A PILOT STUDY OF EXPRESSIVE BODY MOVEMENT ON AUDIO PARAMETERS OF PIANO PERFORMANCES

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ABSTRACT

Body movement plays an important role in music performances and is widely studied by researchers. However, how the expressive body movement and audio parameters change while trying to maintain consistent musical expressive intentions have not been answered. In this paper, a pilot experiment was designed to explore the objective changes in body movement and audio parameters under three expressive body movement conditions: deadpan, normal, and exaggerated. Through audio and motion data analysis, the results showed that changes in expressive body movement can affect the tempo and dynamics of music. In addition, head movement was the most affected body part under different body movement conditions, but the wrists are hardly affected. Lastly, we proposed that the difficulty of the music may have an impact on the expressive body movement in order to achieve a similar musical expression.

1. INTRODUCTION

Musicians move in many ways when performing music. Expressive body movement is an appealing feature of music performing, this characteristic is found in all music cultures [1]. The role of body movement in music performance also has been discussed by researchers for many years. For instance, the musician's body is described as a mediator between the physical environment and the individual musical experience [2]. Moreover, researchers found that body movement is important in the expression of musical performance. Specifically, several studies have shown, in addition to acoustic cues, audiences can also perceive musical expressions through body movement, it contributes to the audience understand the score and the performer's expressive interpretation of music [3–7]. All these studies explicated the role of body movement in music performances and reveal different perspectives on the contribution of auditory and visual information to the expressiveness of musical performance. However, how expressive body movement affects the objective audio parameters of the music performance remains in relatively preliminary stage. Therefore, our main research questions include the following two points:

- How does changing expressive body movement affect audio parameters?
- How expressive body movement changes when performing under different conditions while maintaining original expression intention?

In this paper, we will start with summarizing some previous research around music-related expressive body movement in order to address the research questions and also provide a conceptual framework for our research.

Secondly, we designed a pilot experiment to explore the Root Mean Square(RMS) and duration changes of the same piano performance excerpt with restrained, normal or exaggerated body movements but natural expressive intentions. This experiment aims to modify the method developed by Davidson [3, 4] and Wanderley [8] on music performances in different body movement states. To explore the differences in audio parameters and also the expressive body movement features of piano solo performances under three expressive body movement conditions.

Last but not least, we will draw preliminary conclusions for our pilot study, also reflect on the current study and prospect for future work.

2. BACKGROUND

2.1 Music-related body movement and performance

The precise control of the body is a difficult part of musical instruments' performance. In piano performance, the training of the wrist, arm, and hand is the core part of the piano pedagogy, these body movements are involved deeply in the production of the sound [9]. Davidson [3, 4, 10] conducted a variety of experiments with gradual levels of expression in piano and violin performances. She proposed that pianists will still have a lot of swaying movements at the hips, even in a performance where body movements are supposed to be completely restrained (deadpan condition). Correspondingly, the same result was observed in clarinet performances, where clarinetists were unable to fully restrained their body movements while playing, this result provided concrete evidence of the ingrained nature of body movements in the performance technique and emotional expression [11]. Besides, although the relationship between the pianist's swaying movements and the musical structure is not clear, there is a direct link between the pianist's facial expressions, body movements, and music structure [12]. In a similar study, Castellano and his colleagues [13] found that during the pianist's performance of the Beethoven Sonatas under different emotional modes, the quantity of movement was not much affected, but the speed of the head movement was more variable. In few more recent studies, the relationship between body movement and musical structure is becoming explicit. Through an observation for 13 clarinetists during several performances, researchers claimed that the body movements were closely related to the music structure and its music content. For example, the Bell movement in clarinet performances has been associated with the phrase boundaries with harmonic tension [14]. Moreover, Thompson [15] combined the experiments set up by Wanderley [11] and Davidson [10] explored the pianists' body movements of Chopin's Prelude in E minor. He stated that in specific music phrases such as the music's climax and ones with articulations, the quantity of motion was modified greatly compared to other regions.

Musician's body movements are not only related to the structure of the music, but also linked to the difficulty level of the piece. MacRitchie and her colleagues [16] [17] observed two pianists played two similar structures Chopin Preludes. In different phrases with similar rhythmic patterns, the pianist tends to play them with similar body movements. This further indicated that musicians shape their body movements through musical structure and rhythm. However, researchers also suggested that this phenomenon may vary depending on the difficulty level of the music. For instance, during the pianist's performance of the more complex Scriabin Etude, researchers found that the pianist's body swaying cycle correlated with emotional intensity rather than the rhythmic structure of the regions [18]. Furthermore, researchers demonstrated that in the high-level music excerpts, the body movement may be limited by the content of the music, and thus the body parts swaying motion's amplitude becomes smaller [11, 19]. These may occur because of the relaxation function of the music-related body movement could prevent injury and also helps the pianists' precise execution [18].

