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NEW RESULTS ON THE PITCH OF INTERAURALLY DELAYED WHITE NOISE

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SUMMARY

A white noise signal presented simultaneously to the left and right ear with an interaural time difference (ITD) between 0 and about 1 ms gives rise to the perception of a lateralized image. For ITD's larger than about 3 ms a faint pitch can be perceived corresponding to the reciprocal of the given ITD. The pitch image is positioned near the middle of the head (dichotic repetition pitch: DRP). Recently, it was discovered that the DRP-image can be lateralized by means of an interaural intensity difference (IID), similar to the classical "intensity image" though with a remarkable asymmetry.
Other dichotic pitch phenomena like Huggins pitch, Fourcin pitch, MPS-pitch, binaural edge pitch (BEP), most probably belong to a different class because they are more salient than DRP. More specifically: they don't show IID-lateralizability. Instead, they show ITD-lateralization common to the pure "time image". A tempting conclusion will be that time and intensity are processed separately at the earlier stages of binaural interaction.

INTRODUCTION

Pitch phenomena evoked by dichotic noise signals have influenced our thinking about binaural interaction significantly. For as far as dichotic pitch values were concerned, Bilsen and Goldstein (1974) showed that the similarity of dichotic and monotic repetition pitch with the low-pitch of normal periodic signals requires the existence of centrally generated spectral patterns with resolved (lower) harmonics for dichotic repetition pitch (DRP). From such spectral patterns pitch is extracted by pattern recognition (Bilsen, 1977).

Experiments on the lateralization of dichotic-pitch images of Huggins pitch (HP), Fourcin pitch (FP) and MPS-pitch (Raatgever and Bilsen, 1977; Raatgever, 1980) revealed that these pitch images behave like pure "time images" as postulated by Hafter and Jeffress (1968) for lateralized signals. This led to the conclusion that, for wide band signals, the time image is the result of spectral-pattern recognition in which frequency information is pooled across frequency for particular interaural delays. Based on the Jeffress (1948) scheme, a Central Spectrum (CS) theory of binaural processing was developed (Bilsen, 1977; Raatgever and Bilsen, 1986) that stresses both interaural cross correlation and central spectrum recognition. Recently, the related concept of "straightness" was introduced by Stern and Trahiotis (1991).

From the historical point of view, it is remarkable that dichotic repetition pitch (DRP) triggered our thinking about central spectra (Bilsen, 1972; Bilsen and Goldstein, 1974), whereas it (still) is the dichotic pitch phenomenon that is not easily explained by the CS-theory in its present form. Lately, we discovered that DRP, contrary to the other dichotic pitch phenomena mentioned above, can be lateralized by means of an interaural intensity difference (IID), though with a remarkable asymmetry (Bilsen, 1994, see fig.1 and 2; B: delayed signal attenuated, A: undelayed signal attenuated). In the present paper these results will be pursued further.

LATERALIZATION EXPERIMENT

DRP-stimuli derived from lowpass-filtered gaussian white noise with a high-cutoff frequency of 2000 Hz, were generated in a digital signal processor (Loughborough DSP 96002; sample frequency 25 kHz; (program) code generated by a Comdisco SPW system). Thus a dichotic stimulus (see simplified block diagram in Fig. 1) with an ITD and an IID was obtained.

