Co-Creative Communication in Musical Performance

Tomohito YAMAMOTO and Yoshihiro MIYAKE

Computational Intelligence and System Science,
Dept. of Interdisciplinary Graduate School of Science and Engineering,
Tokyo Institute of Technology
Yokohama, Japan
tyama@myk.dis.titech.ac.jp, miyake@dis.titech.ac.jp

Abstract

There is a communication between players in a musical cooperative performance, and players create relationship or new musical expression with the communication. Such the communication is called "Co-creation" and has been analyzed. The object of this study is to analyze co-creative communication of musical performance and establish a design principle of co-creative communication system between human and artificial agents. The experiment results were that (a) where musical difficulty is high, musical rhythms did not relatively synchronize, however respiration rhythms relatively synchronized, (b) there was a musical interaction between players, and new music tempo pattern emerged, (c) where musical difficulty is high, musical rhythm coupled with respiration rhythm strongly. To interpret these results, we hypothesize that players pay more attention in difficult music part, and propose the new musical communication model, and discuss the design principle of co-creative communication system.

1. Introduction

Human creativity often emerges through communication or collaboration. For example, new good ideas or artistic masterpiece emerge through them. We call such a phenomenon "Co-creation" and have been analyzing it to develop a new man-machine interface [1]-[3]. One typical case in which such a phenomenon is observed is a musical cooperative performance. In a jazz session or orchestra, players develop relationship or new musical expression with the communication. To analyze this communication is helpful not only for understanding the mechanism of musical creativity but also for developing man-machine systems such as an ensemble system [4][5]. Until now, such the communication has been analyzed from two aspects. One is from musical aspect, and the other is from physiological aspect. However, these two aspects have not been analyzed at the same time.

From musical aspect of a cooperative performance, R.A.Rasch [6] analyzed the synchronicity of performance between players when they make a sound at the same time. It revealed that there were 30-50ms of time difference between players. Y.Horiuchi [4] analyzed that how player synchronize with the other in a cooperative performance. It suggested that there was a cross correlation between time lag between a computer and a human performer and the change of duration played by the player. Y.Kobayashi [5] proposed the new ensemble system based on the mutual entrainment of musical rhythm, and suggested that could play music with human.

From physiological aspect of a live performance, I.Koura [7] analyzed the synchronization of respiration between players in playing the guitar. This research suggested that when difficult music is played or armatures play music, respiration rhythms were likely to synchronize. Y.Nakamura [8] analyzed the respiration of a singer and an accompaniment, and suggested that both respiration rhythms synchronized at long pose. We have been investigated the interaction between a player and a listener in a live performance [9][10] and suggested that there was a mutual entrainment between player's music rhythm and listener's respiration rhythm.

The purpose of this research is to investigate the mechanism of the musical communication between players by measuring musical and physiological aspect of a cooperative performance at the same time. From results, we will propose musical communication model for developing man-machine systems.

2. Method

2.1 Experiment procedure

The players were 3 students who had 15 years experience of playing the piano (Male, 20-28). The music used for experiment was SONATA (Composed by R.Beethoven, Op.49, No.2, 122bars).

Experiment procedure is that at first each player played the music five times alone, and next, 2 players played the music five times together. In this experiment, musical performance and respiration were measured as same way as the previous research [9]. From measured data of performance, we used 1-bar period (the time difference between the first note of a bar and the first note of a next bar) and phase difference of 1-bar rhythm between players (the time difference between each players' the first note of a bar) as indices of musical aspect. From measured data of respiration, we used respiration period (the time difference be-

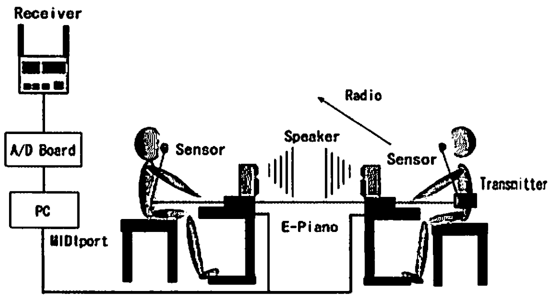


Figure 1. Measuring system of a cooperative performance

tween two high peaks of respiration wave) and respiration phase difference between players (the time difference between high peaks of 2 players) as indices of physiological aspect.

