Acoustic Analysis of Beethoven Piano Sonata Op.110

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Abstract. This paper uses phonetic analysis software Praat to extract the fundamental frequency values and energy values of Beethoven’s Piano Sonata Op.110, and examines the acoustic characteristics of Beethoven’s later piano sonatas. The research shows: fundamental frequency values of Piano Sonata Op.110’s three movements range between 80Hz-600Hz, energy intensity values range between 40dB-80dB, and the theme and emotion the composer expressed in each movement and the playing strength will have a certain effect on the changes in the movement’s fundamental frequency and energy.

Introduction

German composer Beethoven (1770-1827) experienced the late 18th century and the early 19th century, which witnessed great changes in Europe's politics, economy, society and culture, and this deeply affected Beethoven's music creation. Beethoven’s artistic creation roughly divided into three stages: early period (1792-1802), middle period (1803-1812), and later period (1813-1827)[1]. His early works mostly embody Beethoven's inheritance and expansion of Viennese classicism tradition. The middle period is the formative stage of Beethoven’s unique style, when he carried out bold innovation and development of sonatas and formed a creative Beethoven style. In the later period, the restoration of the feudalistic Napoleon and his health problems quenched the fire of Beethoven’s pursuing democracy and freedom, and he began to pursue inner peace of mind and introspection, extensively used fugues, with his musical form structure completely breaking the routine, carrying a strong sense of romance, and thus created a different style from previous works, and this foreboded Beethoven’s ushering into a romanticism style. The style of this work differs greatly from previous works, as its sonata form becomes free, there is strong continuity between each two movements, and the boundary between movement and paragraph is vague, tending to have a freer romanticism style[2]. Op.110 consists of three movements, the overall tone of the first movement is peaceful and lyrical, the second movement is lively, brisk and dynamic, and the third is permeated with passionate sentiments and lofty aspirations. On the basis of traditional piano qualitative research, this paper tries to use acoustic experiment and phonetic analysis software Praat to extract the acoustic parameters of three movements of Beethoven’s Piano Sonata Op.110, such as fundamental frequency and energy, and verify the traditional piano qualitative description in a scientific and quantitative method, before finally coming back to qualitative research[3].

Experimental Method

According to the existing high-quality wave-format piano playing corpus, we use Praat and 3700 to extract the fundamental frequency values and energy values of the four movements of Beethoven’s Piano Sonata Op.110, to analyze the acoustic characteristics of each movement of Beethoven’s piano sonata, and to make a comparative study. This paper’s acoustic analysis will mainly focus on such three movements’ fundamental frequency and energy parameters.
Acoustic Analysis of the First Movement

The first movement has 116 bars, A-flat major, in 3/4 time, sonata form. It includes four parts: exposition, development, recapitulation and coda, of which the exposition has a speed-type intro and is the theme prelude of the whole sonata; this intro has a lovely, amiable keynote, and its melody is very lighthearted and melodious. The development is profound and mild, as if recounting painful memories, ethereally shuttling back and forth between soprano voice and bass voice, recalling the good old days. The recapitulation returns to the original bright, happy atmosphere. And the coda uses material of the conjunction to end the first movement quietly. Figure 1 is the sonogram of the first movement.

Due to piano’s unique timbre, we can see from the sonagram that, its energy concentrates on the area below 2000Hz, and the acoustics is continuously and evenly distributed over time. In terms of the principle of piano playing, piano is a keyboard instrument, which makes a sound when the hammer hits the strings, and therefore grain-like sound is piano’s feature and strong point. The music flowing out of a keyboard is acoustics that involve such music expressing elements as melody, harmony, mode, tonality, gesture, musical form, speed, strength, and the acoustics produced by changing the playing tones can express a rich variety of emotions.

Fundamental Frequency Analysis

The pitch frequency generated by the vibrating strings is called fundamental frequency[4]. We cut a 20s audio clip from the first movement’s exposition, development, recapitulation and coda respectively, and then respectively extract their fundamental frequency values. The following are the fundamental frequency curve graphs extracted.

