MODELLING THE DIRECTION-SPECIFIC BUILD-UP OF THE PRECEDENCE EFFECT

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ABSTRACT

One of the remarkable properties of the auditory precedence effect is that it adapts to the listeners' acoustic environment. The “build-up” of the precedence effect has been investigated in a series of psycho-acoustic investigations to test the hypothesis of a “direction-specific“ build-up effect (Djelani and Blauert, 2001). A result of this work is a first model of the auditory precedence effect based on an inhibition model as proposed by Lindemann (1986a;1986b) and Zurek (1987).

INTRODUCTION

The auditory precedence effect comprises a set of manifestations that improve human listening in enclosed spaces. The perception of direct sound and early reflections as a single auditory event is called “fusion” . The fused auditory event is perceived from a direction close to the direction of incidence of the direct sound. Early reflections do not contribute much to the perceived direction of the auditory image. This observation is called “localisation dominance”. “Lag-discrimination suppression” denotes the reduced sensitivity to the detection of directional changes of a reflection with respect to the direct sound. For a general introduction to the topic see Blauert (1996) or Litovsky et al. (1999). The functional interrelation of the different manifestations of the precedence effect is not completely understood yet. Nevertheless, all sub-effects are related to suppression of spatial information contained in reflected (delayed) sounds with respect to that in the direct (leading) sound.

The build-up of the precedence effect denotes the increased effectiveness of fusion or lag-discrimination suppression after a repeated or temporally extended stimulus presentation. Build-up has not been observed for localisation dominance yet. Clifton (1987) discovered the change in effectiveness of the auditory precedence effect and interpreted the observation as an expectation or attention based phenomenon (Clifton et al, 1994). Recently, strong indication has been found that the build-up effect is direction-specific, i.e. the increase of effectiveness of fusion and lag-discrimination suppression is observed only for those directions from which reflections emanate. On the other hand do intermediate changes of the direction of a reflection not reset echo suppression to initial level for the setting in which the build-up has been occurred before (Djelani and Blauert, 2001; Djelani, 2001). This, however, was assumed in the literature (e. g., Clifton, 1994; Blauert, 1996).

The build-up of the precedence effect can experimentally be observed in a simplified scenario with a direct sound and a single simulated reflection presented in an an-echoic environment. To measure the build-up effect, typically, a train of noise-burst pairs is presented, with each burst pair simulating a direct sound and its reflection. Following the noise-burst train, also being called 'build-up stimulus', a test-stimulus pair is presented to determine, e. g., an echo threshold. The amount of build-up strongly depends on the length of the burst train (Litovsky, 1999). The substantial simplification of the experimental set-up, as compared to natural auditory environments, raises questions about the ecological meaning of the build-up effect.

The goal of our investigations, as described below, was to obtain a better understanding of both the purpose and the mechanism of the build-up effect. Especially the new hypothesis of the direction- specific build-up effect had to be verified.

TEMPORAL EXTENT OF THE BUILD-UP EFFECT

The investigation of the duration of the build-up effect has been performed using a virtual-environment generator with individually measured head-related transfer functions (Blauert et. al., 2000; Djelani et al. 2000). The lead stimulus was always presented from the frontal direction, the lag stimulus from 45° and 0° azimuth (no elevation). The amount of echo suppression has been measured for different delays of 1 s, 4 s and 9 s between build-up stimulus and test stimulus. A schematic set-up of the experiment is depicted in Figure 1(a). The noise bursts were 2 ms broad-band noise with a high- frequency cut-off at 14 kHz. Each build-up stimulus consisted of 20 pair-wise-incoherent bursts pairs presented at a rate of 4 / s. The simulated reflections were copies of the lead bursts. The experiment was performed following Levitt's (1971) 3-down-1-up paradigm with 11 reversals. Seven very experienced listeners participated in the experiment. Each of the listeners took part once in each of the three sessions in random order. This quite sparse amount of data was considered sufficient as the main question to be answered was whether the built-up remains at its level or decays after the presentation of the burst train has finished.

