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Electrodermal activity of professional pianists -Sympathetic arousal in piano performance-

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Abstract

The purpose of this study is to research sympathetic arousal of professional pianists during musical performance. We measured the electrodermal activities of professional pianists who were performing both an original and an arranged score of the same piece of music by attaching electrodes to their left feet. For the data analysis, normalized skin resistance change per beat was used to analyze the electrodermal activities of the pianists originally. We could show a change in electrodermal activities at the onset of the music and at the motif of the music. Comparing the two performance conditions, we could show significant changes in electrodermal activity in dynamic arranged sections and octave up sections. The sympathetic arousal of the pianists changed dynamically in accordance with musical structure.

Keywords: electrodermal activity; sympathetic arousal; skin resistance; piano performance; analytical method

Introduction

In this study, we aimed to investigate the autonomic arousal of musical performers in accordance with music structure. Our hypothesis was that arousal of musicians change in accordance with some kinds of music structures in their performance dynamically. To verify the hypothesis, we measured the electrodermal activity (EDA) of professional pianists during performances of both an arranged score and an original one of the same music. Because there was no effective analytical method of EDA for music performance, we developed our original method, and estimated relationship between EDA and music structure. We also estimated a music arrangement of a famous musician in one case of music arrangement.

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EDA is a well-known method for investigating autonomic nervous activities. When the palm begins to sweat, it leads to sweat on the sole of the foot in situations of arousal. This physiological response is called "emotional sweating" due to rapid fluctuations in the eccrine sweat gland, which results from the release of acetylcholine by the sympathetic nervous system. This response can be measured using Ohm's law represented as "electrodermal activity" [1], [2].

EDA measurement is advantageous compared with other measures of the autonomic nervous system such as heart rate because EDA is under the strict control of the peripheral sympathetic nervous system [1]-[3]. Central brain regions in connection with EDA were investigated using f MRI [4], [5].

There are few studies on the physiology of music performance [6]-[11] compared to the physiology of music listening. Few studies have been done on EDA in music performance [12] compared with in music listening [13]-[18]. In one study that revealed event-related brain potentials (ERPs), EDA and heart rate (HR) were elicited by unexpected chords of original music [12].

However, these studies did not use natural performance conditions. In our study, we attempted to measure the electrodermal activity of the pianists in natural conditions. To achieve our goal, we developed an original method to analyze the EDA of music performers. We measured the electrodermal activity of professional pianists during performances of both an arranged score and an original one of "Pictures at an Exhibition," composed by Modest Mussorgsky (1839~81) to test the effectiveness of our analytical method, and to test effectiveness of music structure on pianists. We were able to confirm the effectiveness of our method and to determine that the electrodermal activities of pianists change dynamically in accordance with mental strain, motor activities and musical structure.

We also showed the physiological effect of the musical arrangement by Vladimir Horowitz (1904~89) on pianists.

Vladimir Horowitz was a famous pianist of the 20th century. He arranged "Pictures at an Exhibition," composed by Modest Mussorgsky, and Horowitz performed the arranged score at Carnegie Hall in 1951 [19], and the audience was fascinated with his arranged performance.

In this study, we could achieve to develop effective method of electrodermal activity measurement to investigate autonomic nervous system activity of music performer in accordance with music structure. And we showed arousal change of pianists in their music performance in accordance with music structures and performing condition.

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Materials and Method

Informed consent

The experimental procedures were fully explained to the subjects, and informed consent was obtained before starting the experiments. All subjects signed their name in experimental questionnaire paper after explanation of the experiment. The experimental procedures were reviewed and approved by the Institutional Review Board of Kobe University.

Subject

The subjects were seven physically healthy pianists (three men and four women). The subjects' ages ranged from 30- to 54-years old. Each had a career as a professional pianist of at least ten years.

Procedures

The experiment was conducted on July 2, 2003, and from April 11 to 18, 2004.

Each subject was asked to visit at the same piano lesson room on two different occasions, either in X University or in Y Women's University in Japan. Room temperature was set from 22 to 24 degrees Celsius.

After reporting to the room, each subject was asked to sit in front of the piano as investigators prepared to place the electrodes. The subject remained seating until the resting skin resistance level was stable before starting the experiment.