The graphs above show that the fundamental frequency value of each part of the first movement of Beethoven’s Piano Sonata Op.110 ranges between 80Hz-600Hz, in which the development and the recapitulation have higher fundamental frequency values, showing obvious undulations, while the exposition’s and the coda’s fundamental frequency values are relatively low, and the curves are relatively mild. Development and recapitulation have intensely uneasy, restless emotions, turning from F minor to E Major, and the music here is lively, brisk yet a bit rash, and therefore, fundamental frequency values of the two parts show obvious undulations and great changes. The coda gradually restores the original tranquility, the melody slows, ending this movement, so it fundamental frequency curve is relatively mild.
Energy Analysis

Energy means the volume level. A piano sonata’s energy intensity has something to do with the player’s playing strength, the greater the playing strength is, the bigger the amplitude of sonic wave is, and the stronger the energy that produces the piano sound. The following are the energy intensity change curve graphs of the four parts of the first movement.
The graphs above shows that, energy intensity of the first movement of Beethoven’s Piano Sonata Op.11 ranges between 45dB-80dB. In the beginning, overall energy of the exposition slowly and smoothly rises, and when it comes to the development and the subsequent recapitulation and coda, it obviously fluctuates with the composer’s emotional changes.

**Acoustic Analysis of the Second Movement**

The second movement is allegro molto, it has 158 bars, F minor, in 2/4 time, and is ternary form. It mainly includes four parts: prelude, trio, recapitulation and coda. 10 is the sonagram of the second movement, which shows that the movement’s middle period has the strongest energy, and the energy in the beginning and the coda’s high frequency region is relatively low.

![Figure 10. Sonagram of the second movement of Op.110.](image)

**Fundamental Frequency Analysis**

We cut a 20s audio clip from the second movement’s four parts: prelude, trio, recapitulation and coda respectively, and then respectively extract their fundamental frequency values, to examine the movement’s fundamental frequency change. The following are the fundamental frequency curve graphs extracted.

![Figure 11. Curve graph of prelude’s fundamental frequency.](image)

![Figure 12. Curve graph of trio’s fundamental frequency.](image)

![Figure 13. Curve graph of recapitulation’s fundamental frequency.](image)

![Figure 14. Curve graph of coda’s fundamental frequency.](image)
The graphs above show that the fundamental frequency value of each part of the second movement of Beethoven’s Piano Sonata Op.110 ranges between 80Hz-500Hz. The prelude expresses some restless, resistant emotion, and its melody shows most obvious undulations. The recapitulation is a regression to the prelude, and its fundamental frequency value stays at a high level. The pace of the trio and the coda gradually slows, their fundamental frequency values are relatively low, and their curves are relatively smooth.

**Energy Analysis**

We cut 20s from the second movement’s four parts: prelude, trio, recapitulation and coda respectively, and then use Praat to extract their energy intensity values respectively to examine the movement’s energy change. The following are the energy curve graphs of the four parts.

![Figure 15. Prelude’s energy intensity graph.](image)

![Figure 16. Trio’s energy intensity graph.](image)

![Figure 17. Recapitulation’s energy intensity graph.](image)

![Figure 18. Coda’s energy intensity graph.](image)

The graphs above show that, the energy values of the second movement of Op.110 range between 40dB-80dB; the energy of prelude and trio is strong, and that of the recapitulation and the coda is weak; the coda’s energy change is not great, and the whole part’s playing is in a smooth state. Energy of trio and recapitulation has great fluctuations, full of alternating ups and downs, which is closely related to the composer’s emotional changes.