2.2 Perception of music-related body movement in music performance

With the development of embodied cognition and multimodal perception theory, in the field of music psychology, researchers have begun to concentrate on the role of visual signals on music perception. Davidson [3] was one of the first researcher in the music research field to apply Johansson's [20] point-light display and multi-model method to reveal the perception of music-related body movement. In her experiment, four violinists and one pianist had various parts of their bodies (head, elbows, wrists, knees) attached to reflective tape and were placed in front of a non-reflective black canvas, with the special camera contrast setting, audiences would only perceive the moving light points in the video. All performers played with three different expressive intentions: deadpan, projected, and exaggerated. "Deadpan" was defined as players who minimize their expressive intent, to reduce dynamic, rhythmic, and timbre variation. "Exaggerated" was the opposite definition of "Deadpan". "Projected" was defined as performing in a normal, natural state, as in a recital. The results have shown that even in the visual-only condition, the observer can still distinguish the performer's expressive intent without sound signals. Besides, observers can best distinguish the different expressive conditions in the visual-only mode compared to the sound-only and audio-visual conditions [3]. In addition to the piano and violin, researchers have begun to shift their attention to other instrumental performances. Dahl and her colleague studied the emotional expression of the marimba performance by recorded a marimba player performing in four emotions: happiness, sadness, anger, and fear. Twenty observers rated the performance videos in four conditions without sound. Not surprisingly, the result demonstrated that the observers were able to discriminate between happiness, sadness, and angry intentions clearly [21], the same conclusion has also been found in clarinet performances [22]. Furthermore, a follow-up study revealed that in the perception of various versions of videos of marimba performance (head only, whole body, no arms), head movements could provide sufficient information for the discrimination of emotions [6]. Similarly, in the clarinetists' performance, researchers also found that not all body movements affect the observer's evaluation of the musicians. To be more specific, they illustrated that limiting the movements of the torso and arms did not affect the expressiveness of the performance compared to the head only or whole body [19].

Visual information not only affects the expressiveness of musical performance but also has an impact on the perception of auditory characteristics of the music. For instance, researchers found that the tension (emotional response to the music) and phrasing (musical structure) perception in the clarinet performance could be influenced by visual information, and they also suggested that visual and auditory channels could convey a similar interpretation of phrasing [5]. In addition, Juchniewicz [23] explored the influence of body movement in piano performance on listeners' perception, this research not only further confirms the positive correlation of visual information on the perception of expressive intention in piano performance, but also implies its positive impact on the observers' subjective perception of musical features such as rubato, dynamics, and phrasing. Moreover, Vuoskoski and her colleagues [24, 25] studied the roles of visual and auditory channels in the auditors' emotional feedback, they demonstrated that in piano solo performance, visual and auditory signals are equally important in contributing to the observer's subjective emotional reaction to musical expression, and visual signals can influence the observer's rating of musical loudness variability. Furthermore, Massie-Laberge [26] stated that auditors can distinguish pianists' different expressive performances in three modalities (audio-only, visual-only, or audio-visual) but are better in the audio-visual modality, and the body movement may have a perceptual impact on music expressive parameters [9, 23, 26, 27].

All these empirical studies established that cognitive processes in music performance are influenced by the sensory interaction between auditory and visual information [27], and visual information regarding the music performer's body movement consistently strengthens the performative ability of artistic expression. However, few studies mentioned which body motion affected specific audio parameters under the same musical express intention. Therefore, our pilot study attempted to understand how body movements that are restricted or modified in piano solo performance, but with a natural expressive intentions that may influence the audio parameters, in order to develop a audio-kinesthetic metrics in the future work.

3. METHOD

We recorded motion and audio data from six excerpts of piano works from romantic periods by Chopin, Liszt, and Brahms at different levels of difficulty.

3.1 Participant and material

3.1.1 Participant

The current pilot experiment only have one piano performer for analysis. The piano performer (male, 23 years old) is the author of this paper, has more than 15 years of training and stage performance experience on piano solo performance. He was familiar with and has mastered all the music excerpts in this experiment.

3.1.2 Music material

For the selection of excerpts, three pieces from three composers (F. Liszt, F. Chopin, J. Brahms) of the romantic period, a total of six excerpts were selected, according to the technical and interpretive difficulty of the music score, all excerpts were divided into three levels: advanced, middle-level, and easy.