The subject performed "Pictures at an Exhibition, Promenade 1," composed by Modest Mussorgsky (1839~81)" 10 times per visit.

Two kinds of musical score

On the first visit, the original score was performed five times, followed five times by the arranged score (See Musical Score) by Vladimir Horowitz (1904~89). On the second visit, the performance order was reversed. Each pianist performed the two kinds of music ten times each at their tempo without a metronome in extremely natural conditions.

Because there was no published score of "Pictures at an Exhibition" arranged by Horowitz, we used a score that had been recorded by pianist Bando, who had repeatedly listened to a CD of "Pictures at an Exhibition" performed by Horowitz [19] (Score).

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Arranged score

For the dynamic arrangement, detailed instructions were given to perform mezzo forte (*mf*) with the right hand and to perform mezzo piano (*mp*) with the left hand. In the same section of the original score, no instructions were given besides to play forte (*f*) at the beginning and so on (See the red colored points in arrangement musical score).

Measurement

We used the GSR measurement system (GSR bridge box, Unique Medical, TOKYO) to measure skin resistance (SR). A pair of Ag-AgCl electrodes (1.0 cm in diameter) was attached on the dorsal side of the left foot and the ventral side of the big toe using paste and tape. The SR of each subject was recorded continuously in each performance. The signals were continuously digitized at 1000 Hz and stored on a computer hard disk. While recording SR, investigators marked all beats that indicated performance progression on the SR curve by listening in real time.

Data Analysis

The investigators marked all beats indicating progression of the performance on SR curves by listening to the performance directly (Figure.1). After each value of skin resistance (SR) measured by 1000Hz sampling frequency was converted to a 10Hz sampling frequency, it was stored in Excel. The values were marked by investigators to reflect each beat of music. Then, the marked values were collected and arranged in chronological order. As a result, we were able to obtain all skin resistance values throughout the entire performance.

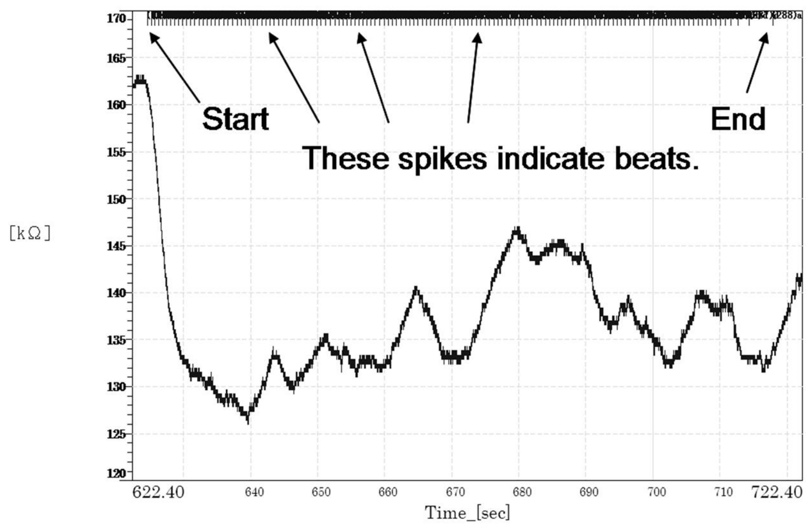

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Figure.1 Skin resistance change curve during a performance
Each spike represents one beat.
Horizontal axis: time (seconds). Vertical axis: Skin resistance (kΩ)

Next, the difference in the value of the adjacent SR marked beat was calculated to obtain the change in value of skin resistance per beat (Figure.2).