**Acoustic Analysis of the Third Movement**

The third movement of Beethoven’s Piano Sonata Op.110 is adagio ma non troppo, A-flat major, having 213 bars. This movement is a Grosse Fugue movement with an adagio prelude. It adopts a non-development sonata form structure, and the development factor is realized through the fugue form, so the third movement mainly includes three parts: prelude, fugue and coda. The prelude has an emotion of singing an elegy, with a sad, sorrowful, melody spraying into the face, reaching a state of forgetting oneself. The fugue has two parts, the first part has a color of sadness, and expresses Beethoven’s painful emotion; and the second part’s emotion gradually rises, with its melody turning into a psalmody full of praises, has an inspiring power, and expresses Beethoven’s determination to overcome all the hardships. The coda also has some strong emotion, making one’s blood boil, and the whole piece ends in surging passion and great momentum. The sonagram of the third movement (see Figure 19) shows that, except that the first part of the fugue has a strong tragedy color, the whole movement’s emotion is generally impassioned and has strong energy.
Fundamental Frequency Analysis

We cut a 20s audio clip from the third movement’s prelude and coda respectively. As the fugue includes two major parts, so we have 40s audio clips, and then respectively extract their fundamental frequency values, and then examines the whole movement’s fundamental frequency change. Figure 20/21/22 are the fundamental frequency curve graphs extracted.

The fundamental frequency curve graphs show, the fundamental frequency curves of the third movement as a whole range between 100Hz-500Hz, and the prelude’s fundamental frequency curves show obvious undulations, which indicates that now Beethoven’s emotion was cadenced; he brought the recitative and aria of vocal music & opera into piano sonata, to express his inner loneliness and pain. The fugue’s fundamental frequency curve obviously contains two kinds of emotions, one is relatively low and mild, and the other is more passionate. The coda generally maintains a magnificent melody.

Energy Analysis

We cut a 20s audio clip from the third movement’s prelude and coda respectively. As the fugue includes two major parts, so we cut 40s audio clips, and then respectively extract their energy values, and examine the changes in the whole movement’s energy intensity. The following are the energy curve graphs extracted.
The energy graphs show, the energy values of the third movement range between 40dB-80dB, and the energy as a whole is high; energy’s intensity changes little over time, and in this movement the composer maintained gradual, even crescendo and diminuendo, so the energy of the three parts of this movement is relatively smooth and steady, emotions are vehement, and energy is strong.

Conclusions

This paper uses phonetic analysis software Praat to extract the fundamental frequency values and energy values of Beethoven’s Piano Sonata Op.110, and examines the acoustic characteristics of Beethoven’s later piano sonatas. After analysis, such conclusions can be drawn: (1) Fundamental frequency values of Piano Sonata Op.110’s three movements fluctuate between 80Hz-600Hz, of which the first movement, because the composer’s emotion has gone through a placid beginning and gradually entered an uneasy, restless state, and finally returns to a tranquil state, so its fundamental frequency melody has a great change, full of alternating ups and downs. Compared with the first movement, the second movement’s and the third movement’ beginning melodies are full of alternating ups and downs, and the overall melody is brisk and lively; when it comes to the middle part and the coda, the fundamental frequency values are relatively smooth and steady, i.e., either keeping a low key, or keeping a high key, showing little change on the whole. (2) Energy values of Op.110’s three movements range between 40dB-80dB, of which the third movement has the strongest energy, and the whole movement’s energy remains above 60dB, and has little alternating change in intensity. Energy intensity of the first movement and the second movement changes greatly, which has a lot to do with the theme and emotion Beethoven expressed in each movement. Meanwhile, the playing strength will also affect each movement’s energy intensity. For the first time, this paper has tried using acoustic analysis to study a piano sonata, and there may be some inadequacies in the research method, and its research content is limited to only one piece of piano sonata, so the research results may have some individual differences, and it's hoped that subsequent studies can gradually find a more scientific research method and gradually extend the research content to Beethoven’s piano sonatas in each period, so as to make the results obtained have more universal significance. While verifying traditional piano research theories, more research results on piano acoustic analysis will be obtained, providing more visualized, convenient learning methods for piano learners.

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References