the level of an intensity increment, $10 \log_{10}(\Delta I/I)$, which was then converted to the sound pressure level difference ΔL, using the relation $\Delta L = 10 \log_{10}(1 + 10^{k/10})$, where $k = 10 \log_{10}(\Delta I/I)$. The initial value of $10 \log_{10}(\Delta I/I)$ was 5 dB. Step size was 5 dB until the fourth reversal and 2 dB for the remaining 6 reversals. This procedure converges on a level difference ΔL corresponding to 79.4% correct responses. Three blocks comprising two randomly interleaved tracks were run in each condition. For each track, the arithmetic mean of $10 \log_{10}(\Delta I/I)$ at the last 6 reversals was taken as the DL estimate. Subsequently, for each type of noise, the six DL estimates were averaged. Listeners received visual trial-by-trial feedback.

Results

As expected, all listeners assigned only small weights to the attenuated segments (1-3) in the fast fade in condition (Fig. 1, upper panel, triangles). Surprisingly, the data indicate a "*delayed primacy effect*": on average, the first unattenuated segment received the greatest weight (Fig. 1, left lower panel).

Mean weights for the slow fade in condition followed essentially the same pattern, except that the last attenuated segment (Nr. 6) was weighted more strongly than the five initial segments. Possibly, this observation can be attributed to the fact that attenuation was 2.5 dB only for segment 6. Listener GA assigned approximately identical weights to all but the first four segments.

A *Segment Type* (Attenuated Segments / Unattenuated Segments) × *Condition* (Fast Fade In / Slow Fade In) repeated measures ANOVA indicated a significant effect of the segment type, $F(1, 4) = 81.94$, $p < .002$. The *Segment Type* × *Condition* interaction was not significant, $F(1, 4) = 0.319$, indicating that the relative weighting of the attenuated and the attenuated segments, respectively, did not differ between conditions. The effect of fade in condition was significant, $F(1, 4) = 50.44$, $p < .003$.

Across listeners and conditions, the percentage of correct responses varied between 63% and 71%. For two listeners (GA and NS), performance was identical in the two conditions. For the remaining subjects, performance was better in the *fast fade in* condition. The mean value of the SDT sensitivity index was $d' = 0.94$ ($SD = 0.20$) in the fast fade in and $d' = 0.83$ ($SD = 0.16$) in the slow fade condition. This difference was not significant, $t_4 = 2.07$.

The difference limen for the 'fade in noise' was considerably larger than for the continuous noise for two listeners only (Fig. 1, right lower panel). The difference between the DL's obtained for the two types of noise was only marginally significant, $t_4 = 1.835$, $p = .07$ (one-tailed).

Conclusions

Perceptual weights again differed from optimal weights as listeners used virtually no information from the attenuated segments constituting the fade-in but showed a "delayed primacy effect" (large weights assigned to the first unattenuated segments) instead.

Intensity difference limens for a 'fade in noise' and a continuous noise of the same duration differed for two listeners only. The data thus provide no unequivocal evidence against the idea that listeners' performance is not affected by the fade in steps which do not decrease the reliability of the level information.

Future experiments will be targeted at designing a level fluctuating noise so that listeners apply equal weight to all temporal segments.

References

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