Construction of a Music Database for Earphone Hearing Loss Prevention and Music Therapy - Discussions on the Relationship between Beethoven's Music and His Deafness -

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ABSTRACT[1]

A music database is indispensable for both basic research on earphone hearing loss prevention and music therapy. In this study, Beethoven's 32 piano sonatas and 16 string quartets are added to into the classical music genre of the database. And then, the relationship between his progress in hearing loss and the pitch distribution used in these works is discussed. Several elements are considered for the information that needs to be included in the music database: WAVE data and the corresponding spectrum obtained by FT analysis, musical score, and optional MIDI data, and the corresponding pitch distribution. The present study shows the following results. Both Beethoven's piano sonatas and string quartets have frequency characteristics close to the natural 1/f spectrum, which is comfortable and not dangerous to the ears. On the other hand, there are minor differences in the same classical music. For example, a string quartet can be effective in inducing sleep, and a piano sonata can be ear-friendly.

Keywords: Piano Sonatas, String Quartets, Note Pitch, Fourier Transform, WAVE Data, MIDI Data.

1. INTRODUCTION

In our laboratory, for the purpose of preventing earphone deafness [1], it is assumed that deafness is caused by the destruction [2] of hair cells [3] in the inner ear, elucidation of the mechanism is tried [4,5]. The laboratory is also conducting basic research toward the realization of music prescriptions as part of the effective use of sound and music [6,7]. A music database is indispensable in both studies. In earphone hearing loss studies, the database is used to calculate the energy of the music that the subject listens to. This estimates the age of the subject's ears. In music therapy studies, the database is used as reference for prescribing the appropriate music in a timely manner. The following things about the patient are considered: musical preference, physical and mental conditions. In our laboratory, music is first grouped. The following database elements were collected to consider whether grouping was appropriate or should be improved: scores, WAVE data and their FT results, MIDI data and their note usage distribution survey results.

By the way, it is the 250th anniversary of Beethoven's birth for one year from December last year. Recent findings examining death certificates concluded that Beethoven may have suffered from an intractable disease called juvenile bilateral sensorineural hearing loss. It has been suggested that the range of his string quartet varies depending on the audible frequency of his ears [8]. On

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the other hand, according to pianists, the range of piano sonatas expands as the range of the piano progresses. The expansion of the range of the piano is not related to the progression of his deafness. The difference in the range used by his string quartets and piano sonatas may be due to the characteristics of the instrument. The influence of the instrument is indirectly reflected in the FT results. Musical instrument elements are essential to the music database. In this study, the sounds that make up Beethoven's 32 piano sonatas as well as his 16 string quartets were tracked in chronological order. WAVE data with FT results and MIDI data with note usage distribution survey results are added as part of the music database. Based on the newly added data, the correlation between his progression of deafness and the range of composed piano sonatas was explained.

2. BEETHOVEN'S COMPOSITION ACTIVITIES AND USED MUSICAL RANGE

Beethoven's Piano History

FIG. 1 shows the composition history of Beethoven's piano pieces. The green circle marks indicate piano sonatas. The solid marks correspond to the official pieces with opus number Op. from No. 1 to No. 32. The open marks correspond to the pieces without opus numbers: studies, unofficial, or partially completed pieces. The green square marks indicate piano concertos. The solid marks correspond to the official pieces with opus number Op. from No. 1 to No. 5. The open marks correspond to the pieces without opus numbers: cadenza only, unofficial or unfinished pieces. The green triangle marks indicate the piano variations. The blue square marks indicate the symphonies. The solid marks correspond to Symphonies from No. 1 to No. 9. The open marks correspond to "Andante" and "Military symphony". The black small points (looks like curves) indicate total works.

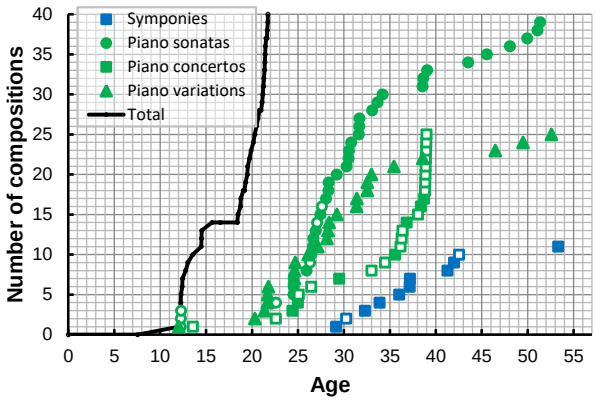


Fig. 1: Beethoven's history to compose piano music.

Table 1: Pianos which Beethoven used and piano sonatas and concerts composed with them.

