Different implementations of a model for subjective duration

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1. Introduction

The perceived duration of short sounds or pauses can differ considerably from their physical duration. For example, a sound burst of 100 msec duration can elicit the same subjective duration as a pause of 380 msec. Hence a factor of 1.0 in the subjective domain corresponds to a factor of 3.8 in the physical domain. Early experiments on subjective duration were reported by Henry (1948), Small and Campbell (1962) as well as Zwicker (1969).

A model based on temporal masking patterns has been proposed (Fastl 1975, 1977) which can account for the effects of subjective duration. In this paper, different simulations of temporal masking patterns are tested in view of their ability to predict subjective duration of sound bursts as well as pauses.

2. Model

The model of subjective duration proposed by Fastl (1975) is illustrated in figure 1. The upper panels show temporal masking patterns measured in psychoacoustic experiments for a tone burst of 100 msec duration (left) and a pause of 290 msec duration (right). The level L_T^* of the test tone impulse is given as a function of time t.

In the left panel, the effects of pre-masking and post-masking are clearly visible. The model predicts that perceived subjective duration can be derived from the temporal masking pattern. More specifically, the time span of the temporal masking pattern 10 dB above its minimum is taken as a measure of the perceived subjective duration (Fastl 1977). This duration is indicated by a double arrow.

In the right upper panel of figure 1, the temporal masking pattern of a pause is shown. Again effects of post-masking and pre-masking are clearly visible. When adopting again the criterion "10dB above minimum", the duration indicated by the double arrow is obtained, which corresponds to the perceived subjective duration of the pause.

The double arrows in the upper panels of figure 1 make clear that the perceived duration of impulses is longer than their physical duration, whereas the perceived duration of pauses is shorter than their physical duration.

Since the measurement of detailed temporal masking patterns requires a lot of time, it is desirable to simulate temporal masking patterns on the basis of the physical data of the sounds concerned. The lower part of figure 1 shows examples of a rather simple simulation of temporal masking patterns. Before going into detail, regarding the results displayed in figure 1 it can be stated that even the simple simulation can account for the prominent effects of subjective duration (compare double arrows in upper versus lower panels).

A simple model simulating temporal masking patterns is illustrated in figure 2. In essence, after spectral analysis, the temporal envelope is extracted and the excitation level calculated. Post-masking is simulated with a first order low pass with a time constant of 50 msec. The block "maximum detection" accounts for a steep rise and a gradual decay of the simulated temporal masking pattern. Finally, the threshold 10 dB above the minimum is calculated leading to the predictions of subjective duration. For further illustration, in the right part of figure 2 the respective signals are schematically indicated after each step of processing within a single channel of the multi-channel model.

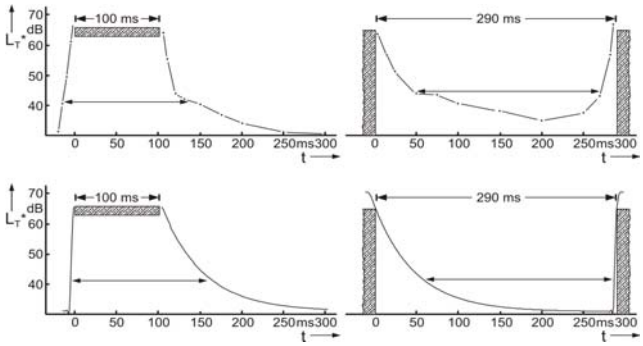

Figure 1: Subjective duration derived from temporal masking patterns for a tone of 100 msec (left) or a pause of 290 msec (right). Upper panels: psychoacoustically measured temporal masking patterns. Lower panels: simulations by a simple model. Double arrows: indications of perceived subjective durations.

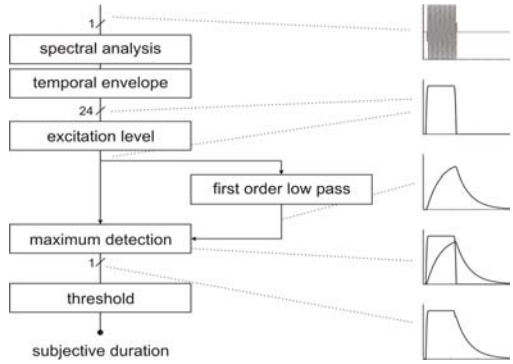

Figure 2: Simplified block diagram of a simple model for simulation of temporal masking patterns (left). Schematic illustration of signals within one channel after each processing step (right).

Since the simple model does not account for the additivity of post- and pre-masking which is in particular relevant for short pauses (e.g. Fastl 1982), again simplifying it was assumed that the interaction has a maximum duration of 50 msec and the additivity of masking is limited to 10 dB.

3. Results and discussion

Calculated subjective durations (i.e. the length of the double arrows as shown in the lower panels of figure 1) were compared to psychoacoustically measured data on subjective duration published in the literature. Some examples are given in figure 3. In figure 3a, data of Burghardt (1972) are given as medians with interquartiles for measurements of halving the subjective duration. This means that on the ordinate the physical duration $T_{i1/2}$ of sound impulses is given which lead to half the subjective duration of sound impulses with physical duration T_i, plotted along the abscissa. The predictions by the simple model illustrated in figure 2 are given as dashed line. Regarding the data displayed in Figure 3a it becomes clear that at long durations, for subjective halving of the duration, T_i and $T_{i1/2}$ have to form a ratio of 0.5. On the other hand, for a duration T_i=100 msec, half the perceived subjective duration is not 50 msec but $T_{i1/2}$=36 msec. This means that short tone impulses are perceived

as being relatively longer than long tone impulses. This behaviour is accounted for by the effects of post-masking.