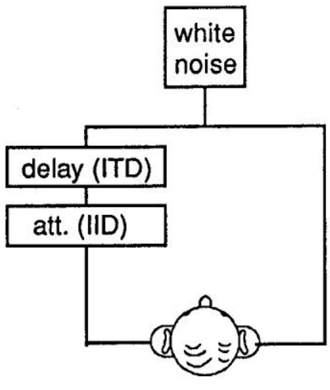


Fig.1. DRP-lateralization experiment

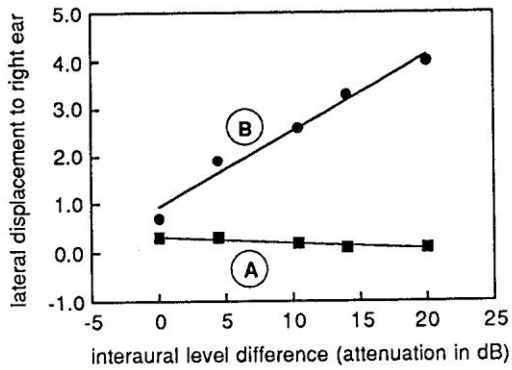


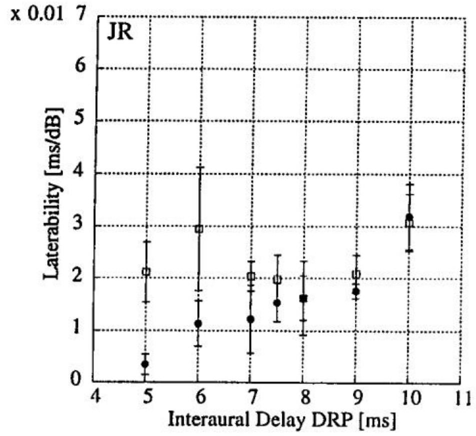
Fig.2. DRP-lateralization (Bilsen,1994)

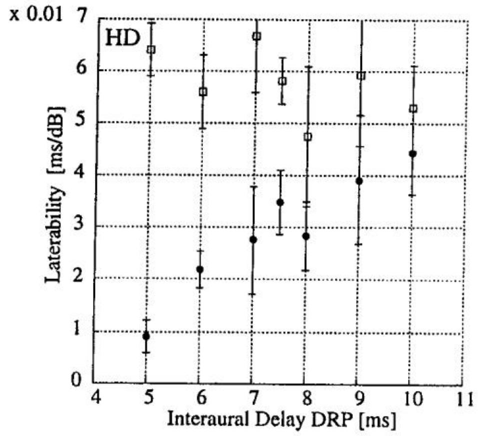
In order to have a comfortable perception of DRP the ITD was programmed such that a 6%-interval in pitch was presented with a stimulus duration of 700 ms and a silent interval of 50 ms. The IID was programmed such that 19 different values were randomly presented ranging from -22.5 dB to +22.5 DB in steps of 2.5 dB, for each of seven values of the ITD in the range of 5.0 to 10.0 ms. The subject was seated in a sound proof booth and listened with headphones (Beyer DT 770) at a sensation level of about 40 dB at the unattenuated side. He had to indicate the in-head position of the DRP-image by adjusting the position of a dichotic white noise (pointer). He could switch between DRP-stimulus and pointer at will. For each of the seven ITD-values, a best linear fit was made (compare fig.2) providing the slope, viz. pointer-ITD-increment (in ms) divided by stimulus-IID-increment (in dB). This slope will be called: *laterability (ms/dB)*. Thus 14 laterability points were obtained, two for each ITD-value.

RESULTS

Three experienced subjects participated in this experiment. Their results are presented in Fig. 3. Open squares indicate delayed signal attenuated (positive attenuation; compare B in fig.1 and 2), while closed circles indicate undelayed signal attenuated (negative attenuation; compare A in fig.1 and 2).

It was investigated in a separate experiment that the pitch of the DRP-stimulus for a particular ITD did not change with varying IID. Thus it makes sense to present the results as a function of interaural delay (ITD).





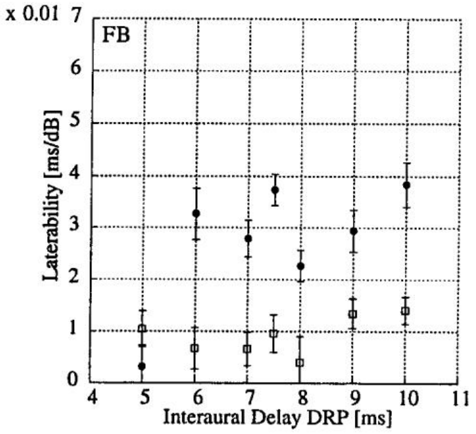


Fig.3. Laterability of a DRP-stimulus as a function of the interaural delay (ITD), for three subjects (JR, HD and FB); closed circles: undelayed signal attenuated, open squares: delayed signal attenuated.