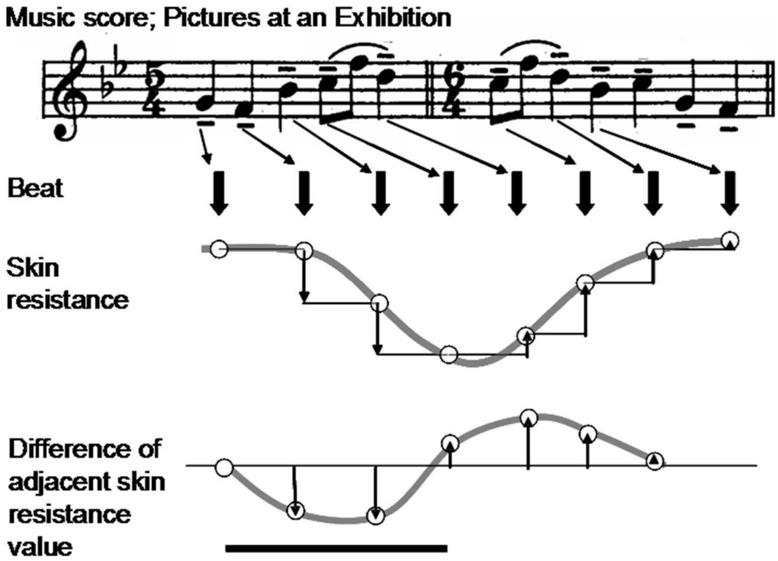

Figure.2 The difference in the value of adjacent skin resistance
The underlined region represents theoretical sweat gland activity. The difference in the value of adjacent skin resistance per beat was calculated to obtain the change in value of skin resistance per beat. The underlined region represents theoretical sweat gland activity.

Additionally, we normalized all values of SR change per beat in each performance to compare the change in SR between the original score performance and the arranged score performance. First, after calculating the difference of adjacent SR value per beat in a performance, we then calculated the standard deviation. Second, we divided the difference in each adjacent SR value by the standard deviation. Thus, we obtained the normalized change rate of SR per beat in each performance. We defined this value as the normalized skin resistance change rate (nSRCR). Third, we calculated the ensemble average of ten nSRCR curves in each performance both with the original score and with the arranged score for each subject. There were two reasons to calculate the ensemble average of nSRCR. The first reason was that the SR levels among the performances and the subjects were different; therefore, we could not compare both the SR value between performances by the same subject and those between subjects. The second reason was that nSRCR curves in the same type of performance were similar; therefore, we tried to clarify the general nSRCR pattern in the performance by omitting different detailed change patterns. Previously, investigations with EDA have not been accepted because EDA does not always correspond one-to-one with stimuli. We attempted to solve this problem using the ensemble average of ten nSRCR curves per beat in each performance. Fourth, we calculated the moving average of the ensemble average nSRCR curve by five beats to offset a seconds-long delay [3] of skin resistance response to stimuli. We defined this moving average of the ensemble nSRCR average as menSRCR (Figure.3).

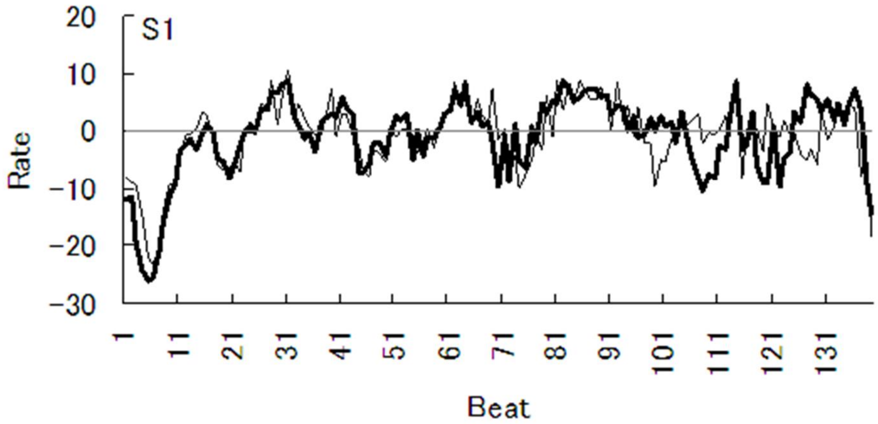

Figure.3 The ensemble average of ten change rate curves of skin resistance in one pianist
Horizontal axis: Beat. Vertical axis: Skin resistance change rate. The regular line indicates performance during the original score. The bold line indicates performance during the arranged score.

Using the method outlined above, menSRCR was calculated as one of the skin resistance response indexes in both performance conditions for each pianist (Figure.4). Negative the menSRCR values represented the activity of eccrine sweat glands decreasing skin resistance according to Ohm's law.