Years	Maker	Range	Number of Keys	Sonatas	Concertos
1700	Cristofori	C2 - F6	54		
1770 - 1782	Stein	F1 - F6	61		
1782 - 1802	Walter	F1 - F6	61	1-3, 20, 4-6, 19, 7, 8-18	1,2,3
1803 - 1806 ?	Érard	F1 - C7	68	21-23	4
1809 -	Streicher	F1 - F7	73	24-32	5
1817 -	Broadwood	C1 - C7	73	29-32	
1824 -	Graf	C1 - F7	78		

At the age of 50, he fell ill for three months, so he composed only canon and piano pieces including Sonata No. 31. After completing Sonata No. 32 at the age of 51, the number of piano pieces decreased. In 1826, one year before his death (March 26 in 1827), Graf's piano was lent to Beethoven. To produce one pitch, it had more strings than normal ones: 3 strings for pitches from C1 to C#4, and 4 strings for pitches D4 to F7. Beethoven with deafness may have been easier to hear the sound created by the piano. His last writing is considered to be a draft of a piano piece.

Development of Piano

Table 1 lists the years, manufacturers, ranges, number of keys, and piano sonatas and concertos composed during that period of pianos used by Beethoven. In the table, the piano sonatas and piano concertos composed during that period for each piano are shown. Beethoven was born in December in 1770 and died on March 26 in 1827. The range of the piano increased significantly from 61 to 78 during his composition activities.

It is considered that Beethoven has used Stein's piano (Mozart also praised) and Walter's piano (Mozart used last). The range of piano sonatas (up to No. 20) was restricted from F1 to F6. It is easy to see that he tried to keep the highest and lowest notes within the range by changing the sequence of sounds. In 1803, Érard donated him the piano with serial number 133. Beethoven was pleased with the loud volume and composed Piano Sonatas No. 21 and No. 23. However, the piano did not produce the delicate sound of Vienna. It took time before the next Sonata No. 24. Due to this dissatisfaction, he started collaborative development of a piano with Streicher. In 1809, a piano with the sound of Vienna and a loud volume was created. He started composing piano sonatas again, and also made Piano Concerto No. 5 "Emperor". In 1818, he received Broadwood piano, whose range was shifted to the bass, as a birthday celebration. The first and second movements of Sonata No. 29 were composed so that they could be played on Streicher piano. The 3rd and 4th movements were composed so that they could be played on Broadwood piano. On the premise that the range of the piano will expand in the future, Beethoven began to aim for pieces which could be played in the future.

Range of Strings [10]
It is considered that stringed instruments had a structure and shape quite similar to those of today's ones in the 16th century. It can be thought that the current stringed instruments had been completed by the time of Scarlatti to Haydn. In addition, it can be said that the instrumental composition of the string quartet has also been decided to be the current one.

The lowest pitch of a stringed instrument is determined by the strings which are stretched. That is, the pitch when the string which produces the lowest bass is opened [9] is the lowest. On the other hand, an endlessly high sound can in principle be produced on the premise that the performer is sufficiently proficient. The violin may have the highest pitch of generally from E7 to G7. By the time of Beethoven, pianos with pitches above the highest range of the violin had not yet appeared.

3. WAVE DATA AND ITS FT RESULTS

Storage of Music
It was the best if music could be recorded as the original sound information. The cerebrum recognizes the physical vibration of the energy transfer medium transmitted to the ear as sound. Since this vibration cannot be retained, reproducing sound information is synonymous with reproducing this vibration. As the methods that can reproduce vibrations, analog methods such as magnetic tapes and vinyl records have been invented. Digital methods are recently developed. Both of the analog method and the digital method have advantages and disadvantages. The change called quantization error occurs when converting vibration from analog to digital. Analog information, on the other hand, is vulnerable to copying.

WAVE Format
The format, usage, and storage method of the database constructed in this study are undecided. Ideally, the database should be constructed by both analog and digital means. Unless you make your own original sound information, as a result of analog means, there is already an error due to copying. Therefore, the construction of the database was first started using the digital method.
Recently, the accuracy of digital data has improved considerably. Further improvement in the accuracy of the database in the future can be expected.

In the present database, the sound information of music is saved in WAVE format. WAVE data, which is officially called RIFF waveform Audio Format, is one of the data formats for digitally recording audio waveforms. It is a free format. The sound information sampled by the linear pulse code modulation (PCM) is usually uncompressed as WAVE data. The WAVE format is created for WINDOWS computers by Microsoft and IBM, while Apple created another Audio Interchange File Format (AIFF) for Mac computers. In recent years, WAVE data is often used even with Mac computers, and the WAVE format is becoming the standard for audio data formats.