CONCLUSIONS

* A DRP-image can be lateralized significantly by the introduction of an IID,
* The direction of movement is always towards the unattenuated ear,
* The lateralization seems proportional with the IID,
* The laterability is dependent on the ITD-value,
* The asymmetry reported by Bilsen (fig.2) is confirmed

For ITD's smaller than 6 ms, case A (closed circles in fig.3) hardly shows any shift in DRP-position with changing IID, whereas case B shows a substantial shift with changing IID. In the latter case, the relation between perceived position and IID is about comparable to the function one observes for the lateralization of diotic noise with changing IID (Blauert, 1983). A simple explanation for this asymmetry could not be found. (An intuitive argument could be that, in normal situations, the sidedness of dichotic white noise tends to the undelayed side if the ITD decreases beyond 9 ms (border of decorrelation). If the auditory system contains two separate mechanisms for ITD and IID, a conflicting situation might appear when the undelayed side is attenuated. Maybe, for an interaural delay less than 6 ms, the influence of the ITD on the lateral position of the DRP is stronger than the effect of the IID.)

For ITD-values larger than 6 ms, the results are rather subject-dependent. The asymmetry becomes less pronounced. Thus a general conclusion cannot be drawn.

In former papers (Raatgever and Bilsen, 1977, 1986), it has been shown that the dichotic-pitch images of HP, FP, and MPS can be lateralized by an (extra) ITD. The lateralization shows great similarity with the behaviour of the time image. IID's, on the contrary, are ineffective in lateralizing these dichotic pitches; they only affect their salience. An extra ITD, of course, cannot influence the lateralization of a DRP-image; it only determines its pitch. In the present paper it is shown, however, that for DRP IID's are effective in lateralizing the pitch image, be it in an asymmetric way.

Summarizing, Dichotic repetition pitch (DRP) is a faint binaural pitch phenomenon, evoked by the interaural delay of a single (white) noise signal. It appears not to be an artefact due to trivial interaural cross-talk (Bilsen, 1994). It has been shown in the past that its pitch behaviour provides evidence for a central-spectrum processing of pitch, rather than cross-correlation processing for which (according to Fourcin) two uncorrelated noise sources would be required. Nevertheless, DRP-extraction is still not fully understood. The present experiments were intended to get further understanding of the binaural processes involved.

The final tempting conclusion, could be that there are two separate mechanisms: a mechanism to evaluate ITD's and a mechanism to evaluate IID's. DRP could very well be the product of the IID-mechanism exclusively, contrary to HP, FP and MPS that are clear exponents of the ITD-mechanism.

REFERENCES

Bilsen, F.A. and Goldstein, J.L. (1974) Pitch of dichotically delayed noise and its possible spectral basis. J.Acoust. Soc. Am. 55, 292-296.

Bilsen, F.A. (1976) Pronounced binaural pitch phenomenon. J. acoust. Soc. Am. 59, 467-468.

Bilsen, F.A. (1977) Pitch of noise signals: Evidence for a "central spectrum". J. Acoust. Soc. Am. 61, 150-161.

Bilsen, F.A. (1994) What do dichotic pitch phenomena tell us about binaural hearing. In: G.A. Manley and H. Fastl et al. (Eds.), Advances in Hearing Research, World Scientific Publishers, Singapore (In press).

Blauert, J. (1983) Spatial Hearing. MIT Press, Cambridge, U.S.A..

Cramer, E.M. and Huggins, W.H. (1958) Creation of pitch through binaural interaction. J. Acoust. Soc. Am. 30, 413-417.

Fourcin, A.J. (1970) Central pitch and auditory lateralization. In: R. Plomp and G.F. Smoorenburg (Eds.), Frequency Analysis and Periodicity Detection in Hearing, Sijthoff, the Netherlands, pp. 319-328.

Hafter, E.R. and Jeffress, L.A. (1968) Two image lateralization of tones and clicks. J. Acoust. Soc. Am. 44, 563-569.

Jeffress, L.A. (1948) A place theory of sound localization. J. Comp. Physiol. 41, 35-39.

Raatgever, J. and Bilsen, F.A. (1977) Lateralization and dichotic pitch as a result of spectral pattern recognition. In: E.F. Evans and J.P. Wilson (Eds.), Psychophysics and Physiology of Hearing, Academic, London, pp. 443-453.

Raatgever, J. and Bilsen, F.A. (1986) A central spectrum theory of binaural processing. Evidence from dichotic pitch. J. Acoust. Soc. Am. 80, 429-441.

Stern, R.M. and Trahiotis, C. (1991) The role of consistency of interaural timing over frequency in binaural lateralization. In: Y. Cazals, K. Horner and L. Demany (Eds.), Auditory Physiology and Perception, Pergamon, Oxford, pp.547-554.