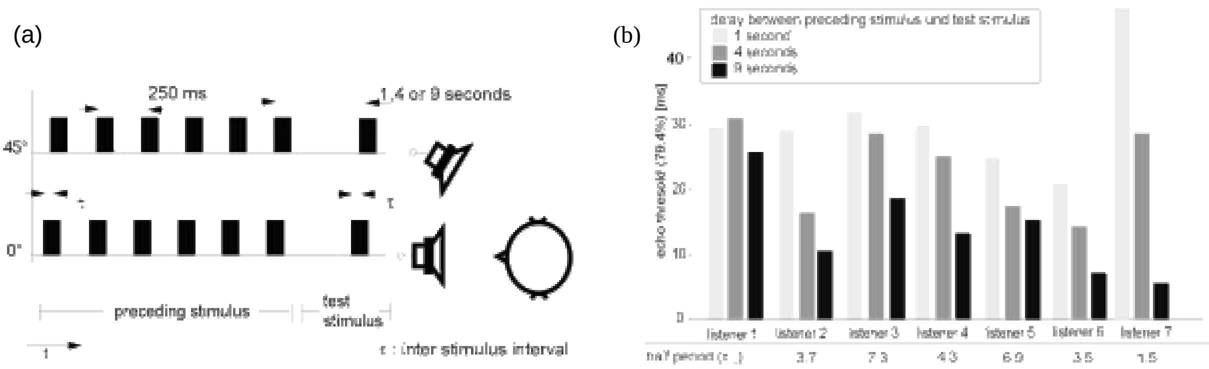

Figure 1: (a) Schematic set-up for the investigation of the duration of the build-up effect. (b) Results of the investigation. The resulting echo thresholds for 7 participants in the experiment. Shown are the echo thresholds for different delays between noise burst train and test burst pair. A resulting half-period value has been calculated for the listeners with a monotonic decay of the threshold value with increasing delay between build-up stimulus and test stimulus.

The results printed in Figure 1(b) were averaged from the last 8 reversals of each session. The resulting threshold values are in accordance with values reported in the literature (i.e. Litovsky et al, 1999). It is easily recognised that the measured echo thresholds decrease with increasing delay between build-up stimulus and test stimulus. The over-all calculated half period of the echo threshold is $\tau_{1/2}$ = 4.5 s ($\pm$ 2.2 s.) Even though the decay of the build-up will probably vary when a further stimulus is presented between build-up and test stimulus, the results strongly indicate that a built-up echo threshold does not need an active reset to disappear.

SPATIAL RESOLUTION OF THE BUILD-UP EFFECT

In an experiment similar to the one described above the solid angle covered by the build-up effect has been determined. The investigation was carried out in an an-echoic chamber with a loudspeaker set-up as shown in Figure 2(a). Again, a broad-band noise-burst train was presented as the build-up stimulus. A test stimulus was presented 1 s after the noise burst. The lead stimulus was always presented form 0°. In the build-up phase the lag emanated from 60° azimuth. The test stimulus lag was constantly presented in each session from 1 out of 4 alternative directions, so that the angular difference between build-up lag and test-stimulus lag was 0°, 20°, 40° or 105° azimuth. Each session was carried out in an adaptive 2-down-1-up procedure with a duration of 11 reversals (Levitt, 1971). The participants were 5 very experienced and 2 less experienced listeners. Each of the 4 session was performed 3 times. Results were calculated from the threshold values of the last 8 reversals.

The results as printed in Figure 2(b) were averaged over the 3 sessions. The listeners with less experience were listeners #6 and #7. The threshold values as measured for the 0° configuration can be considered as saturated build-up, whereas the values from the 105° configuration are close to the basic thresholds. For listeners #1 to #6 it noticeable that the echo threshold decreases steadily with increasing angular distance between build-up lag and test-stimulus lag. No single-step breakdown of the echo threshold is observed, instead we see a rather smooth decay of the "strength" of the echo suppression.