Currently, the standard sampling frequency for music is 44.1 kHz. Data sampled by 48 kHz, 96 kHz and 192 kHz are also used. The value of 44.1 kHz seems to have been set as the lowest value at that time with almost no loss of sound quality. The current WAVE data for music is recorded each sampled value in 16 bits on a CD, and is operated in 24 bits or 32 bits at music production sites. Here, 32 bits is the highest value. The number of channels is, so to speak, the number of sound sources or speakers, and corresponds to the spatial resolution. WAVE data commonly used is either stereo (2ch) or monaural (1ch).

It should be noted that even digital data will be copied with reduced accuracy as analog data, such as when the sampling frequency or bit is dropped. Quality deterioration such as noise which appears once during copying process remains even if the sampling frequency or bits are increased again in the next copy.

Beethoven's Piano Sonatas and String Quartets
At the stage of concrete examination of how to apply the database to ear age measurement and music prescriptions, various data should be obtained in consideration of the differences between performers and pianos. On the other hand, since the database is still in its infancy, 32 piano sonatas and 16 string quartets are available. The analysis was started on a CD that clearly recorded the performances of world-renowned performers. The data collected from the CDs is digital data with a sampling frequency of 44.1 kHz, 16 Bit, and stereo.

There are many performers who play Beethoven's compositions. It is hard to conclude who can play like Beethoven or the best. A complete piano sonata collection of Pollini [11] and a complete string quartet collection of Alban Berg Quartett [12] were first available and were FT analyzed. The following is examples of performers whose complete sonatas CD sets to be added to Beethoven's piano sonata data in the future; Alfred Brendel, Daniel Barenboim, Wilhelm Kempff, Sviatoslav Teofilovich Richter, Friedrich Gulda, Wilhelm Kempff and Wilhelm Backhaus.

WAVE data can be easily converted into sound information by using a smartphone application, PC software, or a CD player. Research ethics was instructed to all concerned so that this data would not be copied or diverted for purposes other than research.

FT Analysis Results
All his 32 piano sonatas and 16 string quartets have been added to the database for each movement. The format are WAVE data and the spectrum obtained based on WAVE data using the general-purpose FT analysis program O-

SCOPE. Overall, it was confirmed that the string quartets have a lower power in the middle frequency range and a higher power in the high frequency range than the piano sonatas.

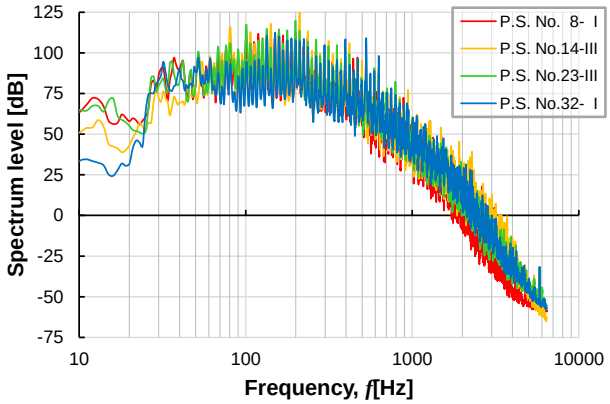
Piano Sonatas: Fig. 2(a) shows the FT results of the first movement of Sonata No. 8 "Grande Sonate Pathetique", Op. 13, Komponiert 1798-1799 (red colored), the third movement of Sonata No. 14 "Sonata Quasi una Fantasia", Op. 27 Nr. 2, Komponiert 1801 (yellow colored), the third movement of Sonata No. 23, Op. 57, Komponiert 1804-1805 (green colored), and the first movement of Sonata No. 32, Op.111, Komponiert 1821-1822 (blue colored). The vertical axis indicates the spectral power in dB, and the horizontal axis shows the logarithmic scale display of the frequency. Every result showed basically the same spectrum, which was represented by a convex curve with a lower at the high frequency range than a straight line. It contains a little more midrange than the natural "1/f spectrum" sound, and the danger as a sound is considered to be extremely small unless it is listened to at a loud volume. Since the power of 0 dB means that the sound of the frequency is not directly on the WAVE data, the region from 2093.0 Hz (C7) to 3136.0 Hz (G7) is considered to be the highest frequency that actually reaches the inner ear, including overtones.

String Quartets: Fig. 2(b) shows the FT results of the first movement of Quartet No. 6, Op. 18 Nr. 6, Komponiert 1800 (red colored), the fourth movement of Quartet No. 9 "Razumovsky", Op. 59 Nr. 3, Komponiert 1806 (yellow colored), the fourth movement of Quartet No. 10 "Harp", Op. 74, Komponiert 1809, and the fourth movement of Quartet No. 16, Op.135, Komponiert 1826, with the same axes as Fig. 2(a). Every result showed basically the same spectrum, which was represented by a convex curve with a lower at the high frequency range than a straight line, where the power around 1000 Hz is rather stronger. It is close to the 1 / f spectrum. The region from 3136.0 Hz (G7) to 4978.0 Hz (D#8) is considered to be the highest frequency that actually reaches the inner ear, including overtones.

