Inferences from Dichotic Pitch for Binaural Modeling

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Definition of dichotic pitch (DP):

- pitch & timbre
- lateralization
Psychophysical facts on dichotic pitch (DP):

1. Similarity of pitch and timbre (parsimony) for DP signals and natural (ecological) signals

2. Coupling of DP-value and -image position

3. DP-image position is IID insensitive
Cross Correlation (CC) hypothesis:

In the spirit (not the detail) of Jeffress’ model and Licklider’s triplex theory, Fourcin (1962, 1972) tried to explain his findings on Fourcin Pitch with the wide-band cross-correlation function.

Present extensions:

• Similarly, one might consider the possible virtues of a “Summary Cross Correlo-Gram (SCCG)”, in analogy with the SACG (Meddis, Yost, Patterson).

• Alternatively, one might try narrow-band cross correlation
Central Activity Pattern (CAP):

$N_0$
Central Spectrum (CS):
Selection from the CAP of a spectral pattern giving rise to the central sensation of pitch

Selection criteria:
• resemblance with monaural spectra (parsimony)
• common internal delay ("straightness")
• infinite peak-to-valley ratio in the pattern selected

Note. CAP-CS theory predicts pitch value on the basis of either a) spectral pattern matching on a Central Spectrum selected, or b) joint auto correlation applied on the time structure of resolved harmonics in a Central Spectrum (compare SACG)
Repetition Pitch (Low Pitch, Musical Pitch, Periodicity Pitch, Residue Pitch, Virtual Pitch) :

harmonic power spectrum

inhomarmonic power spectrum

frequency
Equalization Cancellation (EC) model:

Equalization is performed on the left and right ear signals by adjustment of level and/or interaural delay. Then cancellation is performed by addition or subtraction (Durlach, 1972).

Present restrictions and extras:

- The addition mode is considered only, because the correct prediction of both pitch and lateralization always calls for addition instead of subtraction.
- It is assumed that the EC mechanism, in the absence of a signal, strives for maximum reduction of the noise.
- The equalization parameter might be considered a predictor of position (lateralization)
Modified Equalization Cancellation (mEC):

Equalization is performed by adjustment of level and/or interaural delay (up to \( \pm 5 \) ms) \textit{in each frequency channel (auditory filter) independently}. The residual energy in each filter after cancellation is plotted as a function of center frequency to generate a "recovered spectrum", which thus reflects the degree of interaural de-correlation present in each frequency channel (Culling et al., 1998).

Note 1. Essentially no prediction of position (lateralization)
Note 2. One unique solution for each signal configuration
$\text{aFP}^+$

Interaural phase vs. frequency

Frequency vs. internal delay

CS

CAP
pitch: \[ \frac{1}{T_1 - T_2 \pm 0.8} \]

example:

\[ \frac{1000}{(5.5-0.5\pm0.8)} = 173, 238 \text{ Hz} \]

CC:–, EC:–, mEC:+, CAP:+

laterization: \[ -T_2 \pm 0.8 \]

\[ -1.3, +0.3 \text{ ms} \]
CC:+, EC:±, mEC: – (vanishing peak), CAP:+
CC: –, EC: –, mEC: – (no recovered spectrum at all), CAP: +
## Overall evaluation: (pitch, lateralization)

<table>
<thead>
<tr>
<th></th>
<th>EC</th>
<th>CC</th>
<th>CAP</th>
<th>mEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>HP</td>
<td>(+,+)</td>
<td>(+,+)</td>
<td>(+,+)</td>
<td>(+,–)</td>
</tr>
<tr>
<td>MPSP</td>
<td>(–,–)</td>
<td>(+,–)</td>
<td>(+,+)</td>
<td>(+,–)</td>
</tr>
<tr>
<td>aFP</td>
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<td>(+,+)</td>
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</tr>
<tr>
<td>sFP</td>
<td>(–,–)</td>
<td>(–,–)</td>
<td>(+,+)</td>
<td>(–,–)</td>
</tr>
<tr>
<td>DRP</td>
<td>(–,–)</td>
<td>(–,–)</td>
<td>(+,+)</td>
<td>(–,–)</td>
</tr>
<tr>
<td>BEP</td>
<td>(±,±)*</td>
<td>(+,+)</td>
<td>(+,+)</td>
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<tr>
<td>BICEP</td>
<td>(–,–)*</td>
<td>(–,–)</td>
<td>(+,+)</td>
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</tbody>
</table>

* Consistency in pitch and lateralization in addition mode only

**:predicts aFP only**: (vanishing) HP

**:no CS at all**:
Conclusions:

• The psychophysical DP data are predicted **consistently** by the CAP-CS theory only

• Pitch image position is predicted by the **internal delay** of the Central Spectrum selected, **not** by the SCCG (as in Licklider’s triplex theory)

• Pitch value extraction seems to precede lateralization (compare Darwin c.s.)
INFERENCES FOR BINAURAL MODELING IN GENERAL:

- CC (or SCCG) is not a universal predictor of position

- ITDs and IID are processed separately in the “periphery”

Additional note:
Combination of the EI-cell-based cancellation theory of pitch (compare: SACG) (de Cheveigné) and EI- (instead of EE-) cell based binaural interaction for lateralization and detection (Breebaart) seems a possible though not plausible alternative to fulfil monaural and binaural pitch similarity (parsimony)
Remaining questions:

• Relations between CS straightness, DP salience and DP-image compactness have to be measured yet

• A low-frequency paradox in binaural pitch (Hartmann)?

• Why exists prevalence for a centrally localized DRP (A separate mechanism)?
Some logic on the importance of DP phenomena:

- Parsimony implies **DP signals** to be processed by the same central pitch processor as ecological signals.

- No separate pitch processor for **non-ecological** signals like DP signals (teleological argument).

- Thus: DP phenomena are **natural byproducts** of the mechanism of binaural hearing.
200/220-Hz MPSP interval; listening (diotically) to hypothetical central spectra at different interaural delays: 0.8, 0.6, 0.4, 0.2, 0 ms
(Bilsen and Raatgever, JASA 2000)

\[
\Delta T = |T_1| - |T_2|
\]
\[ CAP(f, \tau_i) = [H(f) + \exp j2\pi f \tau_i]^2 \]

\[ = 1 + \cos \{ \phi(f) + 2\pi f \tau_i \} \]

- \( \tau_i \): internal delay
- \( H(f) \): complex interaural transfer function
- \( |H(f)|^2 = 1 \): white noise input
- \( \phi(f) \): interaural phase function

Note. After introduction of peripheral auditory properties similar pitch values are predicted (Culling et al., 1998)
Binaural Interaction:

The Jeffress Coincidence Model (1948)

From data of cat
(Joris, Yin & Smith, 1990)
<table>
<thead>
<tr>
<th>Acron.</th>
<th>Interaural phase</th>
<th>Pitch</th>
<th>Lateralization</th>
<th>Central Spectrum</th>
<th>CC</th>
<th>EC</th>
<th>mEC</th>
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<tr>
<td>HP⁺</td>
<td>![Graph HP⁺]</td>
<td>(f_c)</td>
<td>0</td>
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<td>+₂⁺</td>
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<td>aFP⁺⁺</td>
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<td>(\frac{1}{T_1-T_2})</td>
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