Pitch of the missing fundamental, timbre.

**Pitch and the missing fundamental:**

There are three primary auditory perceptions, pitch, loudness and timbre. Pitch plays a role in music and harmony perception as well as in prosody in speech and tone in tonal languages. Pitch is the perceptual correlate of periodicity or repetition rate. A harmonic complex tone repeats at a rate corresponding to the fundamental frequency, and the decomposition of the tone results in high harmonics which frequencies that are integer multiples of the fundamental frequency. Irrespective of differences in timbre and loudness, if two tones have the same fundamental frequency, they are perceived as having the same pitch. However, some listeners face difficulty in judging pitch when there are large differences in timbre. It has been established that even if the energy of the fundamental frequency is removed or masked, the perception of pitch according to the fundamental frequency remains. This is called the pitch of the missing fundamental. Harmonics that are exclusively represented within single filters are referred to as “resolved,” whereas harmonics that interact with others within auditory filters are referred to as “unresolved.” Resolved harmonics produce peaks in the excitation pattern and filtered waveforms that are similar to single pure tones at that frequency. Unresolved harmonics produce no distinct peaks and complex waveforms that reflect the interaction between multiple harmonics (Oxenham, 2012).

Pure tones above 6kHz were not perceived to have reliable melodic information, however when combined with other harmonics and having a significantly lower fundamental frequency, melodic information could be extracted. This could be because of the integration of multiple tones within the complex tone to form an accurate representation of pitch, which cannot occur when a tone is pure. This is not the case from lower frequency pure tones and their respective complex tones. So this effect could only be a component of higher frequency tones. One explanation for the inability to extract melodic information from higher frequency tones is due to less frequent exposure to them during development (Oxenham et al., 2011).

The phenomenon of the missing fundamental is described at the perceived pitch corresponding to a fundamental frequency for which no vibrations are present in the air. The harmonic complex tone exhibits large amplitude peaks spaced at intervals equal to the inverse of the fundamental frequency. When three equispaced tones are shifted linearly, the perceived pitch also shifts linearly, therefore, the possibility that the brain computed the fundamental frequency from the difference of the constituent frequencies of a complex tone does not stand (Chialvo, 2003).

The over-dependence on the Fourier theorem and the insistence of early physicists to explain the cochlea using it, lead to problems regarding the explanation of the missing fundamental. As their efforts to use the Fourier theorem to explain pitch perception fell through in the face of the missing fundamental problem, and their inability to let the theory go, limited them within an explanation of hearing that was not true. According to pattern matching models, reconstruction of incomplete information is what gives rise to the missing fundamental phenomenon. Autocorrelation and pattern matching are the two major explanations of pitch. Pattern matching does not work for unresolved harmonics. The autocorrelation model works for both resolved and unresolved harmonics, but two separate mechanisms would be at play. However, the breaking down of pitch perception for higher unresolved harmonics would favour the pattern matching theory (Cheveigne, 2004).

According to the spectral explanation of pitch, pitch is the frequency of the lowest fundamental. However, this theory fails in the face of the pitch of the missing fundamental. Non-linearity in cochlear transduction is one possible explanation for the pitch of missing fundamental. However, experiments have shown that the missing fundamental problem is non associated with the non-linearities involved in transduction or the non-linear structure of the periphery of the ear. The temporal explanation of pitch perception employs autocorrelation. Autocorrelation is the Fourier transform of the power spectrum of a signal. . That is, an original time pattern, x(t), is time shifted (by É) and multiplied times the original pattern, and the products are integrated (summed). The integrated product is determined as a function of the time shift (É, lag) between the original and time-shifted pattern, and this forms the autocorrelation function. The normalized autocorrelation function is the integrated products divided by the autocorrelation value obtained when the lag is 0. The autocorrelation can explain the pitch of the missing fundamental phenomenon. Despite autocorrelation being able to account for a range of complex pitch phenomena, it still comes short at being a complete model of pitch perception (Yost, 2009).

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