# AN ASPECT OF THE PERCEPTION OF PITCH

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Although the pitch of voiced sounds is perhaps one of the most readily perceived of their subjective attributes, the satisfactory laboratory determination of a physical correlate presents great difficulty. The basic problems of experimental speech analysis are essentially also those of perception and if more were known of the processes in the hearing mechanism which underlie the perception of pitch the instrumentation requirements could be more accurately defined. The present work relates only to a small part of this large subject and is especially concerned with a particular aspect of a possible neural mechanism for the mediation of pitch.

The peripheral hearing mechanism is normally supposed to have one, or both, of two different modes of operation. For one, the cochlea acts as a hydromechanical frequency analyzer and produces a sort of fourier analysis of the acoustic time pattern delivered to its ear. For the other, the cochlea behaves as a complicated pressure waveform to neural flux transducer and merely precedes a neural place analysis.

Many auditory phenomena may be satisfactorily interpreted on the basis of the first, frequency analyzer, point of view but some appear to refute it entirely; binaural beats, some sound localization phenomena, and Huggins' effect (Huggins and Cramer, 1958) all seem to require the neural processing of temporal features of the original acoustic stimulus.

With this sort of consideration in mind Licklider has set up and elaborated a theory (Licklider, 1959) which offers the basis for an explanation of the recalcitrant phenomena – and in particular those involving pitch – in terms of the operations of delay, comparison and summation (together termed correlation) which may be associated with the neural pathways from the cochleas to the higher centres of the brain. If a periodic signal is compared with itself delayed then maxima of resemblance are obtained for delays which are integral multiples of the signal period. The situation is illustrated for a particularly simple waveform in Figure 1. The pattern of these points of maximum resemblance, in a suitable delay system, could be employed as the basis of an estimation of periodicity. As the basis for an explanation of the mechanism of pitch perception the method has the advantages of being fundamental in character and possibly ambiguous in result – the multiplicity of comparison peaks can lead to octave confusion.

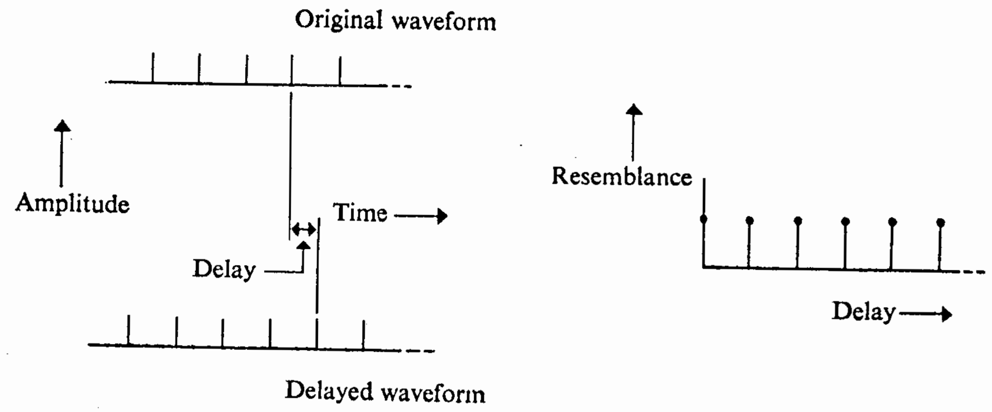


Fig. 1.

It is difficult to design experiments to investigate whether or not the correlation mechanism of Licklider's theory is operating. If stimuli are monaurally presented it would be possible neither to identify the operation of a delay patterning mechanism, from experiments on an intact observer, nor to demonstrate that a cochlear frequency analysis is inoperative. This is because any stimulus which could be associated with a regular delay pattern is necessarily periodic and a fourier type analysis, cochlear or neural, could equally well provide the basis for any pitch sensations which it might induce. There is however the binaural stimulus configuration due to Huggins which at least eliminates the possibility of cochlear frequency analysis as the basis for the pitch sensation with which it is associated. The experimental arrangement is illustrated in Figure 2. An observer listens to white noise with one ear and to the same noise changed only in phase spectrum with the other. Peripheral frequency analysis cannot account for the resulting pitch sensation since the spectral envelopes of the stimulus intensities at both ears are free from peaks. It is only possible to conclude that the neural processing of temporal features of the noise stimuli is involved in the pitch perception mechanism. The type of neural processing is not deducible in principle since if the stimulus at the right ear is added to that at the left a signal with pronounced peaks in its spectrum is obtained and whether correlation or frequency analysis type neural processing are involved a pitch sensation could result.