When comparing data points and dashed curve in figure 3a it is seen that even the simple model accounts in principle for the effects of subjective duration of tone impulses.

Perhaps even more important are the differences between impulses and pauses. A typical example based on psychoacoustic data measured by Burghardt (1973) is illustrated in figure 3b. The physical duration T_i of impulses is plotted along the abscissa, the physical duration T_p of pauses along the ordinate. If at same physical duration impulses and pauses would have the same subjective duration, all measurement points should lie on the dotted line, which corresponds to the equation $T_i = T_p$. Only at rather long durations near 1 sec physical and subjective duration are in line. At shorter durations, for physically equal duration, pauses are perceived as systematically shorter than impulses. For example, an impulse of T_i=36 msec physical duration elicits the same perceived duration as a pause of 100 msec. When comparing data points and dashed curve in figure 3b it can be stated that the simple model nicely accounts for the large differences in perceived duration of impulses versus pauses.

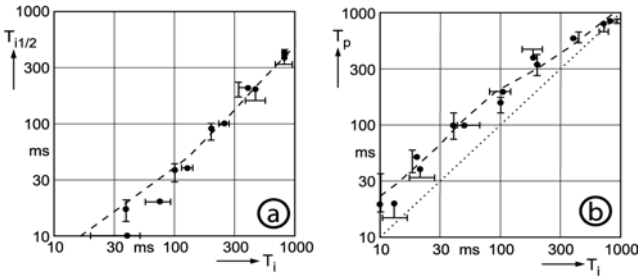

Figure 3: Halving the subjective duration of impulses (a) and comparison of subjective duration of impulses and pauses (b). Medians and interquartiles: psychoacoustically measured data by Burghardt (1972, 1973). Dashed curves: predictions by the model illustrated in figure 2.

The model for the simulation of temporal masking patterns illustrated in figure 2 contains severe simplifications. Nevertheless, in principle it can account for the effects of subjective duration. In order to get a feeling whether it pays off to use for the description of the effects of subjective duration a much more elaborate model, calculations of subjective durations were also performed by the dynamic loudness model (DLM) proposed by Chalupper and Fastl (2002). Since this model is described in detail in the literature, here it should only be mentioned that it accounts for the temporal non-linearities of post-masking, i.e. the dependence of post-masking on both the level and the duration of the masker. To get an indication about the quality of the alternative models with respect to the simulation of temporal masking patterns in view of effects of subjective duration, the following comparisons were performed: From the data published by Fastl (1975), the subjective durations calculated on the basis of psychoacoustically measured temporal masking patterns were taken as target values. The differences of the subjective durations calculated from the simulations of the temporal masking patterns were taken as a measure for their suitability to describe effects of subjective duration. The related results are given in figure 4. Both for the calculated duration of impulses (left) and pauses (right), the deviations from the target values are given. Deviations from target are indicated by dashed lines for the simple model illustrated in figure 2 and by solid lines for the DLM. The shaded range in figure 4 encompasses deviations of +/- 10%, a relatively strict criterion given the variability of temporal masking patterns.

The results displayed in figure 4 suggest that both simulations of temporal masking patterns can predict subjective duration derived from psychoacoustically measured temporal masking patterns with an accuracy of about +/- 10%. This means that for the description of effects of subjective duration it seems not to be necessary to take into account the complicated temporal processing of the DLM, but also a very simple model as illustrated in figure 2 can do the job. Of course, for other psychoacoustic magnitudes like the modelling of loudness for normal hearing and hearing impaired subjects, the DLM has its merits (Chalupper and Fastl 2002), but for the description of subjective duration a much simpler model seems to be sufficient.

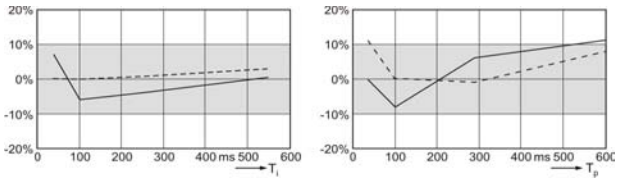

Figure 4: Percental differences to calculations for the duration of impulses (left side) and pauses (right side) based on psychoacoustically measured temporal masking patterns by Fastl (1975). Dashed lines: simple model according to figure 2, solid lines: results calculated by DLM.

4. Conclusion

From the results described in this paper, at least two main conclusions can be drawn:

1.) The fact that the psychoacoustic data on subjective duration of Burghardt can be simulated even with a rather simplified version of the model for subjective duration can be regarded as a further confirmation of the validity of the model of subjective duration based on temporal masking patterns (Fastl 1975).

2.) For the description of the effects of subjective duration by a model based on temporal masking patterns it is not necessary to implement a rather sophisticated model for the simulation of temporal masking. Even a rather simplified model can account for the effects of subjective duration.

Acknowledgements

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