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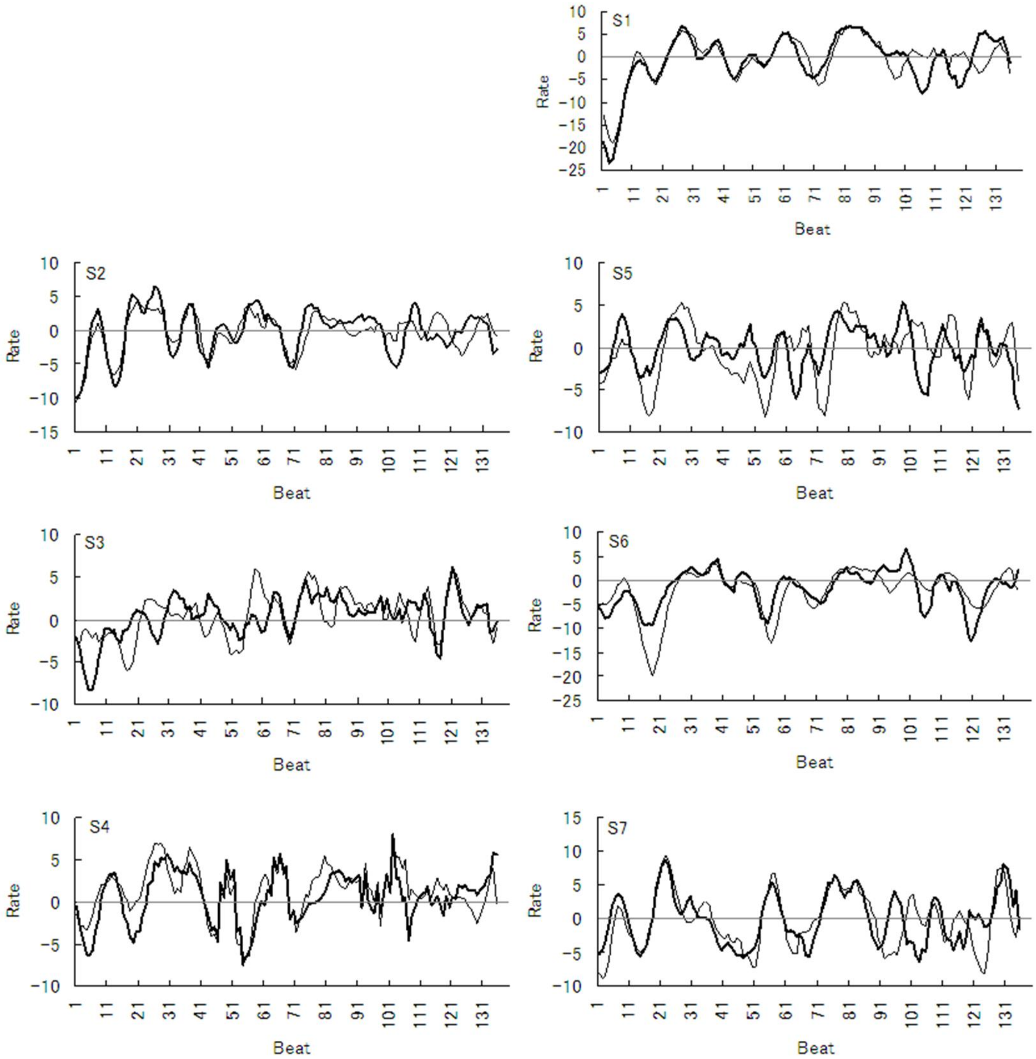

Figure.4 The moving average of the ensemble average curve of normalized skin resistance change rate by 5 beats.
(S1~S7 indicate subject number.)
Horizontal axis: Beat. Vertical axis: Skin resistance change rate.
The regular line indicates performance during the original score.
The bold line indicates performance during the arranged score.

Also, we calculated the average of the menSRCRs of seven pianists to identify the difference of menSRCRs between the original performance and the arranged performance, comparing the electrodermal activities of pianists during two types of performances. Statistical analysis using Wilcoxon rank test per beat was conducted to identify significant differences between the averages of menSRCRs in the two performances (Figure.5).