If the correlation processes of the pitch analysis part of Licklider's theory are applied to the part which deals with localization, and the Jeffress (1948) coincidence system is replaced by cross correlation (following Sayers (1957), but for simplicity assuming complete conservation of waveform before correlation), the Huggins' stimuli give a localization pattern of the form of Figure 3. The peak for zero delay is produced by those components in the two signals which are in phase. The other peaks occur as a result of the frequency dependent delay of the phase shifting network; the noise components involved here are those which would give rise to fourier



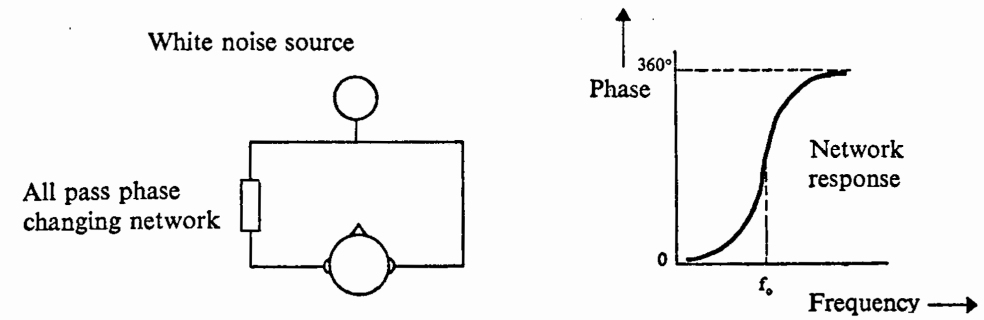


Fig. 2.

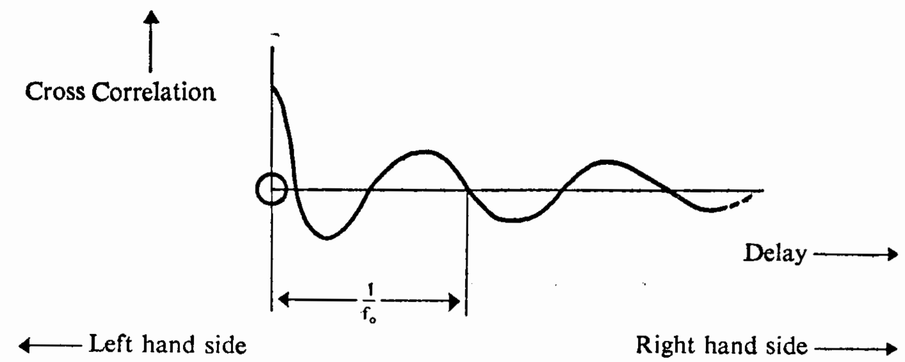


Fig. 3.

periodicities if they were added. This pattern is similar to those obtained from the autocorrelation of quasi-periodic stimuli and it is not impossible that it makes a contribution to the sensation of pitch. Indeed from the point of view of organization efficiency it would almost be surprising if this were not so.

Experimentally it would appear that the possible pitch importance of a localization patterning can be investigated since patterns approximating to the form of Figure 3 can be synthesized from the binaural presentation of stimuli which are, individually, pitch-free. A first approximation of this type is shown in Figure 4(iii). By using two independent noise generators both a central peak and a lateral peak of localization can be produced; the central peak is obtained by applying the same stimulus to both ears and the lateral localization merely by delaying the stimulus to one ear relative to the other (the delay being independent of frequency). By employing independent white noise sources flat frequency spectra are obtained at the two ears, as for the Huggins configuration. And by the use of a synthesis approach a subject can be presented with a sequence of patterns, as in Figure 4(i), (ii) and (iii), by employing one or both noise generators. The synthesis of delay patterns also makes it possible to extend the patterning of Figure 3 to both sides of the mid-sagittal plane and examples of symmetrical localization patterns are shown in Figure 4(iv) and (v).

An experiment was performed using all the configurations of Figure 4, except (i),