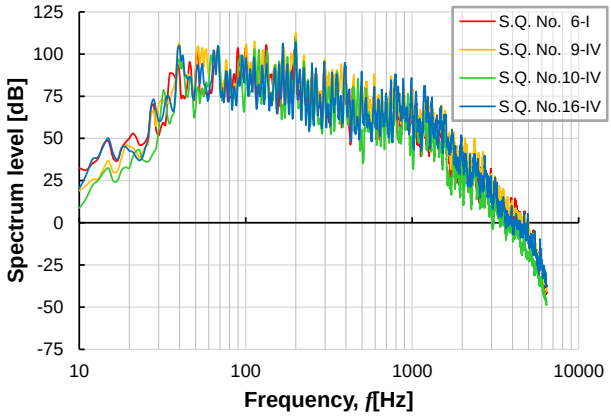
4. MIDI DATA AND COUNTING NUMBER OF NOTES USED

Backgrounds

Apart from the spectrum, how many notes of each pitch were used was investigated and added to the database. Here, it is needed to read the score and count the notes one by one, which takes a lot of time and effort. MIDI data of his piano sonatas and string quartets have been uploaded on the Internet. The authors played them on a PC and listened to them. It was confirmed that the played sound was slightly different from the Henle version of the score. The MIDI data were decided to be used, because it was judged that they would have sufficient accuracy for comparison between pieces and for overall discussion. With MIDI data, the program uploaded on the Internet can automatically count notes for each pitch [13].



(a) 4 piano sonatas.



(b) 4 string quartets.

Fig. 2: Examples of FT analysis results.

Although it depends on how the data is used, the length of each note should be included in the data as well as the number of occurrences of the note. Since the piano is a percussion instrument and the sound of the piano is attenuated, on the other hand, it seems that there is almost no effect of the length of the sound [14]. Bowed string instruments such as violins and cellos have a long-lasting sound, so the effect of length will be considerable. Bowed string instruments such as a Violin, a Viola and a Violoncello have a long-lasting sound. The length of notes will have a considerable effect, while the volume at the moment of pronunciation (attack point) will be rather louder.

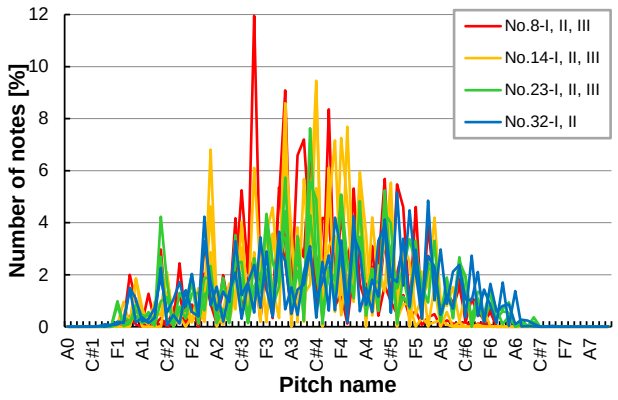
Distribution of number of each pitch notes

For Beethoven's 32 piano sonatas and 16 string quartets, the number of notes for each pitch was counted from MIDI data for each movement. Table 2 shows the number of pitches used in each movement of Sonatas No. 8, 14, 23 and 32. In addition, the year of composition, the total

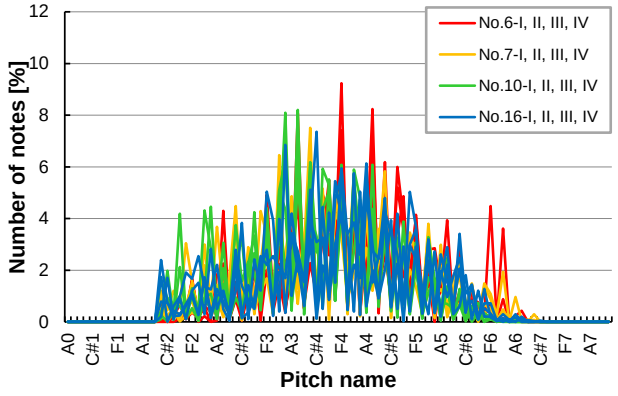
number of notes used, and the total number of notes G6 and above are also shown. In the table, the yellow column shows the pitch that there was no piano playing that pitch at that time. The orange column shows the pitch that Beethoven wrote the note of that pitch in the score even though there was no piano to play that pitch at that time.