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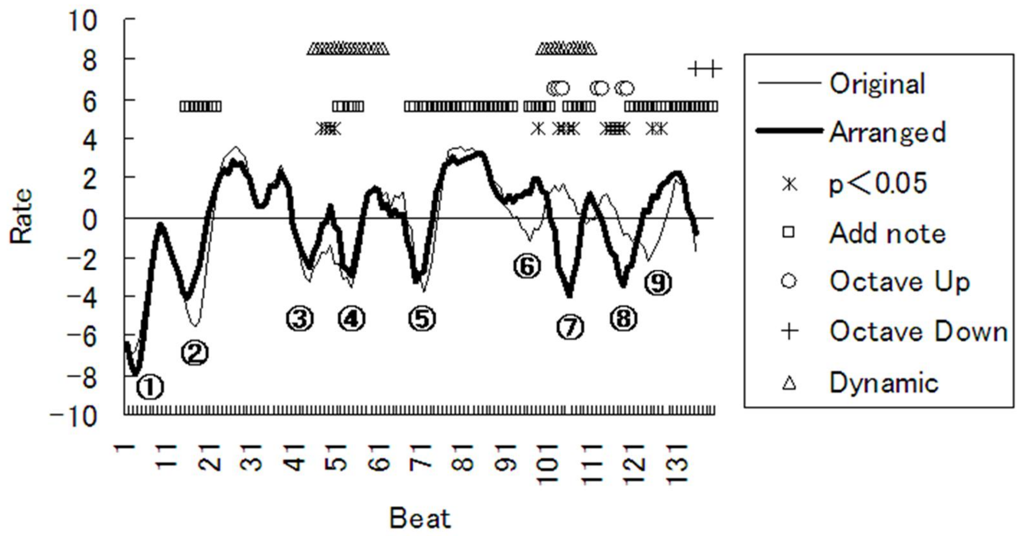


Figure.5 The average change in moving average of the ensemble average curve of normalized skin resistance change rate (menSRCR) of seven pianists in both performance conditions (arranged or original).
Horizontal axis: Beat. Vertical axis: Rate
The regular line indicates menSRCR of the seven pianists during the original performance.
The bold line indicates menSRCR of the seven pianists during the arranged performance. "*$p<0.05$" represents statistically significant points (Wilcoxon's rank test, $p<0.05$, N=7) comparing the two performing conditions (arranged performance and original performance).
"□Add note" represents where a musical note was added. "○ Octave Up" represents where the octave was raised. "＋Octave Down" represents where the octave was lowered. "△ Dynamic" represents a change in the dynamic mark.
Numbered 1~9 represents each curve's notable local minimum values of the average of menSRCR of the seven pianists.
These points represent notable areas of decreasing skin resistance.

Result

The average of the menSRCRs curves moving averages of the seven pianists in the two performance condition (original or arranged) are represented in Figure.5. Both curves show seven major decreasing sections. In the original performance, seven major menSRCR decreases (Figure.5: 1, 2, 3, 4, 5, 6, 9) were observed. In the arranged performance, seven major decreases in the menSRCR curve were found (Figure.5: 1, 2, 3, 4, 5, 7, 8).

Comparing the menSRCR curve in the original performance with that in the arranged performance, the first five major decreasing parts (1, 2, 3, 4, 5) overlapped. Phase reversal between 6 and 7 and phase lag between 8 and 9 can be observed in both performance curves in Figure.5. The greatest decrease was at the beginning of both performances (Figure.5:1). The decrease of this section was associated with the first appearance of the musical motif in both the original and arranged performances.

Statistical analysis using Wilcoxon's rank test per beat was conducted to identify significant differences between the averages of the menSRCRs in both performances. As a result, sixteen statistically significant ($p < 0.05$) differences in beats were found; i.e., the 47th, 48th, 49th, 50th, 98th, 103rd, 104th, 105th, 106th, 114th, 115th, 116th, 117th, 118th, 125th, and 127th beats (Figure.5). Between the 47th and the 50th beat, the menSRCR average of the original performance was smaller (EDA was higher) than that of the arranged performance. This section corresponded to the dynamic arrangement performance of the score by Horowitz.

At the 98th beat, the average original performance menSRCR was smaller (EDA was higher) than that of the arranged performance. At that beat, additional musical notes were added in the arrangement score. Also, the 98th beat is located right before the crescendo at the 99th beat.

Between the 103rd and 104th beat, the arranged performance menSRCR average was smaller (EDA was higher) than that of the original performance. In this section, the right hand goes up one octave while the left hand goes up two octaves. At the same time, the musical dynamic changes to forte (*f*).

