Mapping the interrelation between spectral centroid and fundamental frequency for orchestral instrument sounds

Kai Siedenburg
Department of Medical Physics and Acoustics and Cluster of Excellence Hearing4all, University of Oldenburg, Oldenburg, Germany
kai.siedenburg@uni-oldenburg.de

Introduction

Spectral envelope and fundamental frequency (F0) are important parameters for the acoustical description of musical sounds and often considered as key acoustical determinants of timbre and pitch perception, respectively. Although both factors are ubiquitous in research on psychoacoustics, little empirical work has addressed their interrelation in acoustical instrument sounds. Considering instruments that adhere to a source-filter model of sound generation, Patterson, Gaudrain, and Walters (2010) outlined that instrument sounds exhibit F0-invariant spectral envelope shapes that are characteristic of the respective instrument family. Furthermore, it was hypothesized that instrumental register (or size) is determined by the position of the spectral envelope along the log-frequency axis. The latter hypothesis would imply that smaller instruments from the same family (e.g., tenor compared to alto) generate sounds with higher spectral centroids (SC), that is, yielding a brighter sound. The present study sought to test this hypothesis by characterizing the relation between F0 and SC for acoustic instrument sounds from six different instrument families of the Western orchestra.

Method

Sounds were obtained from the Vienna Symphonic Library (www.vsl.co.at) and were sustained for durations of 250 ms plus instrument-specific decay times. For this analysis, we considered sounds from 6 different instrument families (brass, double-reeds, saxophones, strings, woodwinds, and voices). Sounds were played with their regular articulation (strings were bowed). Each instrument contributed with its full playing range at 3 different dynamic levels (pp, mf, ff). The SC was measured based on an ERB-spaced spectral binning and plotted as a function of F0.

Results

Figure 1 shows SC trajectories for the 29 instruments (or voices) involved, averaged across dynamic levels. For brass and double-reed instruments, SC is relatively constant across F0 and there is a clear increase of SC for higher registers (e.g., trumpet compared to tenor trombone). SCs from saxophones, woodwinds, and string sounds vary more linearly with F0 and do not seem to show any systematic variation of SCs for instruments from different registers. For instance, the clarinet, surprisingly, does not show consistently higher SCs compared to the bass clarinet. Sounds from the voice (the archetypal source-filter system) appear to have relatively fixed SC values at least up until the tenor register, but do not show any consistent separation of SC for the different vocal registers.

Discussion

This study seeks to empirically characterize the relation between F0 and SC in a large set of instrument sounds. The SC is a primitive yet useful measure of the center of gravity of the spectral envelope, and correlating F0 and SC revealed several differences between instrument families. Specifically, the hypothesis that instrumental size (or register) is associated with a shift of spectral envelope along log-frequency (Patterson et al., 2010) could only be confirmed for the brass and double-reed families. For sounds from the saxophones, woodwinds, strings, and voices, no consistent shift of SC was observed. Further exploring the relation between these elementary acoustical parameters may help to clarify the acoustical underpinnings of several perceptual phenomena related to the interaction of pitch and timbre, such as instrument identification (Steele & Williams, 2008), dissimilarity perception (Marozeau, de Cheveigne, McAdams, & Winsberg, 2003), pitch interval perception (Russo & Thomson, 2005), or auditory short-term memory (Siedenburg & McAdams, 2018).

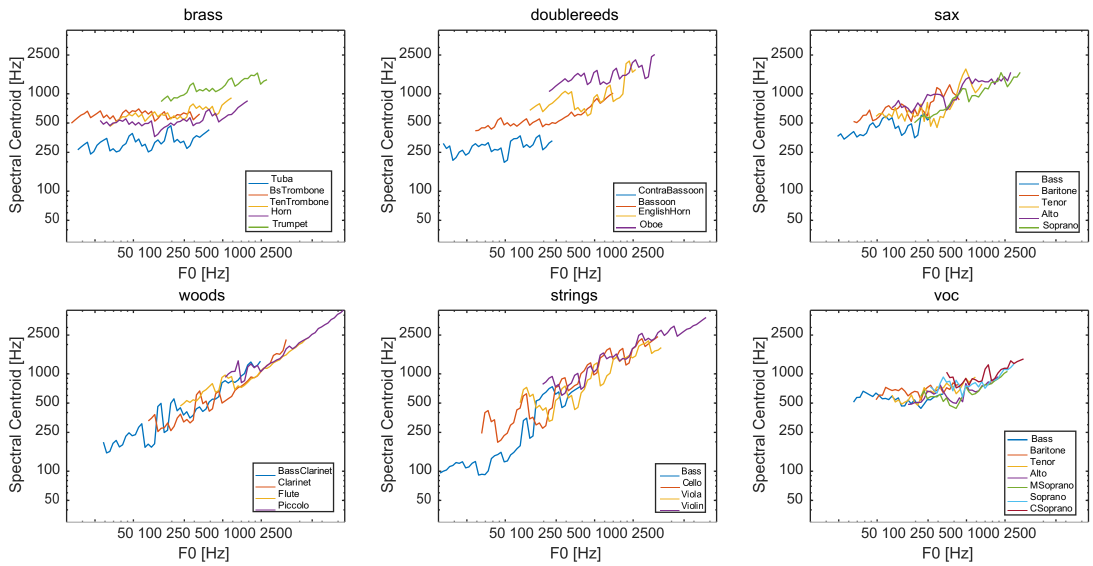

Figure 1: Relation between spectral centroid and fundamental frequency for sounds from six instrument families.

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