Transition of Pitch Used

Fig. 3(a) shows the distribution of the number of notes of each pitch in each piece presented in Table 2. In addition, Fig. 3 (b) graphically displays the distribution of the number of notes in the 1st movement of String Quartet No. 6, the 4th of No. 7, the 4th of No.10 and the 4th of No. 16. It seems that the pitch range used in piano sonatas gradually expands as the range of the piano expands, and that the percentage of using the high-pitched sounds increases with the years. On the other hand, the range of pitches used in his string quartets is almost unchanged because the ranges of the violin, the viola and the violoncello have not changed. And the frequency of use of treble is rather decreasing.



(a) Piano Sonatas No. 8, 14, 23 and 32.



(b) String Quartets No. 6, 7, 10 and 16.

Fig. 3: Distributions of number of notes used in.

Table 2: List of number of pitches used in Piano Sonatas.

when	1798-1799			1801			1804-1805			1821-1822	
No.	8			14			23			32	
Pitch	1 mov.	2 mov.	3 mov.	1 mov.	2 mov.	3 mov.	1 mov.	2 mov.	3 mov.	1 mov.	2 mov.
A0	0	0	0	0	0	0	0	0	0	0	0
A#0	0	0	0	0	0	0	0	0	0	0	0
B0	0	0	0	0	0	0	0	0	0	0	0
C1	0	0	0	0	0	0	0	0	0	1	0
C#1	0	0	0	0	0	0	0	0	0	0	0
D1	0	0	0	0	0	0	0	0	0	1	2
D#1	0	0	0	0	0	0	0	0	0	5	0
E1	0	0	0	0	0	0	0	0	0	4	4
F1	3	2	1	1	0	4	54	3	48	5	16
F#1	11	0	1	11	0	11	2	16	5	10	12
G1	119	0	10	1	0	7	8	9	10	82	118
G#1	56	12	2	21	8	122	58	18	32	58	14
A1	10	0	0	3	0	46	28	6	11	11	29
A#1	76	5	1	1	0	6	27	10	28	16	11
B1	10	5	2	11	0	42	21	2	7	40	28
C2	177	0	8	9	0	28	279	42	132	104	182
C#2	2	5	0	24	14	131	114	49	14	30	5
D2	40	2	3	1	0	9	0	4	3	57	37
D#2	72	40	17	5	4	22	86	33	31	94	10
E2	12	3	0	12	0	35	58	13	30	42	113
F2	51	13	19	2	4	11	133	55	86	111	46
F#2	28	0	2	17	8	52	28	56	5	22	33
G2	185	17	49	4	2	60	124	27	62	180	340
G#2	109	34	21	53	30	446	123	100	68	94	66
A2	11	6	3	5	0	62	39	6	11	35	124
A#2	118	22	14	1	6	42	123	29	92	74	16
B2	38	22	14	11	2	109	17	6	18	52	107
C3	249	31	70	15	14	44	179	105	173	180	168
C#3	34	86	11	30	32	264	114	107	37	66	25
D3	109	34	32	2	2	34	10	6	35	93	134
D#3	159	196	59	16	30	400	102	113	45	130	44
E3	35	28	7	29	2	141	135	56	77	40	277
F3	114	31	53	2	38	31	146	186	190	158	118
F#3	49	17	8	41	48	97	50	106	50	23	31
G3	217	80	128	16	16	22	102	72	177	163	294
G#3	149	149	79	78	90	415	293	246	167	139	54
A3	39	18	8	42	0	79	50	36	41	27	122
A#3	167	108	83	2	40	84	142	124	171	78	36
B3	66	118	64	65	2	81	61	10	47	89	169
C4	196	59	162	22	46	106	283	239	374	157	249
C#4	67	44	15	104	99	349	139	210	130	60	28
D4	130	11	100	14	0	27	24	5	28	94	201
D#4	342	137	100	53	64	203	138	98	99	150	50
E4	74	13	23	82	6	229	117	52	96	35	337
F4	253	21	76	14	76	29	167	218	248	181	235
F#4	153	2	19	88	50	160	80	109	38	39	14
G4	221	36	127	18	10	90	196	47	123	192	342
G#4	180	53	39	68	48	343	227	207	169	156	48
A4	84	5	22	41	0	134	28	37	53	46	120
A#4	138	51	46	5	44	69	120	95	110	99	45
B4	53	7	56	20	18	154	111	26	42	63	265
C5	204	26	136	17	34	89	247	187	257	225	312
C#5	57	16	15	31	58	318	193	171	97	105	43
D5	122	8	131	3	0	50	97	5	21	94	415
D#5	182	20	110	10	34	206	149	85	57	185	127
E5	60	6	17	10	0	163	222	30	37	42	360
F5	188	10	110	0	24	31	156	124	162	162	167
F#5	48	1	8	4	22	75	42	67	38	42	25
G5	141	6	93	1	0	107	162	40	108	149	390
G#5	120	8	36	2	16	275	147	142	117	125	82
A5	47	0	17	3	0	62	23	10	9	25	239
A#5	71	4	33	1	6	52	125	78	69	67	71
B5	43	2	21	0	0	100	24	14	29	38	170
C6	92	2	44	2	0	15	159	108	131	125	191
C#6	20	3	4	0	0	84	126	83	57	58	29
D6	65	0	26	0	0	4	12	0	20	55	220
D#6	56	2	12	1	0	46	89	37	54	115	33
E6	10	2	8	0	0	42	84	9	24	10	115
F6	34	1	17	0	0	0	79	39	72	90	66
F#6	0	0	0	0	0	0	21	29	29	32	11
G6	0	0	0	0	0	0	39	4	33	44	137
G#6	0	0	0	0	0	0	36	18	46	47	3
A6	0	0	0	0	0	0	3	0	0	5	110
A#6	0	0	0	0	0	0	15	5	3	15	1
B6	0	0	0	0	0	0	3	0	0	13	2
C7	0	0	0	0	0	0	4	8	18	6	1
C#7	0	0	0	0	0	0	0	0	0	0	0
D7	0	0	0	0	0	0	0	0	0	0	0
D#7	0	0	0	0	0	0	0	0	0	2	0
E7	0	0	0	0	0	0	0	0	0	0	0
F7	0	0	0	0	0	0	0	0	0	0	0
F#7	0	0	0	0	0	0	0	0	0	0	0
G7	0	0	0	0	0	0	0	0	0	0	0
G#7	0	0	0	0	0	0	0	0	0	0	0
A7	0	0	0	0	0	0	0	0	0	0	0
A#7	0	0	0	0	0	0	0	0	0	0	0
B7	0	0	0	0	0	0	0	0	0	0	0
C8	0	0	0	0	0	0	0	0	0	0	0
Total	5966	1640	2392	1145	1047	6549	6593	4287	4901	5462	8039
above G6 [%]	0.00	0.00	0.00	0.00	0.00	0.00	1.52	0.82	2.04	2.42	3.16

