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PITCH OF DICHOTICALLY DELAYED NOISE

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1. Introduction.

Continuous noise (or any other appropriate sound) presented to one ear and the same noise delayed to the other ear give rise to the following sensations. For a delay shorter than (roughly spoken) 2 ms, the noises fuse and a single noise image is perceived whose position depends on the delay. As the delay τ increases beyond this bound, the noise image remains at one side of the head, but becomes more diffuse.

Recently, we have observed that, in addition to this increase in diffuseness, a faint but distinct pitch image corresponding to $1/\tau$ appears in the middle of the head.

In view of the close analogy that exists between this pitch phenomenon and monotic repetition pitch (MRP), produced by noise added to its delayed version in the same ear (Bilsen, 1970), we shall for convenience refer to the former as dichotic repetition pitch (DRP).

Although DRP is fainter than MRP, both have equal subjective pitch and timbre qualities. There is, however, a significant difference in existence region; MRP has been reported for $1 < \tau < 10$ ms, whereas DRP exists for roughly $\tau > 3$ ms.

2. Experiments

Pitch matching experiments by five subjects, using wide-band white noise as well as narrow-band white noise as basic stimuli, were performed to explore the characteristics of DRP in more detail. A subject, who heard the signal by headphones at a sensation level of about 25 dB (in a silent anechoic room), was free to follow two possible matching procedures. Either he was allowed to make an MRP(τ_m) equal to a DRP(τ_d) by adjusting the (monotic) delay τ_m, for a fixed

(dichotic) delay τ_d (see Fig.1). Or, in addition, he might use an MRP(τ_o) and a DRP(τ_o) as a fixed reference. In the latter case, he was matching a musical MRP interval against a musical DRP interval. Control experiments were performed with a pure tone (period τ_m and τ_o) as a matching stimulus.

The results of individual pitch matchings are represented in Figs 2 and 3 for wide-band noise (white noise with high-cutoff 2000 Hz). When the (un)delayed noise is phase inverted, the pitch, DRP$_-$, deviates significantly from the pitch, DRP$_+$, for equal polarity of the undelayed and delayed noise. In general, two pitches can be perceived, one a little higher, the other a little lower than $1/\tau_d$ (ambiguity of pitch).

Measured points for narrow-band white noise (third octave with center frequency f_o) are represented in Fig.4 in normalized form. Here $DRP_-(\tau_d,f_o)/DRP_+(\tau_d,f_o)$ is plotted as a function of n ($=f_o\tau_d$), for several values of f_o. Note that $DRP_+(\tau_d,f_o)$ is always equal to $1/\tau_d$.

With good approximation the results can be represented by the following empirical formulas (solid lines):

$$DRP_-(\tau_d) = 1/(\tau_d \pm 0.0008) \; ; \; DRP_-(\tau_d,f_o) = 1/(\tau_d \pm 1/(2f_o)) \; .$$

The wide-band DRP$_-$values may be related to the narrow-band DRP$_-$values by assuming the existence of a dominant spectral region (c.f. Bilsen, 1970, for MRP). This region is found by equating the two expressions; thus,

$$f_o(\text{dominant}) = 1/(2\text{x}0.0008) = 625 \text{ Hz}.$$

It is noteworthy that this is approximately the frequency region for optimal binaural beats (Licklider et al., 1950).

Additional experiments with multiple-source dichotic stimuli (see Figs 1, 5 and 6) show that the DRP phenomena are subjectively similar and probably involve the same binaural mechanisms as the FP phenomena studied by Fourcin (1970). The principal new finding is that pitch can be evolved by a single dichotically-presented source.

3. Conclusions and speculations

Because DRP signals do not provide the cochleae with spectral information, given the essential independence of the two cochleae, timing information must be used in the creation of a central pattern of neural activity from which pitch is extracted.

Houtsma and Goldstein (1972) have supplied evidence that musical pitch of complex tones is mediated by a central processor operating on neural signals derived from those effective stimulus partials that are

tonotopivally resolved. Thus, parsimony would require the neural activity pattern pitch is extracted from to resemble a "central spectrum".

Within the framework of binaural mechanisms that effectively add the cochlear outputs separately for resolved frequency bands, like those postulated by Durlach (1970) and Colburn (1969) in their models for binaural signal detection, the central spectrum should be a cosine-like function of frequency for DRP_+, or a sine-like function for DRP_-. Compare BMLD patterns for dichotically delayed noise.

In particular, this can explain the similarity between the narrowband MRP behavior (Bilsen, 1970) and the corresponding DRP behavior as expressed by the empirical formulas.

Consideration of how pitch is extracted from the central spectrum leads to questions of place- or time-pattern processing, partly, like those that arise in monaural pitch (de Boer, 1956; Schouten et al., 1962; Ritsma, 1970; Whitfield, 1970; Bilsen, 1970).

