Perceptual Analysis of Vibrating Bars Synthesized with a Physical Model

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Abstract: Sound synthesis based on a physical model of simple structures such as bars allows precise control of physical parameters of the source. Multidimensional analysis of the perception of such sounds makes possible a correlation between physical parameters and timbral attributes. Moreover, this type of analysis provides information concerning the relevance of analytic acoustic parameters derived from recent multidimensional timbre studies.

INTRODUCTION

People have a remarkable capacity to quickly and efficiently understand certain aspects of the current state of the world based on the behavior of sound-producing objects, even those outside the field of vision. Early work on the subjective representation of sound events consisted of correlating abstract perceptual parameters (timbre) with parameters stemming from spectral analyses (attack time, spectral center of gravity, etc.) by means of multidimensional scaling (MDS) analysis (1). These analytic spectra-temporal parameters were based on a simplified representation of the acoustic signal, which may not account completely for the complexity of human perception. The principal objective of the work presented here was to attempt to find a direct link, if possible, between the physical nature of the vibrating object that produces sound events and the perception of that object by listeners. We thus hypothesized that the perceptual system should be sensitive to aspects of the acoustic environment that have biological importance for the listener or that have acquired a particular value through auditory experience with sounds of the daily environment. Such an approach has been already used in a discrimination paradigm (2), but without simulating sounds with a physical model, thus impeding the establishment of a direct link between perceptual dimensions and source properties.

STIMULI AND PROCEDURE

Sounds are produced with a program of numerical simulation of keyboard percussion instruments based on a physical model (3). The program simulates variable-section bars suspended on an elastic support. It allowed us to produce sounds from a set of physical data. Physical parameters such as Young's modulus, material density, internal and radiation losses or geometrical form have a direct influence on the frequency composition of the sounds produced and thus on their pitch and timbre. Two parameters were selected for study: material density and a damping factor. There were 16 sounds derived from a constrained random combination using 16 values each of density and damping factor (Fig. 1). All sounds were equalized in loudness and had the same fundamental frequency (440 Hz). This kind of percussive sound can be decomposed into a sum of sinusoidal terms, each weighted by an exponential envelope. From this signal representation, the parameters spectral center of gravity, damping time constant, and harmonic frequencies can be used to characterize the resulting signal (see correlational analysis below). The listener's task was to compare the pairs of sounds and rate directly their degree of dissimilarity on a continuous slider, the ends of which were labeled "very dissimilar" and "very similar" (4). There were 120 distinct pairs of stimuli to be judged and no instructions were given to the subject concerning the nature of the sound generation procedure.

RESULTS

The main aim was to determine, on the one hand, whether the analytic characteristics selected to represent essential attributes of timbre correspond to those varied in the physical model, and, on the other hand, whether the perceptual dimensions revealed by the MDS analysis correspond to analytic "surface" parameters and/or the mechanical parameters of the synthesis model. The analysis of the data proceeded in two stages.

First an MDS analysis using the hybrid model EXSCL (5) was performed to account for the mental representation of timbre according to a "timbre space" in which the distance separating the sound objects is related monotonically to their degree of perceptual dissimilarity. A likelihood ratio test (BIC) was used to determine the best
model. According to these analyses the selected model had two dimensions with weights on each dimension for each listener (Fig. 2). Note that the dimensionality of the perceptual space corresponds to that of parameter variation with the physical model.

The second stage consisted in evaluating the correlations among the different physical, analytic, and perceptual parameters. Two different clusters of highly intercorrelated parameters can be observed. Dimension 1 of the perceptual space is related by a power function (exponent = 0.3) to damping factor ($R^2 = 0.97$) as well as to a linear combination of two analytic parameters: spectral center of gravity and the logarithm of the envelope decay time constant ($R^2 = 0.99$). The coefficients of the linear equation were determined with a stepwise regression procedure. These latter two parameters are related to the perception of timbre. Dimension 2 is related to material density ($R^2 = 0.86$) and the frequency of the second harmonic ($R^2 = 0.87$) which determines the perceived pitch. Correlations between parameters across these two clusters are quite low on average indicating their orthogonality.

DISCUSSION

These results confirm a very tight correspondence between the mechanical properties of vibrating objects and the acoustical properties of sound events created by them, on the one hand, and between acoustical properties (sometimes in linear combination) and perceptual attributes underlying dissimilarity on the other hand. This correspondence is responsible for the high correlation between perceptual judgments and mechanical behavior of the source itself, suggesting not only that the proximal stimulus structure (acoustic waveform at the eardrum) available to the auditory system carries a great deal of information concerning the distal stimulus structure (vibrating mechanical object), but also that the human auditory system is sensitive to the available information structure. Future work will be addressed to improvement of the physical model which will allow us to understand better another essential aspect of the timbre: its role in source recognition.

ACKNOWLEDGMENTS

We especially thank B. Smith and S. Winsberg for their ideas and help on this study.

REFERENCES