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Compatibility of models with data on dichotic pitch

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Dichotic pitch phenomena are generally considered natural byproducts of the mechanisms of binaural hearing. Two main aspects of dichotic pitch are the specific value of the pitch given the interaural phase relationship and the lateralized position of its pitch image. Models like cross correlation (CC), (modified) Equalization-Cancellation (EC and mEC) and the Central Spectrum theory (CAP-CS) have to predict these aspects correctly to be qualified as generally applicable.

CENTRAL SPECTRUM MODEL

Dichotic pitches are perceived when the same white noise is presented to both ears but with a particular interaural phase relationship. The following dichotic pitches have been reported: the Huggins Pitch (HP) for a 2π-phase transition in a limited frequency range [See e.g. 1, 2; for variations 6], the (a)symmetric Fourcin Pitch (aFP and sFP) for two uncorrelated noises with interaural delays T_1 and T_2 [2, 3], the Dichotic Repetition Pitch (DRP) for only one single interaural delay T [1, 2, 3, 4], the Multiple Phase Shift Pitch (MPSP) for a series of 2π-phase transitions equally spaced in frequency [1], the Binaural Edge Pitch (BEP) for a π-phase transition in a limited frequency range and the Binaural Coherence Edge Pitch (BICEP) [2, 5]. Acronyms and interaural phase configurations are summarized in Fig. 1 (columns 1 and 2).

HP, BEP and BICEP have a pure tone character, while DRP, FP and MPSP behave like periodicity pitch. In addition, a dichotic pitch has a more or less well-defined binaural image separated, in general, from the (diffuse) image of the generating dichotic noise itself. As both pitch value and pitch image position (lateralization) have been shown to be correctly predicted by the Central Spectrum (CS) theory [1, 2, 3, 4, 6], existing data are "summarized" by CS equations in columns 3 and 4 of Fig. 1.

In accordance with CS theory, pitches and their lateralizations can already be prognosed from the interaural phase patterns (column 2) by inspecting the dash-dotted lines. Being straight and going through the origin (0 phase, 0 frequency), these lines symbolise an internal delay τ_i (similar to an interaural delay T). For example, for HP^{+} and MPSP^{+} the intersection with the phase pattern indicates the value and position of peaks in the central activity pattern (CAP) at $\tau_i = 0$. For aFP^{+}_{-} the dash-dotted line runs parallel to the dashed line T_2 and shifted by π, thus indicating a straight valley of zero power from noise 2 in the CAP at $\tau_i = T_2$, which "highlights" the central spectrum part due to noise 1 at this internal delay. Different highlighting is obtained in the case of sFP^{++} by the additive interference of T_1 and T_2 at τ_i. Such highlighting is absent with the DRP stimulus, which therefore offers an infinite range of central spectra each with its own pitch and lateralization [4][1].

CROSS CORRELATION

Now it is examined to what extent also other current theories comply with these data. A summary is given in columns 6 to 8 of Fig. 1. Correct prediction is indicated with + and incorrect or non-prediction with – for pitch value and lateralization respectively (+,–).

The inadequacy of the concept of cross correlation (CC) is manifest already from the simple fact that identical pitch values are predicted for the aFP and sFP cases, which is in conflict with the data [3]. Further, it is unclear how ambiguity of pitch should be predicted from one cross-correlation peak pair, the more so as the peaks have equal polarity as in the case of aFP^{+}_{+}. Also, it is not clear how a negative peak at T_2 should predict a pitch image position corresponding to an internal delay T_2.

Alternatively, one might consider the possible virtues of a "Summary Cross Correlogram (SCCG)", to be defined as the result of the "addition" of peripherally-filtered cross correlation functions, very much in analogy with the Summary Auto Correlogram (SACG) as promoted in studies on monaural periodicity pitch [7]. It has been shown that the SACG resembles the wide-band auto correlation function in its main features (e.g. position of first peak). Likewise, the SCCG resembling the wide-band cross correlation function should be expected to be unable to explain dichotic pitch behaviour for reasons similar to those mentioned above [3].

EQUALIZATION-CANCELLATION

Durlach's original Equalization-Cancellation (EC) model is basically able to predict HP, MPSP, BEP and BICEP values [2, 5]. Also aFP^{+}_{-} is correctly predicted in addition mode. However, the model has to switch to subtraction mode for aFP^{-}_{+} [2, 3]. Further, sFP data are not predicted by the EC model, simply because equali-