Beethoven's Deafness and Compositions

Fig. 4 shows the transition of the percentages of notes with G6 or higher pitch used in his piano sonatas and string quartets. Each point corresponds to each work. There was no piano with a G6 until 1803. Among the string quartets, the three pieces composed in 1800 and 1816 show a high ratio, but they are generally constant at about 0.5%. On the other hand, in his piano sonatas, the usage rate is increasing with the years.

Saccenti, et.al. examined the proportion of notes with G6 or higher pitch in the score of violins I (part of the first violins) of the Beethoven's string quartets. It decreased with the progression of his deafness, became the lowest in 1810 and increased again for the last five pieces [8]. In this study, notes were counted not only for violin I but also for all the 4 parts (violins I, violins II, violas and violoncellos), and the ratio was calculated for the entire piece. It was found that the ratio of using higher notes than G6 was never higher for his last 5 string quartets. Objectively inferring from various references, it is natural to think that Beethoven's hearing loss is getting worse year by year. Therefore, it can be concluded that the frequency of using high notes in his piano sonatas has increased despite the progress of deafness.

5. DISCUSSIONS

Range of Piano Sonatas and String Quartets

As can be seen from Figs. 2 and 3, the distributions of the number of pitches used in both his 32 piano sonatas and 16 string quartets are close to a mountain shape. The string quartet is closer to the natural spectrum, so if you are looking for healing and soothing effects, the string quartet is not bad. In addition, since the frequency characteristics of the piano have low power in the high frequency range, it is presumed that the piano is the instrument which is hard to make its listener hard to be deafness and whose sound is easy to hear even for people with deafness.

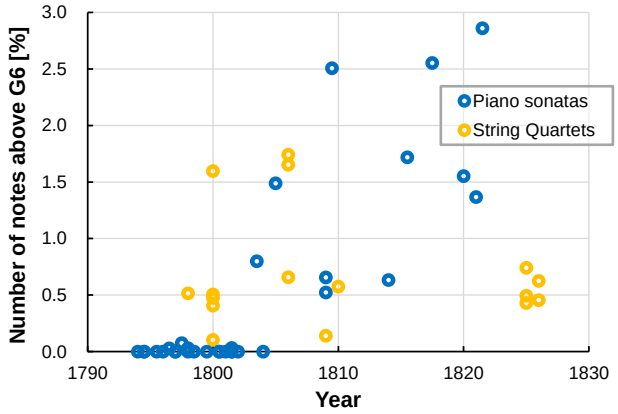


Fig. 4: Time history of percentage of notes above G6.