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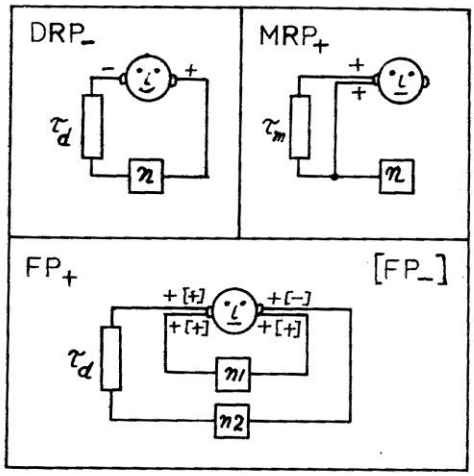

Fig.1 Stimulus configurations

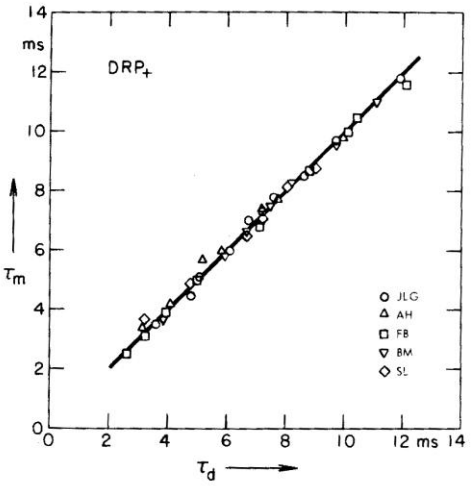

Fig.2 Wide-band DRP_+ matches

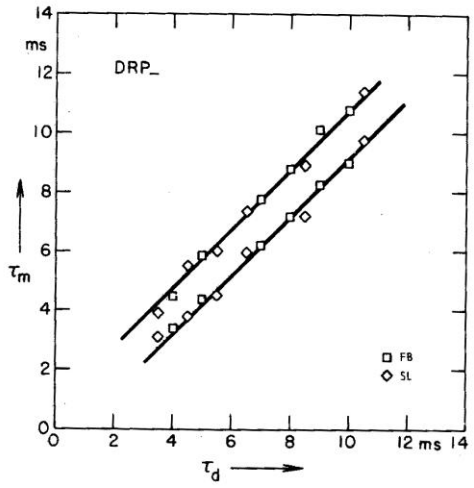

Fig.3 Wide-band DRP_- matches

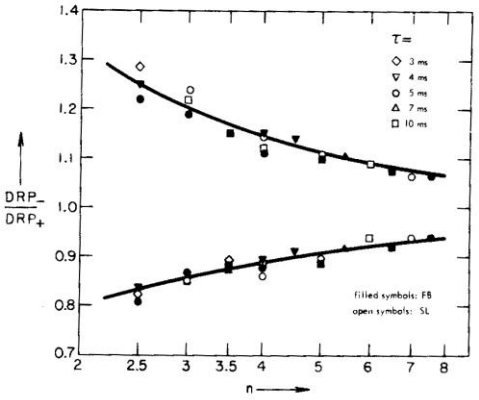

Fig.4 Narrow-band DRP_- matches

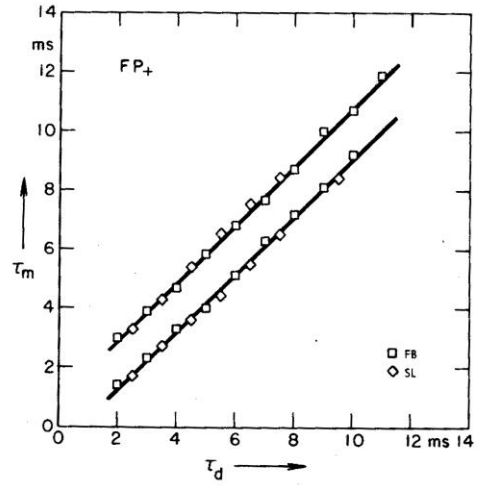

Fig.5 Wide-band FP_+ matches

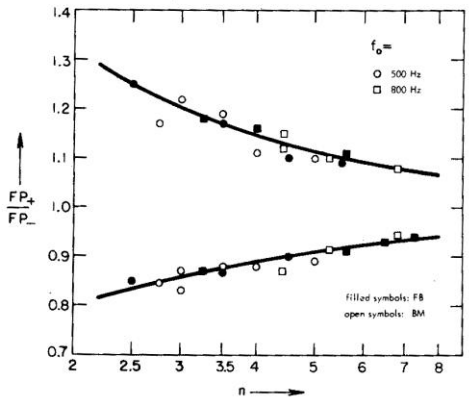

Fig.6 Narrow-band FP_+ matches