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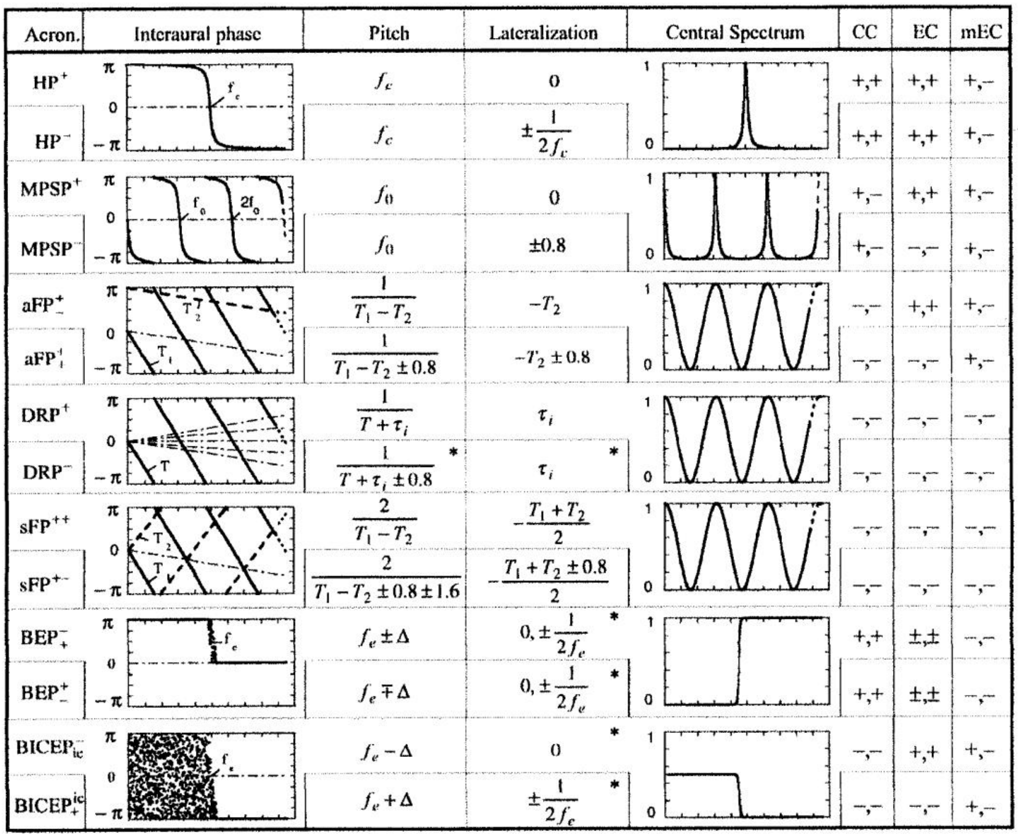
[1] Recent observations by the first author show that the sFP stimulus can be used successfully to draw one's attention to one spectrum from the continuum of central spectra of a DRP stimulus.



Acron.	Interaural phase	Pitch	Lateralization	Central Spectrum	CC	EC	mEC
HP$^+$		f_c	0		+,+	+,+	+,–
HP$^-$		f_c	$\pm\frac{1}{2f_c}$		+,+	+,+	+,–
MPSP$^+$		f_0	0		+,–	+,+	+,–
MPSP$^-$		f_0	± 0.8		+,–	–,–	+,–
aFP$^+_-$		$\frac{1}{T_1-T_2}$	$-T_2$		–,–	+,+	+,–
aFP$^{\vert}_{\vert}$		$\frac{1}{T_1-T_2\pm0.8}$	$-T_2\pm0.8$		–,–	–,–	+,–
DRP$^+$		$\frac{1}{T+\tau_i}$	τ_i		–,–	–,–	–,–
DRP$^-$		$\frac{1}{T+\tau_i\pm0.8}$ *	τ_i *		–,–	–,–	–,–
sFP^{++}		$\frac{2}{T_1-T_2}$	$-\frac{T_1+T_2}{2}$		–,–	–,–	–,–
sFP^{+-}		$\frac{2}{T_1-T_2\pm0.8\pm1.6}$	$-\frac{T_1+T_2\pm0.8}{2}$		–,–	–,–	–,–
BEP$^-_+$		$f_e\pm\Delta$	$0,\pm\frac{1}{2f_e}$ *		+,+	±,±	–,–
BEP$^+_-$		$f_e\mp\Delta$	$0,\pm\frac{1}{2f_e}$ *		+,+	±,±	–,–
BICEP$^-_{ic}$		$f_e-\Delta$	0 *		–,–	+,+	+,–
BICEP$^{ic}_+$		$f_e+\Delta$	$\pm\frac{1}{2f_c}$ *		–,–	–,–	+,–

FIGURE 1. Dichotic pitch data "summarized" by Central Spectrum equations [1]; frequency (f) in kHz and time (T) in ms; * no data available. CC, EC (addition), and mEC model performance [2,3,4,5] is expressed by +,– for pitch, lateralization respectively

zation by interaural delay always recovers the difference between the two delays, not the averaged value.

The interaural delay needed in the cancellation process could possibly be extracted as an indicator for pitch-image position. But given this possibility, we still are faced with the problem that multiple images are not predicted. Moreover, the correct prediction of both pitch value and lateralization always calls for addition instead of subtraction in the cancellation process. Therefore, in column 7 of Fig.1, we choose to consider the EC model in its addition mode only (Note that this implies a deviation from the general preference for subtraction in the modelling of BMLDs). Further, it is assumed that the EC mechanism (in the absence of a signal) strives for maximum reduction of the noise.

Culling and colleagues [2] proposed a modified Equalization-Cancellation (mEC) model performing an equalization by adjustment of internal delay (and/or level) in each frequency channel (auditory filter) independently. An obvious reason for its failure to predict sFP along with aFP is its unique way of operation, i.e. to generate only one optimal "recovered spectrum". For DRP, the mEC model does not predict any recovered spectrum at all. Further, lateralization is not dealt with by the mEC model, because the possibility to extract a single equalization delay as an indicator for laterality, is essentially absent.

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