- Hungarian Rhapsody No.2, S.244/2 - Franz Liszt
- Ballade No.1, Op.23 - Frédéric Chopin
- 6 Klavierstücke, Op.118 - Johannes Brahms

For the rest part of the paper, these excerpts will be marked as Liszt1 (middle-level), Liszt2 (advanced), Liszt3 (advanced), Chopin1 (easy), Chopin2 (middle-level), and Brahms1 (easy). The pianist performed each excerpt in each body movement condition (normal, deadpan, exaggerated) three times in order, and he can choose the performance tempo and expression that he found appropriate for each excerpt, but be as consistent as possible in different conditions. Normal is defined as the body movement required for normal performance, the performer does not deliberately change his body movement while performing. Deadpan is defined as using only the body movement necessary for the performance and reducing all expressive body movement as much as possible. Exaggerated is defined as an exaggerated expressive body movement condition, which increases the range of music-related physical activity as much as possible. All these three different performance conditions require the pianist to keep the artistic expression as similar as possible.

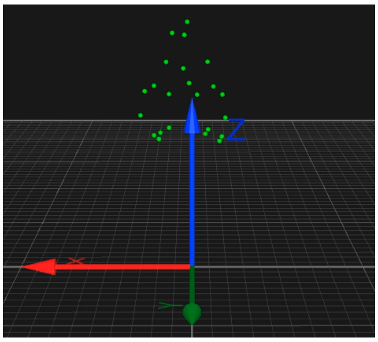

Figure 1. Recorded markers on Qualisys

3.2 Procedure

3.2.1 Measurements and Analysis

In the Motion Capture section, motion data were collected, at 120 frames per second, with an 8-camera Opti-Track Motion Capture system using 25 passive reflective markers (Figure 1) on the performer's upper body (heads, wrists, shoulders, torso, elbows, and arms)

To measure the movement of various body parts while performing, 21 of the 25 measurement points are used for analysis, the four points located at the waist were discarded because of incoherence and errors during the measurement. According to the position of the human body, these points are grouped into six parts: head, shoulders, elbows, wrists, arms, and torso. In the coordinate system, the X-axis indicates horizontal movement along with the keyboard, the Y-axis indicates movement perpendicular to the keyboard, and the Z-axis represents upward and downward movement of the body. All motion data were analyzed by a custom Python script with two main aspects: Quantity of Motion and motion velocity. We also calculated the cumulative data for each expressive body movement condition by body part, as well as the variance of the data for the different movement conditions (normal condition was treated as a reference point).

In the audio recording section, audio and MIDI files were recorded by a pair of AKG C414 microphones in AB Stereo format and MIDI output from YAMAHA electronic piano through Logic Pro X linked to SSL 2+ Audio Interface, sampled at 48 kHz, 24 bit. The audio files were analyzed with the Python Librosa toolkit [28], and normalized the duration in advance. Since the duration and sound recording amplifier level as well as the microphone position of the same excerpt were consistent. Therefore, by extracting the audio file duration and the RMS value of each audio file, an objective reflection of their average tempo and dynamics could be obtained.

4. RESULT AND DISCUSSION

Through audio feature extraction and motion capture data analysis, we analyzed duration, dynamics, motion velocity, and Quantity of Motion(QoM). The data for each excerpt in each condition was averaged from three repetitions of the performances. Additionally, for the data analysis, we

	Normal(s)	Deadpan(s)	Exaggerated(s)	De-deviation	Ex-deviation	Level
Brahms1	79.5	83.83	81.33	5 %	2 %	Easy
Chopin1	79.9	83.33	80.67	4 %	1 %	Easy
Chopin2	36.83	37.17	39.01	1 %	6 %	Middle-level
Liszt1	48.17	48.41	48.17	1 %	0 %	Middle-level
Liszt2	29.89	26.78	28.79	-10 %	-4 %	Advanced
Liszt3	30.91	29.23	30.96	-5 %	0 %	Advanced

Table 1. Average duration and deviation

calculated the arithmetic mean of the data in each condition and also the deviation in the exaggerated and deadpan states, where the deviation was calculated by taking the data in the normal state as the baseline and using the difference between conditions divided by the baseline data, and the results are marked in the following tables as 'De-deviation' and 'Ex-deviation' in percentages.