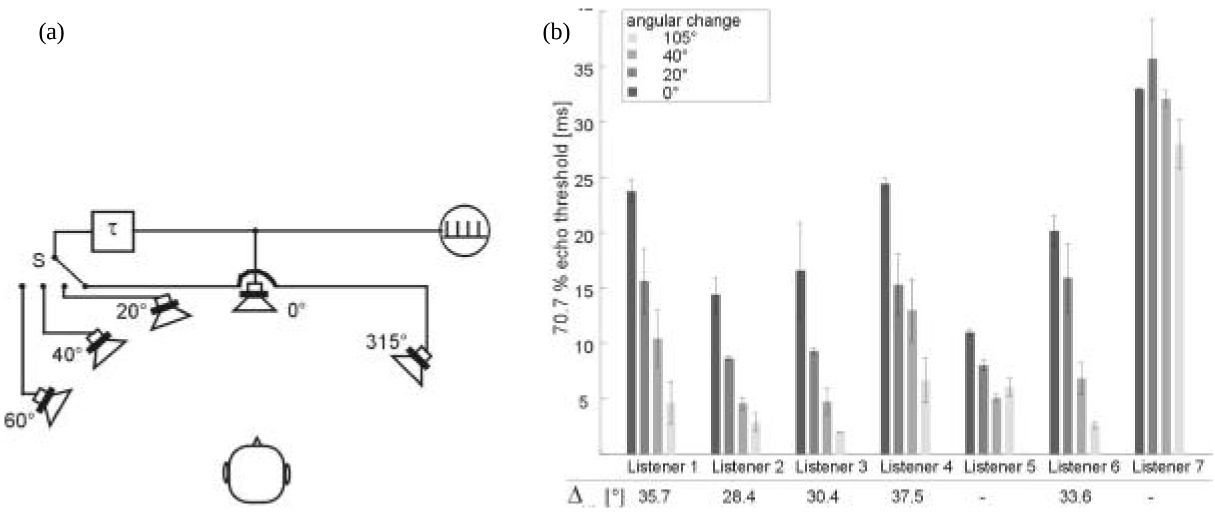

Figure 2: (a) Schematic set-up for the investigation of the spatial extension of the build-up of the echo threshold. (b) Results for the 7 participants in the investigation. Presented are the averaged echo thresholds for 4 different spatial separations between build-up-stimulus reflection and test-stimulus reflection. Error bars denote the standard deviation over 3 sessions. The angular width of the build-up effect has not been calculated for listener #7, because in his case the dependency of angular distance and threshold value is non-monotonic.

The average width of the build-up effect was calculated assuming a symmetric exponential decay of the threshold value. The resulting average width is $\Delta_{1/2}$ = 33.1° (± 3.7°). The angular "resolution" of the build-up effect is about two times broader than the minimum audible angle (Litovsky, 1997) of a simulated reflection, but it is still good enough to consider the effect an adaptive instrument for suppressing reflective sounds.

MODEL OF THE DIRECTION SPECIFIC BUILD-UP OF PRECEDENCE

The idea of the direction-specific build-up effect combined with the latter results on the spatial and temporal decay of the built-up of echo suppression prompted the concept of an extending the inhibition model of the precedence effect as introduced by Lindemann (1986a,b), or in a more general way by Zurek (1987). The model, as shown in Figure 3, is based on a cross-correlation function with a hair-cell model as used by Lindemann (1986a). The hair-cell model consists of a band-pass-filter bank with a half-wave rectification and compression. In contrast to the Lindemann model, the cross-correlation algorithm, here, is not equipped with a contralateral inhibition. The inhibition algorithm rather affects the cross-correlation output. The onsets are calculated as suggested by Wolf (1991). They trigger the temporary inhibition of the output signal in a similar way as in Zurek's model or in the dynamic-inhibition component of Lindemann (1986b). Additionally, the inhibitory signal strength increases when the responsible inhibition module is triggered several times and regularly. This increase of inhibition is responsible for modelling the build-up effect.