Table 3: Error of counting notes used in Sonata No. 32.

Pitch	Piano Sonata No.32-I					Piano Sonata No.32-II				
	Add	Del	Total	by Pgm.	by Pnt.	Add	Del	Total	by Pgm.	by Pnt.
A0			0	0	0			0	0	0
A#0			0	0	0			0	0	0
B0			0	0	0			0	0	0
C1			0	1	1			0	0	0
C#1			0	0	0			0	0	0
D1			0	1	1			0	2	2
D#1			0	5	5			0	0	0
E1			0	4	4			0	4	4
F1			0	5	5			0	16	16
F#1			0	10	10			0	12	12
G1	2	1	1	82	83			0	118	118
G#1	1		1	58	59			0	14	14
A1			0	11	11			0	29	29
A#1			0	16	16			0	11	11
B1			0	40	40	2		2	28	30
C2			0	104	104		4	-4	182	178
C#2			0	30	30			0	5	5
D2			0	57	57			0	37	37
D#2		2	-2	94	92			0	10	10
E2	2		2	42	44	2		2	113	115
F2		1	-1	111	110		2	-2	46	44
F#2			0	22	22	2	1	1	33	34
G2	2	1	1	180	181	1		1	340	341
G#2	1		1	94	95	2		2	66	68
A2			0	35	35		2	-2	124	122
A#2			0	74	74			0	16	16
B2	1		1	52	53			0	107	107
C3			0	180	180		1	-1	168	167
C#3			0	66	66	1		1	25	26
D3			0	93	93	2		2	134	136
D#3		2	-2	130	128			0	44	44
E3	2		2	40	42		2	-2	277	275
F3		1	-1	158	157			0	118	118
F#3			0	23	23			0	31	31
G3			0	163	163		1	-1	294	293
G#3			0	139	139	1		1	54	55
A3			0	27	27	3		3	122	125
A#3			0	78	78	4		4	36	40
B3	1		1	89	90		4	-4	169	165
C4			0	157	157	3	1	2	249	251
C#4	1		1	60	61	4		4	28	32
D4		1	-1	94	93	1	6	-5	201	196
D#4		2	-2	150	148	1		1	50	51
E4	2		2	35	37	2		2	337	339
F4			0	181	181	1		1	235	236
F#4			0	39	39			0	14	14
G4			0	192	192			0	342	342
G#4			0	156	156			0	48	48
A4			0	46	46			0	120	120
A#4			0	99	99	5		5	45	50
B4			0	63	63		3	-3	265	262
C5		1	-1	225	224		2	-2	312	310
C#5	1		1	105	106	1	1	0	43	43
D5			0	94	94	2	7	-5	415	410
D#5			0	185	185	1		1	127	128
E5			0	42	42		9	-9	360	351
F5	2		2	162	164	2		2	167	169
F#5			0	42	42			0	25	25
G5			0	149	149			0	390	390
G#5			0	125	125			0	82	82
A5		2	-2	25	23		1	-1	239	238
A#5			0	67	67	2		2	71	73
B5			0	38	38		2	-2	170	168
C6	1		1	125	126	2	2	0	191	191
C#6			0	58	58	2		2	29	31
D6			0	55	55		1	-1	220	219
D#6		2	-2	115	113			0	33	33
E6	2	1	1	10	11			0	115	115
F6			0	90	90			0	66	66
F#6			0	32	32			0	11	11
G6			0	44	44			0	137	137
G#6			0	47	47			0	3	3
A6			0	5	5			0	110	110
A#6			0	15	15			0	1	1
B6			0	13	13			0	2	2
C7			0	6	6			0	1	1
C#7			0	0	0			0	0	0
D7			0	0	0			0	0	0
D#7		1	-2	2	1			0	0	0
E7			0	0	0			0	0	0
F7			0	0	0			0	0	0
F#7			0	0	0			0	0	0
G7			0	0	0			0	0	0
G#7			0	0	0			0	0	0
A7			0	0	0			0	0	0
A#7			0	0	0			0	0	0
B7			0	0	0			0	0	0
C8			0	0	0			0	0	0
Sum	21	18		Error=	34	49	52		Error=	85

It is said that Beethoven almost completely lost his hearing during 1810 to 1825. The range of his piano sonatas expanded in the treble direction regardless of his progress of deafness. The piano may have been devised in various ways, but the hypothesis that the sound of the piano is easy to hear holds true. The first reason is thought to be the difference in the sound waveforms of the piano and stringed instruments. First, the piano sound could perhaps be recognized as a piano sound even if its overtones cannot clearly be heard. Secondly, since the piano sound is a striking sound, it may be easy to determine whether or not it rang.