2.2 Experiment system

Fig.1 shows experiment system. Musical performances were performed with the electrical piano (Roland: RD-600). Sound was presented by the speaker (ONKYO: GX-R3). There are 2.7m between players. Performances were recorded by the MIDI sequencer (emagic: Logic Audio platinum Ver.3.5). Respiration of players were measured by an attached thermistor sensor (NIHON KODEN:TR-511G) at nasal cavity (Therefore singing or humming was restricted). Measured data were sent to receiver (NIHON KODEN:WEB-5000) from transmitter (NIHON KODEN ame:XB-581), and those were sent to PC (Intel Pentium III 1GHz) through A/D converter (ADTEK:AXP-AD02) with 256Hz sampling rate and 12bit resolution. Measurement accuracy of performance is 0.04sec, and that of respiration is 0.01sec.

3. Results

3.1 Inter-personal relation between musical aspect and physiological aspect

In this subsection, inter-personal relation between musical aspect and physiological aspect of a cooperative performance are analyzed with phase difference of 1-bar and respiration rhythm.

Fig.2a-c show the 1st and 5th time course of 1-bar period when Player_1-3 played alone. Fig.3a-c show the time course of respiration period corresponding to Fig.2a-c.

Fig.4a shows the time course of 1-bar period of a cooperative performance of Player_1 and Player_2. Fig.4b shows of Player_2 and Player_3, Fig.4c shows of Player_1 and Player_3. Fig.5a-c show the time course of respiration period corresponding to Fig.4a-c.

To investigate the synchronicity of musical aspect, phase difference of 1-bar rhythm is analyzed. Fig.6a-c show the time course of the phase difference of a cooperative performance shown in Fig.4a-c. Solid line of Fig.8 shows the mean phase difference that was calculated from all cases (15 cases) of absolute value in each 5 bars. In this figure, if the value is low, synchronicity is high. In Fig.8 there is significant difference between each bar position (Kruskal-Wallis ANOVA; H=37.135, $p<0.05$), therefore there is each synchronicity in each bar position. As a reason of the difference of synchronicity, we focus on the difficulty of music score. To estimate the difficulty of music score, we use the proposed method [14]. This estimation method is only for right hand part, however we apply it to left hand part, and regulate each value, and sum them up. Thick solid line of Fig.8 shows the time course of the difficulty of music score.

The cross correlation between the time course of synchronicity and that of the difficulty of music score is 0.384. The value is not so high, however there is a positive correlation. This result means that where music difficulty is high, performances do not synchronize.

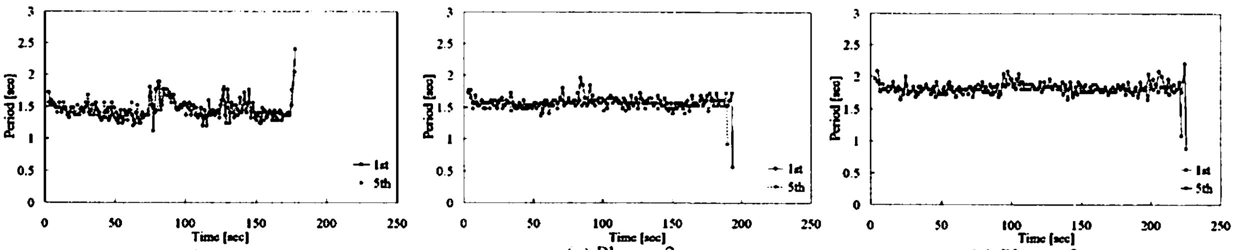
Next, to investigate the synchronicity of physiological aspect, phase difference of respiration rhythm is analyzed. Fig.7a-c show the time course of the phase difference of cooperative performances shown in Fig.5a-c. Solid line of Fig.13 shows the mean variance of respiration phase difference that was calculated from all cases (15 cases) of variance value through corresponding 5 bars. In this figure, if the value is low, synchronicity is high (The reason why mean variance are used to estimate synchronization is that respiration wave peaks of players do not have 1 to 1 correspondence.). In Fig.9, there is significant difference between each bar position (Kruskal-Wallis ANOVA; H=33.792, $p<0.1$, $p=0.0618$), therefore there is each synchronicity in each bar position. The cross correlation between the time course of synchronicity of respiration and that of the difficulty of music score is -0.425, and there is a negative correlation. This result means that where music difficulty is high, respiration rhythms are likely to synchronize.

These results suggest that synchronicity of musical aspect and that of physiological are opposite property.