Between the 105th and 106th beats, the arranged performance menSRCRs average was smaller (EDA was higher) than that of the original performance.

At the 105th beat, an additional musical note is added and the dynamic changes to piano (*p*) in the arrangement score. At the 106th beat, an additional musical note is added and the crescendo is performed at the same time in the arrangement score.

Between the 114th and 118th beats, the arranged performance menSRCRs average was smaller (EDA was higher) than that of the original performance. In this section, between the 112th and 120th beats), the right hand goes up one octave while the left hand goes up two octaves in the arrangement score.

Only the 118th beat completely corresponds to a going up octave arrangement beat. At the 125th and 127th beats, the original performance menSRCRs average was smaller (EDA was higher) than that of the arranged performance. In this section, an additional note was added in the arrangement score.

Discussion

Electrodermal Activities of Professional Pianists

Contrary to most assumptions, it is difficult to use measurements of the electrodermal activity of pianists under natural performance conditions to investigate physiological conditions. To analyze the data more easily, we marked all beats that indicate the progression of the performance on each skin resistance curve in each performance by listening to the performances. In data analysis, the constant time scale was replaced by beats and the fluctuation of time between beats. This fluctuation was not a problem for analyzing skin resistance responses because the skin resistance response is not very rapid [3]. The ohmic perturbation duration (OPD) index [20] is the preferred method to analyze skin resistance response elicited by monotonous stimuli; however, no efficient method for analyzing continuous skin resistance changes elicited by continuous stimuli as encountered in musical performance has been invented.

We invented a methodology to analyze the continuous change in skin resistance during musical performance and defined menSRCR as an index of electrodermal activity. Comparing the averages of seven pianists' menSRCRs of two kinds of performances, both curves overlapped in most parts of the music (Figure.5). This showed that the control experiment with this analytical method was valid. We strongly believe that the electrodermal activities of professional pianists are relatively regulated during their own performances.

Nakahara et al. examined autonomic and cardio-respiratory responses of 9 elite pianists during solo performances of the same musical piece. The study demonstrated that the expressive condition of playing music was associated with significantly higher levels of heart rate, sweating, minute ventilation, and tidal volume, and lower respiratory rate levels than the non-expressive condition. The research also showed no difference in oxygen consumption between these conditions. The researchers revealed that expressive performance clearly produces higher levels of valence and arousal than the non-expressive condition [21]. Our results were well supported by their results because the wave form of menSRCR and their sweating rates were very similar. We were able to show that menSRCR reflects emotional sympathetic arousal of pianists during their performance. We believe that menSRCR is a useful index for peripheral sympathetic nervous activity of musicians during their performances.

The Effects of the Music Arrangements on Pianists

The menSRCR average of 7 pianists performing the original score and the arranged score was calculated to investigate the effect of a musical arrangement by Horowitz on the electrodermal activity of performers in general (Figure.5). Especially in the opening, in motif sections (Figure.5, Score: 1), in repetition of the motif (Figure.5, Score: 2), and in partial developmental sections of the motif (Figure.5, Score: 3, 4, 5), the decrease in menSRCR became larger compared to other sections. We showed the difference in menSRCR in parts of arrangement such as dynamic change (Figure.5, Score: 3, 4, 6, 7), going up an octave (Figure.5, Score: 6, 7), and adding a musical note (Figure.5, Score: 6, 7, 9). The arrangements that reflected a decrease in menSRCR were a dynamic change and going up an octave. Regarding dynamic change, the decrease in menSRCR in both arrangement sections when making soft sound (*p*) and when increasing sound indicated that concentration on performing a dynamic change had more of an impact on EDA than making a louder sound with an aggressive kinetic movement. In fact, performing softly with a piano (*p*) is very difficult in musical expression. Adding a musical note was not critical to decreasing the menSRCR because there was no relationship in menSRCR between the shape of the curve and the addition of a musical note.