By the way, the following predictions can be made as taking care of a person with insomnia. If her/his goal is to sleep, recommendation is to listen to a string quartet. Of course, the volume should be low enough. Since the high-frequency energy contained in string quartets is higher than that of piano sonatas, high volume cannot help giving the listener feeling pressure. On the other hand, piano sonatas are recommended for taking a break during the day. It can be said that the music is clear and does not hurt your ears, so to speak, it is gentle to your ears. Pieces which belong to classical music genre should also be used in detail according to the purpose. Various classifications will be made in classical music in the future.

Comparison of FT Spectrum and MIDI Histogram

Figs. 2 and 3 mean different things. Piano Sonata No. 32 uses a lot of treble. For an example, the frequency of using pitches higher than G6 (1568.0 Hz) is 2.417% in the 1st movement and 3.160% in the 2nd movement, which is higher than other sonatas. The FT results do not show a clear difference in the power spectrum around 3000 Hz compared to No. 14 and No. 23. On the score of No. 32, it is confirmed that many notes with a pitch of C6 or higher are instructed to be played with forte. Fig. 3 shows that the treble and bass are used equally around F4 in his string quartets. Of course, there are differences depending on the pieces. For an example, the distribution for No. 6 is used slightly biased toward the treble side, and that for No. 10 is biased toward the bass side. On the other hand, Fig. 2 shows that his piano sonatas have a higher midrange and lower treble spectrum than his string quartets.

A detailed comparison of piano sonatas shows that at frequencies above 500 Hz, No. 8 is the lowest, followed by numbers No. 23, No. 32 and No. 14 the highest. The spectrum also includes the overtones and sounds of the piano, as well as the reverberation of the venue. If the energy of the music you are listening to is important, the spectrum is likely to provide more accurate information than the pitch distribution. The database will need both a spectrum of FT analysis of WAVE data and a histogram of notes.

Error of Counting Notes

When playing the MIDI data that existed on the Internet, which was added to the database this time, as music using the general-purpose program Musescore on a PC, a number of obvious mistakes were discovered. A pianist who plays Beethoven often listens to the played music and compares it to the Henle version of the score. It is desirable to automatically count notes directly from the score, but there is still no way to do that accurately.

Table 3 lists the number for each pitch of notes to be added to (that is, missing) or to be deleted from (that is, extra) the MIDI data for each movement of Piano Sonata No. 32. The error rate was 0.62% (34 out of 5462) in the 1st movement and 1.06% (85 out of 8039) in the 2nd movement. It's not a big deal as a percentage, but it can still lead to false conclusion which is based on the discussion without recognizing the error. For an example, one extra D#7 with the highest pitch is counted. With the present check method, it cannot be revealed which is incorrect: the MIDI data itself, or the data transforming from MIDI data to music by Musescore. In the future, the automatic method that notes can directly be counted for each pitch and length by scanning the Henle version of the score would be developed.

5. CONCLUSIONS

The 32 piano sonatas and 16 string quartets as well as 9 symphonies are pieces that Beethoven continued to compose throughout his life. So they were added to the music database and tracked how they changed as his hearing loss progressed. The conclusions obtained are as follows:

1) The spectra obtained by FT analysis of WAVE data and the pitch distribution obtained by numerically processing MIDI data mean that they are different in detail. WAVE data, spectrum, score, MIDI data and pitch distribution are all considered to be important information that should be included in the music database.
2) Based on the spectral characteristics, the highest note of the string quartet is about 3136.0Hz (G7) to 4978.0 (D # 8) Hz, and the highest note of the piano song is about 2093.0Hz (C7) to 3136.0 (G7) Hz. The danger is not great.
3) The details of the spectral characteristics differ between his piano quartet and his string quartet. The spectrum of his string quartet is close to the natural 1/f spectrum, and that of his piano sonata has less power in the treble range.
4) Based on MIDI data, the distribution of the number of notes in each pitch used in each piece were investigated. Looking at the frequency of use of sounds of G6 and above, it decreased in string quartets, but gradually increased in piano sonatas as the range of the piano expanded. For people with

deafness, the sound of the piano may be easier to hear.

5) The following can be considered as future research topics. Add symphonies to the database and collate with Beethoven's history of deafness. (To examine the difference in timbre.) Symphonies are added to the database and are matched against Beethoven's history of hearing loss. WAVE data of different performers, performance locations, and pianos of the same piece will be collected and added to the database. The length of the sound will be added into the pitch distribution information and be discussed its effect. The error in handling MIDI data will be quantitatively evaluated. The method that can automatically count the pitch distribution more accurately will be developed. The equivalent energy of each piece will be estimated.

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