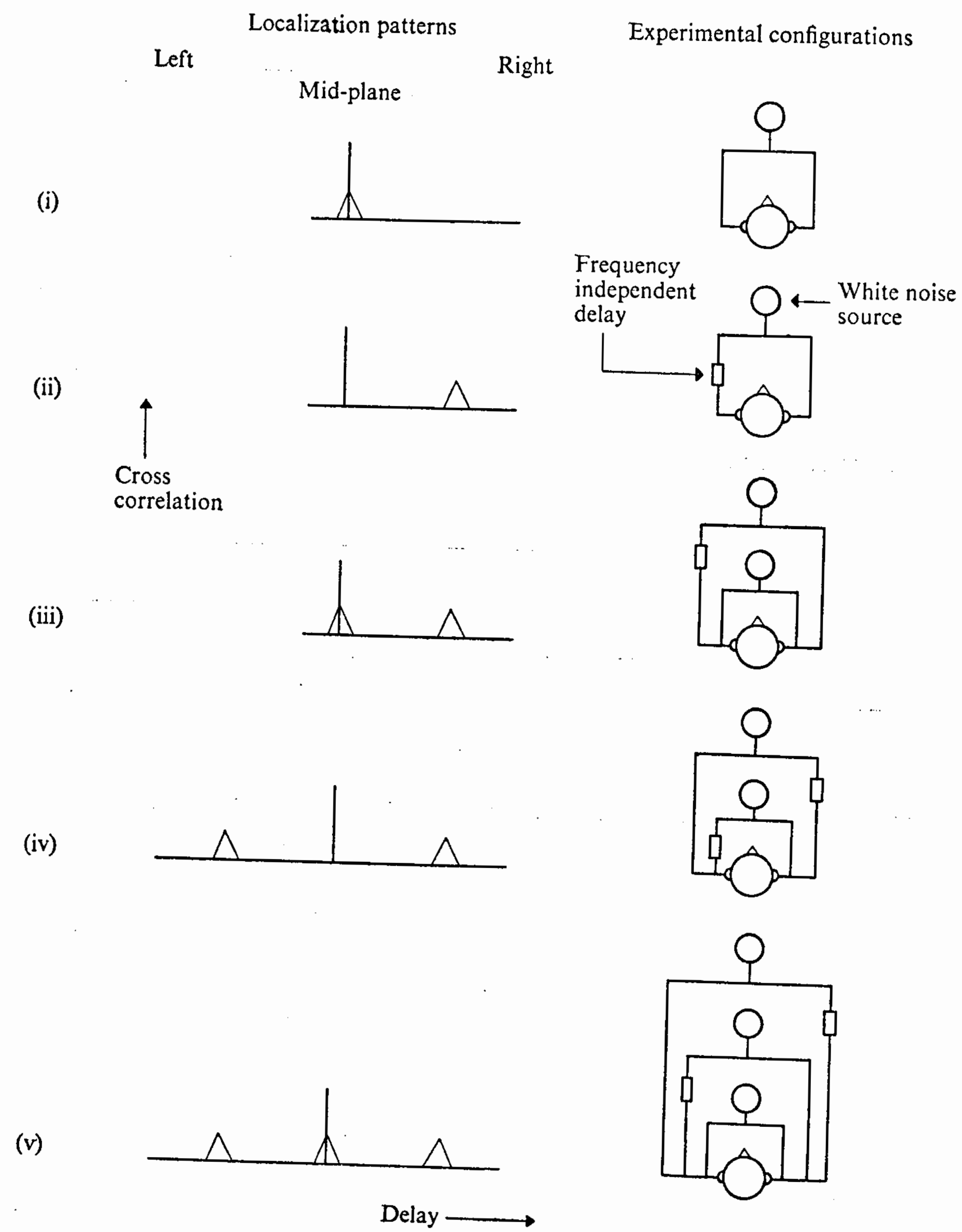


Fig. 4.

with delay lines capable of giving a continuously variable delay between 1 ms. and 4 ms. – for Figure 4 (iv) and (v) the delay controls were coupled together. 14 subjects were employed and all the binaural stimuli were successively presented, via headphones, in ascending and descending order. Each subject was able to alter the delay



as he pleased and was asked simply to describe the quality of the sound he heard. In the ascending order of presentation only one subject heard anything corresponding to a tonality in the noise for the stimulus configuration of Figure 4(iii), but ten of the fourteen subjects described, in almost as many ways, the presence of a pitched component in the noise for the pattern associated with the experimental configuration of Figure 4(v). For the descending presentation all of these ten subjects heard this pitched quality for the arrangements of Figure 4(iv) and (iii). The pitch went up in all cases with a decrease in the associated delay time. Not one subject however heard the pitch quality in the noise associated with Figure 4(ii). This result has been obtained repeatedly in similar tests.

The configuration of Figure 4(iii) can produce a sensation of pitch, that of Figure 4(ii) cannot. The simplest interpretation which it appears possible to make of this finding is that the particular sensation of pitch with which it is associated is dependent on a neural delay and comparison patterning, there seems to be no better way of accounting for the importance of the noise source which is directly common to both ears. In consequence this result gives direct experimental support for the spirit, if not the letter, of Licklider's correlation theory. The details of Licklider's theory are not supported because of the localization context of the present experiments: in addition, pitch matching experiments, the details of which it is hoped to publish later, show an ordering which is difficult to interpret in terms of simple correlation.

It is pleasant to record the help and advice received from Dr. F. S. Cooper and his colleagues when this work was done at the Haskins Laboratories, New York, U.S.A. during a period of leave from the Signals Research and Development Establishment, Ministry of Aviation, Christchurch, England.

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