Unfortunately, there is no study that was performed under the same conditions to compare our results with. However, there was one study that investigated physiological responses in pianists who performed unexpected musical chords. This study revealed that event-related brain potentials (ERPs), EDA (skin conductance responses: SCRs) and heart rate (HR) were activated by unexpected chords of original music (homemade music) performance [12]. Considering the decrease in menSRCRs in sections with dynamic changes and when the octave was raised from an aspect of unexpected sound performance, it is no surprise that unfamiliar arranged sounds elicited EDA in the pianists because six pianists out of seven of them had never performed the arranged score by Horowitz. However, comparing relative major decrease of menSRCRs of 1, 2 and 5 with 3, 4, 6 and 7 in Figure.5, we were able to observe that the degree of decrease in menSRCR during the arranged section was not larger than that of the unarranged section. The largest decrease in menSRCR section 1 was located at the section of the first motif described as the lead of the music (See Musical Score). The decreasing section in menSRCR 2 was the repetition of the first motif section in the score (Score). Those of 3, 4 and5 were the second motif-like sections in the score (Score). Those of 7 and 8 included the first motif structure in the score and the final motif in the score. Performances of motif structures in the music were especially effective in lowering menSRCR.

In conclusion, decreases in menSRCR (elicitation of EDA) of pianists are elicited by emotional change and arousal in their performances. Most importantly, the effects on EDA were strongly related to sympathetic arousal in initial kinetic movement and stress at the beginning of the performance, during the motif and motif development-like structures, in dynamic change, and in going up an octave, when the performer required more arousal and concentration (See Table1).

Table1. Major continuous decreases in the menSRCR average of the seven pianists and the relationship between the menSRCR and electrodermal activity (EDA), comparing the original and the arranged performance condition.

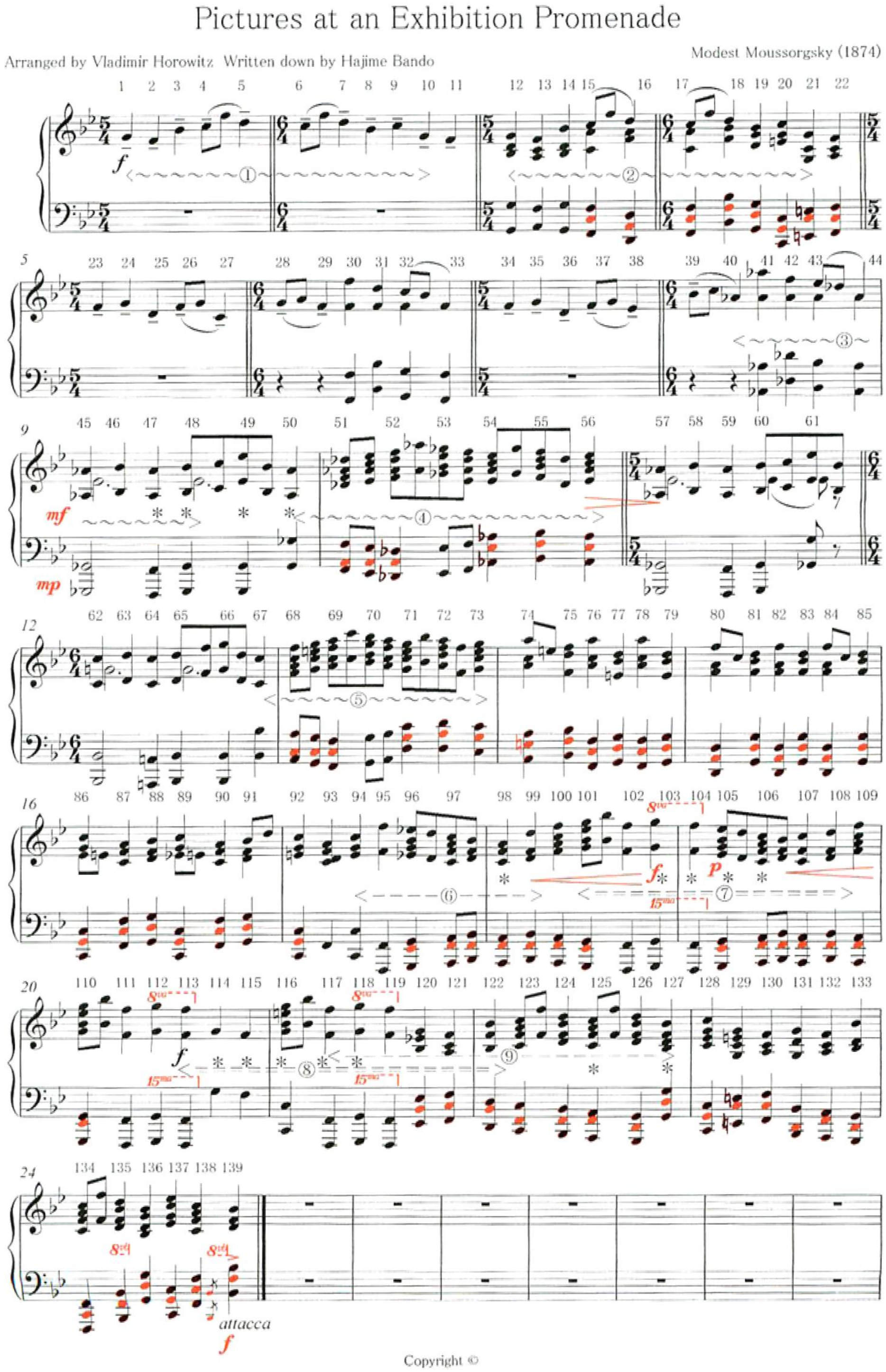
menSRCR decrease	Beat	Original	Arranged	Statistically significant beat	Arrangement	EDA
①	1～10	○	○	N.S.	− (Start, Theme)	O≒A
②	12～21	○	○	N.S.	Add note	O≒A
③	40～48(49)	○	○	47,48,(49)	Dynamic	O>A
④	50～56	○	○	50	Dynamic, Add note	O>A
⑤	67～73	○	○	N.S.	Add note	O≒A
⑥	94～99	○		98	Add note	O>A
⑦	101～108		○	103,104,105,106	Octave Up, Dynamic, Add note	O<A
⑧	113～122		○	114,115,116,117,118	Octave Up, Dynamic	O<A
⑨	117～127	○		125,127	Add note	O>A