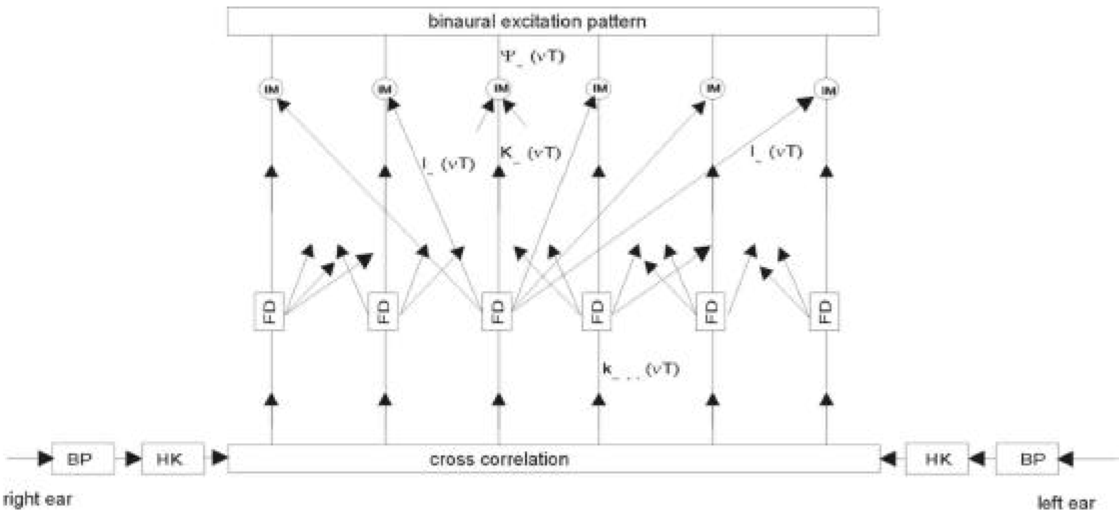

Figure 3: Structure of the signal-processing model to simulate the direction-specific build-up of the echo threshold. The depicted structure is repeated to process the ear signals in each frequency band. BP: band-pass filter. HK: envelope. FD: onset detector. IM: inhibition module

The model was used to successfully simulate the results of some psycho-acoustic investigations as performed by Clifton (1987), Blauert and Col (1992) and Djelani and Blauert (2001). Figure 4 shows the binaural excitation pattern of an input stimulus very similar to that as used by Clifton (1987) to demonstrate the so-called “Clifton effect”. The input signal was a train of broadband-noise-burst pairs simulating a direct sound and a reflection. At the beginning, the lead stimulus was presented from the frontal direction (0°) and the lag stimulus from -45^{o} azimuth. After 5 repetitions the lag-stimulus direction altered to +45°. The lead-lag delay was 11 ms. The time interval between two bursts pairs was 100 ms.

Each peak of the model output as displayed in Figure 4 can be interpreted as an auditory event perceived at the direction indicated by the lateralisation axis at an instant identified by the time axis. Thus the output shows an increase of lag stimulus suppression for –45° at the beginning of the burst train and for +45° after the lag-stimulus direction was altered. This result corresponds to the psycho-acoustical findings as often summarised under the term "Clifton effect."

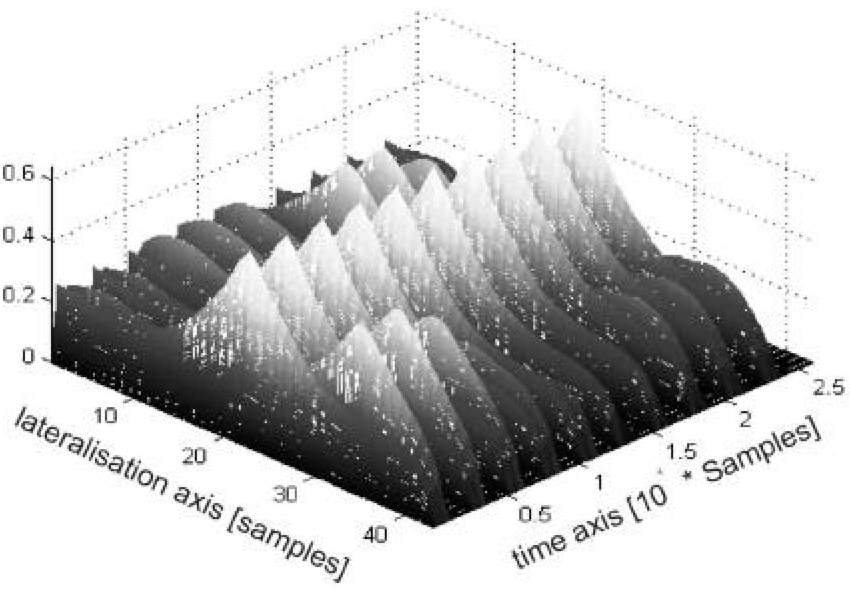

Figure 4: Output of the model of the direction-specific build-up effect. Shown is a binaural excitation pattern of frequency band 780-920 Hz for a noise-burst train with a single simulated reflection. The direct sound is presented from the front (mid of the lateralisation axis) The lag bursts are presented from 315° at the beginning. After 5 stimulus presentations the lag is switched to 45°. Peaks are representing auditory events. It is observable that the suppression of the lag stimulus increases for the presented direction only. The stimulus configuration is very similar to that as used for the investigation of the Clifton effect (Clifton, 1987). The speckles in the diagram are due to a non-compatible graphics program. The authors apologize.