4.1 Duration

To measure how the pianists modified music tempo regarding the different level of expressive body movement, the duration and variance between three different conditions of each normalized excerpt were extracted, the results are shown in Table 1, the order of the table is arranged from easy to advanced. Through the data, we found that in excerpts with high difficulty level, the average tempo become faster with restricted body movement. In addition, the modified body movement made the easy level excerpts like Brahms1/Chopin1 slower than the normal version. From the deviation perspective (Table 1), compared with the two advanced level excerpts from Liszt, the body movement modifications rarely affect the duration in the two excerpts with the lowest difficulty factors, which are also the tend to be slow in music performance perspective. Furthermore, it seems that restricting body movement can affect the performance's duration more than exaggerating them. This pattern also matches the performer's subjective feeling: It is more difficult to control the performance by restricting body movement than exaggerating body movement.

4.2 Dynamics

The Root Means Square (RMS) indicates the average energy of the audio file, as all the files recorded in the same sound level, microphone position, and piano position, so comparing the average RMS for audio files between the different conditions gives an indication for the overall dynamic of the performance. Similarly, we extracted the RMS feature for each excerpt and calculated the average value of three times performances also the variance between different expressive body movement conditions. As the data states in Table 2, we found that in the two advanced excerpts, the dynamics were significantly reduced under the exaggerated condition. According to the performer's feedback, this is likely because the difficulty and the higher speed of the notes made hands span a lot, and the exaggerated body movement made the fingers touche shallower and the sound intensity becomes less. we hypothesize that this may be a sign of a lack of control of the fingers under exaggerated expressive body movement. On the other hand, In the excerpts with lower difficulty, RMS generally increased in the exaggerated condition. This may be due to the exaggerated expressive body movement affecting the expressiveness of the music. Moreover, from the RMS deviation, it appears that the exaggerated condition could affect more compared with the deadpan condition. Last but not least, In the high-level difficulty segments, the restriction of body movement did not seem to influence the average dynamics of the performance.

	Normal	Deadpan	Exaggerated	De-deviation	Ex-deviation	Level
Brahm1	0.0730423	0.0735019	0.0801834	1 %	10 %	Easy
Chopin1	0.0639395	0.0570978	0.0747326	-11 %	17 %	Easy
Chopin2	0.0707555	0.0644689	0.0720551	-9 %	2 %	Middle-level
Liszt1	0.0551501	0.0586513	0.0597626	6 %	8 %	Middle-level
Liszt2	0.0688623	0.0699486	0.0570865	2 %	-17 %	Advanced
Liszt3	0.0908191	0.0911494	0.0830875	0 %	-9 %	Advanced

Table 2. Average RMS and deviation

Brahms1	Whole Body (mm/s)	Head (mm/s)	Shoulder (mm/s)	Wrist (mm/s)	Elbow (mm/s)	Arm (mm/s)	Torso (mm/s)
Normal	110.17	181.85	88.59	122.37	105.19	80.20	77.17
Deadpan	73.58	97.43	44.57	111.88	74.05	51.67	37.98
Exaggerated	132.06	210.52	103.65	151.81	131.05	95.77	90.67
De-deviation	-33 %	-46 %	-50 %	-9 %	-30 %	-36 %	-51 %
Ex-deviation	20 %	16 %	17 %	24 %	25 %	19 %	17 %
Liszt3	Whole Body (mm/s)	Head (mm/s)	Shoulder (mm/s)	Wrist (mm/s)	Elbow (mm/s)	Arm (mm/s)	Torso (mm/s)
Normal	165.71	204.11	65.92	300.11	184.60	116.52	50.29
Deadpan	120.87	82.29	41.17	256.04	145.86	89.46	29.96
Exaggerated	208.85	326.79	92.13	333.27	227.61	148.55	71.24
De-deviation	-27 %	-60 %	-38 %	-15 %	-21 %	-23 %	-40 %
Ex-deviation	26 %	60 %	40 %	11 %	23 %	27 %	42 %

Table 3. Average motion velocity and deviation

4.3 Motion velocity

For the analysis of body movement velocity, we demonstrated the average data from Brahms1 and Liszt3, which have the highest and lowest difficulty levels, and the fastest and slowest tempo among all excerpts. We calculated the displacement distance of each measurement point from the body and divided it by the duration to get the velocity of body movement (Table 3). It appears that under the three movement conditions of all six excerpts, the average motion velocity of the head and wrist are the fastest, and the velocity of the torso is the slowest. Moreover, the velocity of the wrist is positively correlated with the tempo of the excerpt. From the overall trend, body motion velocity and expressive movement conditions are positively correlated, which conform to the design intention of the experiment.

When comparing the movement velocity deviation of three different conditions, we found there was a huge modification of the velocity of the head movement changes, which mainly contribute to the emotional expression of the performer [21]. On the other hand, there was less change in the wrist. We assume that the movement velocity of the wrist is mainly related to the difficulty, tempo, and structure of the music itself, and has less connection with expressive intention of body movement during the performance.