Number 1～9: Major continuous decrease in the menSRCR average of the seven pianists in both original and arranged performances (Figure.2).
Beat: Musical sections (Beat) correspond to numbers 1～9.
Original: ○ indicates the presence of a major continuous decrease in the menSRCR average during the original performance.
Arranged: ○ indicates the presence of a major continuous decrease in the menSRCR average during the arranged performance.
Arrangement:
− (Start, Motif): There is no arrangement. This section represents the start of music and the first appearance of the motif in both kinds of performances.
Dynamic: Change in loudness.
Add note: Addition of a musical note.
Octave Up: Raising an octave.
Significant different beat: Beats that indicate a statistical difference in the menSRCR average between the original and the arranged performance according to Wilcoxon's rank test ($p<0.05$).
N.S. indicates no statistical significance.
EDA; O≒A: Electrodermal activity in both the original (O) and the arranged (A) performance is equivalent.
O＞A: Electrodermal activity in the original (O) performance is higher than that of the arranged (A) performance.
O<A: Electrodermal activity in the arranged (A) performance is higher than that of the original (O) performance.
*(49): In the 49th beat of the original performance, a major continuous decrease in the menSRCR average was observed that did not occur in the arranged performance.

Effect of arrangement of "Pictures at an Exhibition Promenade1"by Horowitz

Our results suggest that the arrangement of "Pictures at an Exhibition Promenade 1" by Horowitz changed the peripheral sympathetic nervous activity of pianists. In addition, Horowitz's arrangement evoked elicitations of EDA twice before the last motif-like section (Figure.5, Table 1, Musical Score: 7, 8). We think the arrangement contributes to eliciting higher emotional arousal by the music performer especially in the last half of the music compared with the original one.

Musical Score



Arranged score of Modest Moussorgsky's 'Pictures at an Exhibition Promenade 1' by Vladimir Horowitz (Scored by a pianist)

Number 1〜9 in musical score (Score) correspond to 1〜9 in Figure.5.

Small number 1~139 indicate beat.

~ ~Number~ ~: Wave ray of 1, 2, 3, 4, 5 indicate major continuous decreases in the menSRCR average in both the original and arranged performance condition.

- - Number- -: Single dash lines 6 and 9 indicate continuous decreases in the menSRCR average only in the original performance condition.

= =Number= =: Double dash lines 7 and 8 indicate continuous decreases in the menSRCR average only in the arranged performance condition.

* indicates statistically significant beat in comparison between menSRCRs between in original and arranged performance (See Figure. 5).

(This music was scored using the software Sibelius 4)

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