SUMMARY

This article presents a series of psycho-acoustic experiments that investigate spatial and temporal properties of the build-up of the echo threshold in the context of the auditory precedence effect.. The obtained results show that both spatial and temporal extent of the build-up effect are limited, and that no active reset is needed to explain the psycho-acoustical data as reported in earlier literature.

The acquired knowledge has further been applied to the development and implementation of a first model for the build-up of echo suppression. This novel model may easily be extended to other manifestations of auditory precedence. Thus it is capable of explaining most of the known psycho-acoustical results regarding the build-up effect.

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REFERENCES

Blauert J., Col, J.P. (1992), Irregularities in the Precedence Effect, In: Auditory Physiology and Perception, Eds.: Cazals, Y., Damany, L., Horner, K., Pergamon Press, Oxford, 531-538

Blauert, J. (1996), Spatial Hearing: The Psychophysics of Human Sound Localisation (revised and extended edition), MIT Press, Cambridge (MA)

Blauert, J., Lehnert, H., Sahrhage,J., Strauss, H. (2000), An Interactive Virtual-Environment Generator for Psychoacoustic Research I: Architecture and Implementation, Acta Acustica / ACUSTICA, **86**, 94-102

Clifton, R.K. (1987), Breakdown of Echo Suppression in the Precedence Effect, J. Acoust. Soc. Am., 82, 1834-1835

Clifton, R.K., Freyman, R.L. (1989), Effect of Click Rate and Delay on the Breakdown of the Precedence Effect, Percept. Psychophys., 46(2), 139-145

Clifton, R.K., Freyman, R.L., Litovsky R.Y., McCall, D.D (1994), Listeners' Expectations Can Raise or Lower Echo Threshold, J. Acoust. Soc. Am., 95(3), 1525-1533

Djelani, T., Pörschmann, Ch., Sahrhage, J., Blauert, J. (2000), An Interactive Virtual-Environment Generator for Psychoacoustic Research II: Collection of Head-Related Impulse Responses and Evaluation of Auditory Localisation, Acta Acustica / ACUSTICA, **86**,1046-1053

Djelani, T., Blauert, J. (2001), Investigation into the Build-up and Breakdown of the Precedence effect, Acta Acustica / ACUSTICA 87(2), 253-261

Djelani, T., Blauert, J. (2001), Some New Aspects of the Build-up and Breakdown of the Precedence Effect, in Psychological and Physiological Bases of Auditory Function, Eds. Breebart, D.J., Houtsma, A.V.J.M., Kohlrausch, A., Prijs, V.F., Schoonhoven, R., Shaker Verlag, 200-207

Djelani, T. (2001), Psychoakustische Untersuchungen und Modellierungsansätze zur Aufbauphase des auditiven Präzedenzeffektes (Psychoacoustical Investigations and Modelling Approaches to the Build-up of the Auditory Precedence Effect), doctoral thesis, Institut für Kommunikationsakustik, Ruhr-Universität Bochum,

Levitt, H. (1971), Transformed Up-down Methods in Psycho-Acoustics, J. Acoust. Soc. Am., 49(2), 467-477

Lindemann, W. (1986a), Extension of a Binaural Cross-correlation Model by Contralateral Inhibition. I. Simulation of lateralisation for stationary signals, J. Acoust. Soc. Am., 80, 1608-1622

Lindemann, W. (1986b), Extension of a Binaural Cross-correlation Model by Contralateral Inhibition. II. The law of the first wave front, J. Acoust. Soc. Am., 80, 1623-1630

Litovsky, R.Y. (1997), Developmental Changes in the Precedence Effect: Estimates of Minimum Audible Angle, J. Acoust. Soc. Am., **102**, 1739-1745

Litovsky, R.Y., Colburn, H.S., Yost, W.A., Guzman S.J. (1999), The Precedence Effect, J. Acoust. Soc. Am., **106** (4), 1633-1654

Wolf, S. (1991), Lokalisation in geschlossenen Räumen (Localisation in Enclosed Spaces) doctoral dissertation, Inst. für Kommunikationsakustik, Ruhr-Universität Bochum

Zurek, P.M. (1987), The Precedence Effect, in Directional Hearing, Eds: Yost, W.A., Gourevitch, G., Springer-Verlag, New York, 85-115