3.2 Relation between players in musical aspect

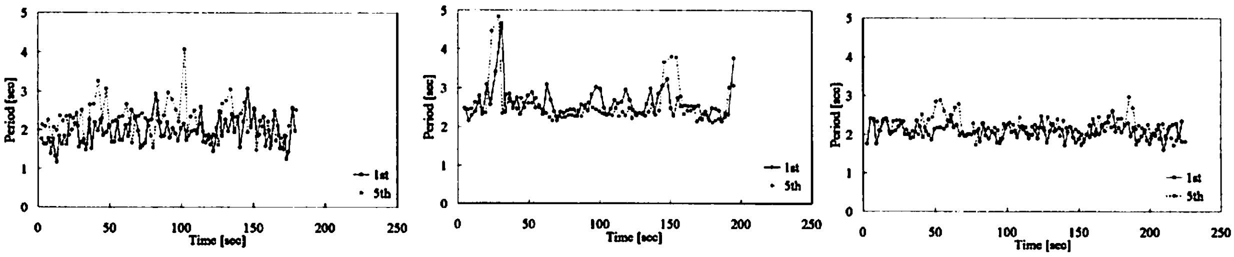
In this subsection, musical aspect of a cooperative performance is analyzed with the time course of 1-bar period.

Table 1a show the cross correlation between Player_1's time course of 1bar period and Player_2's time course of 1-bar period. Table 1b show between Player_2's and Player_3's, and Table 1c show between Player_1's and Player_3's. The cross correlation is calculated from 120 bars of 122 bars. "Alone" line of the 2nd row in Table 1a-c (Player_1-Player_2, Player_2-Player_3, Player_1-Player_3 row) shows the cross correlation between 5th performances in playing alone (For example, in Table 1a, the cross correlation between 5th of Fig2a and 5th of Fig2b). "1st-5th" line of 2nd row in all tables shows the cross correlation in cooperative performances. "Alone" line of 3rd and 4th row