4.4 Quantity of Motion

By processing the motion data from Qualisys through Python, we obtained the Quantity of Motion (QoM) data through a custom Python script for each body part of Liszt3 and Brahms1, as well as the deviation under three different body movement conditions (Table 4). It illustrated

Brahms1	Whole Body	Head	Shoulder	Wrist	Elbow	Arm	Torso
Normal	74.26	13.95	13.44	9.75	11.33	12.78	13.01
Deadpan	68.76	12.92	12.49	9.03	10.49	11.72	12.11
Exaggerated	78.18	15.26	14.15	10.05	11.89	13.14	13.69
De-deviation	-7 %	-7 %	-7 %	-7 %	-8 %	-7 %	-7 %
Ex-deviation	5 %	9 %	5 %	3 %	3 %	4 %	5 %
Liszt3	Whole Body	Head	Shoulder	Wrist	Elbow	Arm	Torso
Normal	31.08	6.12	5.62	4.01	4.63	5.22	5.48
Deadpan	29.75	5.78	5.41	3.86	4.42	5.01	5.27
Exaggerated	32.35	6.27	5.87	4.19	4.87	5.43	5.72
De-deviation	-4 %	-6 %	-4 %	-3 %	-4 %	-4 %	-4 %
Ex-deviation	4 %	2 %	4 %	5 %	5 %	5 %	4 %

Table 4. Average QoM and deviation

that the exaggerated/restrained performance prominently expanded/reduced the total quantity of body movement. And we found that the amount of head and shoulder movement is the highest, while the wrist is the lowest. This pattern also has been also appeared in other excerpts, which is related to classic piano pedagogy, that is, strategic relaxation and stable of the wrist is vital to maintaining the high-efficiency performance [29]. As with the movement velocity, the average head movement was the highest in all six excerpts also the change was the most variable across the three conditions, followed closely by the shoulders and elbows. Meanwhile, through qualitative observation, we found that in the deadpan condition, the amount of head movement is significantly reduced. This may be because, from a kinematics point of view, even though the head movement has a strong expressive functionality [21], but the direct contribution of head movement to sound-producing activity is not obvious enough.

5. CONCLUSION

This paper focuses on the variation of expressive body movement and audio parameters in maintaining the consistent musical expressive intentions. As a pilot study, all these audio and motion capture data not only provide the basis for more comprehensive studies in the future, but also allow us draw the following tentative conclusions. it is not difficult to find that the modification of expressive body movement has a obvious impact on the sound of piano solo performance.

Through the analysis of audio, we propose that:

- Changes in expressive body movement affect the tempo and dynamics of the piano performance, which is related to the difficulty of the music, with the higher the difficulty factor the bigger the impact on the music.
- Compared to exaggerated expressive body movement, restricting expressive body movement will affect music performance more drastically.

The first conclusion partially coincides with the findings of Thompson and Luck [15], they likewise found rhythmic differences resulting from modified expressive body movement and suggested that deadpan states were usually played faster, while exaggerated condition were played slower.

From the analysis of expressive body movement, we can state following conclusion:

- The head, wrists move fastest during the piano performance, while the torso moves the slowest.
- The motion velocity and QoM of the head is greatly affected by playing under different conditions, while the wrists are hardly affected by restriction or exaggerated conditions.
- The difficulty of the music may have an impact on the expressive body movement in order to achieve a similar musical expression.

Similarly, although we can't find identical experiments in past studies, the data from our pilot experiment partially overlap with the findings of the Camurri et al. [18], Thompson and Luck [15], MacRitchie et al. [17], and Teixeira et al. [14], Massie-Laberge [26]. It is still worth mentioning that not all pianists use similar piano performance techniques and intentions to handle different musical expressions, variations are the outcome of individual interpretation, which can also vary greatly depending on the musician's cultural background as well as the genre of music [26].

6. FUTURE WORK

Admittedly, the current sample size does not allow us to draw statistically significant conclusions, but the pilot experiment has provided us with detailed practical experience for future experiments. For example, firstly, by setting up additional ground cameras could provide more comprehensive motion capture data with a higher signal-to-noise ratio. Secondly, restricting the movement of a specific body part could lead us to a more prominent relationship between audio and expressive body movement, also to develop the audio-kinesthetic metrics in the future. Last but not least, recruiting more pianists from different cultural backgrounds and increasing the number of music excerpts, could promote existing research also contribute to the piano pedagogy, helping piano performers to take purposeful control of their bodies and systematically predict the audience's reaction to the performance.

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