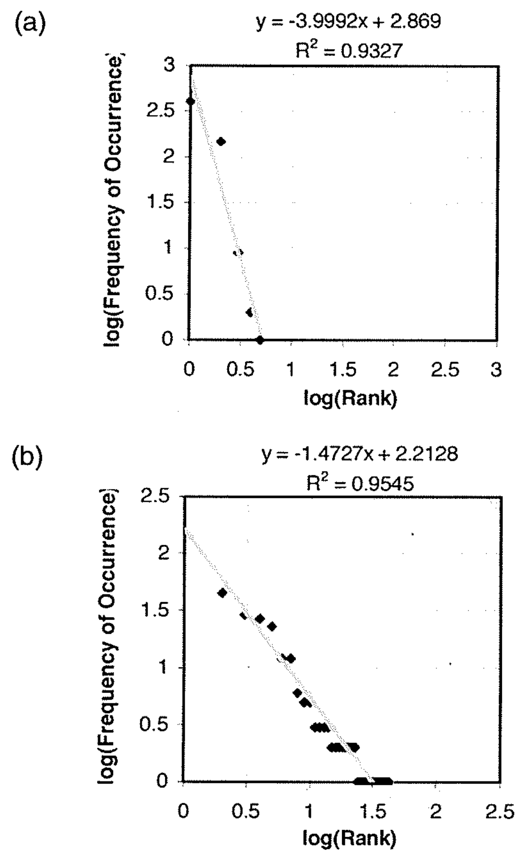
Figure 2. (a) Rank-frequency distribution of note durations from the score of Bach's Two-Part Invention No. 13 in A minor, *BWV 784; (b) the more "natural" distribution from the interpretation of this piece as performed by harpsichordist John Sankey.*



distributions with slope less than –2 are collectively called *black noise,* as opposed to brown noise (slope of –2), pink noise (slope of –1, i.e., Zipf's ideal), and white noise (slope of 0). (See Schroeder 1991, p. 122.)

The tendency of music to exhibit rank-frequency distribution slopes between 0 and –2, as observed in our experiments with hundreds of MIDI-encoded music pieces, suggests that perhaps composing music could be viewed as a process of stabilizing a hierarchical system of pitches, durations, intervals, measures, movements, etc. In this view, a completed piece of music resembles a dynamic system that has come to rest.

For a piece of music to resemble black noise, it must be rather monotonous. In the extreme case, this corresponds to a slope of negative infinity (–∞), i.e., a vertical line. Other than the obvious "minimalist" exceptions, such as John Cage's *4′33″*, most performed music tends to have some variability across different parameters such as pitch, duration, melodic intervals, etc. Figure 2a shows an example of black noise in music. It depicts the rank-frequency distribution of note durations from the MIDI-encoded score of Bach's *Two-Part Invention No. 13 in A minor.* This MIDI rendering has an unnatural, monotonous tempo. The Zipf-Mandelbrot slope of –3.9992 reflects this monotony. Figure 2b depicts the rank-frequency distribution of note durations for the same piece, as interpreted by harpsichordist John Sankey. The Zipf-Mandelbrot slope of –1.4727 reflects the more "natural" variability of note durations found in the human performance.

Music Classification and Zipf's Law

There are numerous studies on music classification, such as Aucouturier and Pachet (2003), Pampalk et al. (2004), and Tzanetakis et al. (2001). However, we have found no references to Zipf's Law in this context.

Zipf's Law has been used successfully for classification in other domains. For instance, as mentioned earlier, it has been used to authenticate and date paintings by Jackson Pollock (Taylor et al. 1999). It has also been used to differentiate among immune systems of normal, irradiated chimeric, and athymic mice (Burgos and Moreno-Tovar 1996). Zipf's Law has been used to distinguish healthy from non-healthy heartbeats in humans (see arxiv.org/abs/physics/0110075). Finally, it has been used to distinguish cancerous human tissue from normal tissue using microarray gene data (Li and Yang 2002).

Experimental Studies

We performed several studies to explore the applicability of Zipf's Law to music classification. The studies reported in this section focused on author attribution and style identification.

Author Attribution

In terms of author attribution, we conducted five experiments: Bach vs. Beethoven, Chopin vs. De-