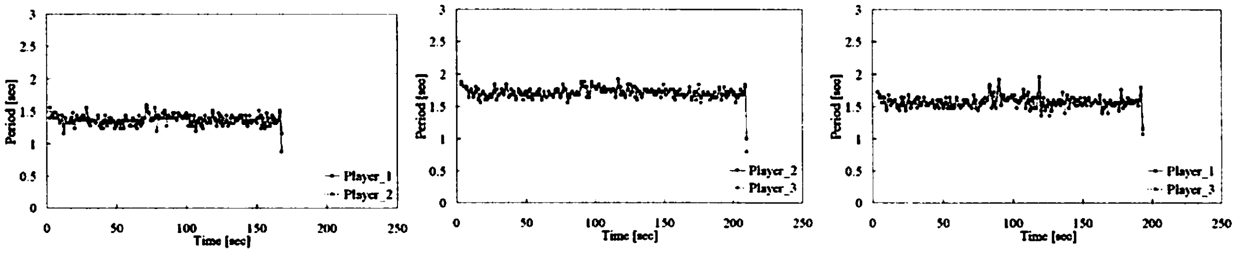
(a) Player_1 (a) Player_2 (a) Player_3

Figure 2. Time course of 1-bar period of playing alone



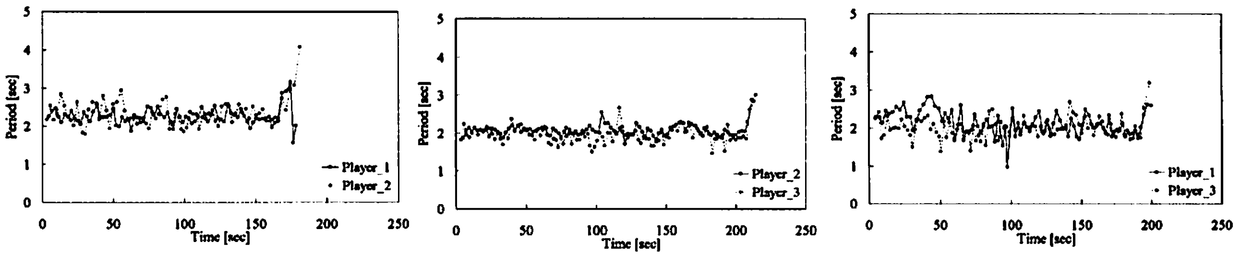
(a) Player_1 (a) Player_2 (a) Player_3

Figure 3. Time course of respiration period of playing alone



(a) Player_1 and Player_2 (a) Player_2 and Player_3 (a) Player_1 and Player_3

Figure 4. Time course of 1-bar period of a cooperative performance



(a) Player_1 and Player_2 (a) Player_2 and Player_3 (a) Player_1 and Player_3

Figure 5. Time course of respiration period of a cooperative performance

Table 1 Correlation cofficient between 1-bar periods

(a) Player_1 and Player_2

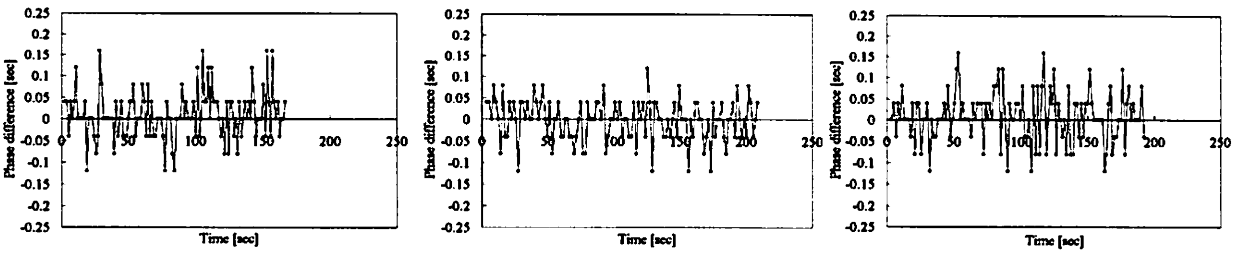
	Player_1-Player_2	Player_1-Player_1	Player_2-Player_2
Alone	0.345	0.711	0.571
1st	0.430	0.542	0.405
2nd	0.421	0.533	0.330
3rd	0.346	0.399	0.422
4th	0.433	0.441	0.431
5th	0.392	0.420	0.417

(a) Player_2 and Player_3

	Player_2-Player_3	Player_2-Player_2	Player_3-Player_3
Alone	0.327	0.571	0.486
1st	0.639	0.378	0.366
2nd	0.894	0.423	0.307
3rd	0.805	0.471	0.373
4th	0.930	0.360	0.407
5th	0.791	0.476	0.378

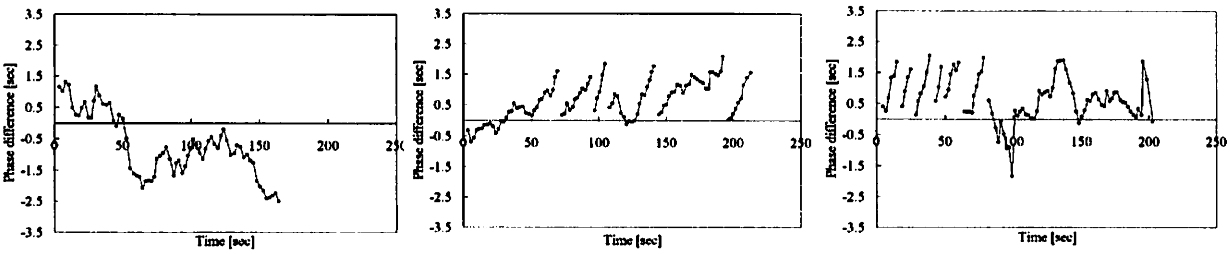
(a) Player_1 and Player_3

	Player_1-Player_3	Player_1-Player_1	Player_3-Player_3
Alone	0.318	0.711	0.486
1st	0.478	0.463	0.321
2nd	0.598	0.483	0.481
3rd	0.500	0.420	0.355
4th	0.736	0.514	0.401
5th	0.513	0.500	0.427



(a) Player_1 and Player_2 (a) Player_2 and Player_3 (a) Player_1 and Player_3

Figure 6. Time course of phase difference of 1-bar period



(a) Player_1 and Player_2 (a) Player_2 and Player_3 (a) Player_1 and Player_3

Figure 7. Time course of phase difference of respiration period

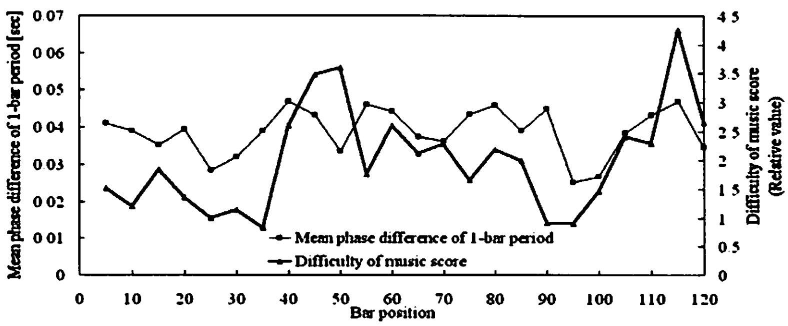


Figure 8. Time course of mean phase difference of 1-bar period and difficulty of music score

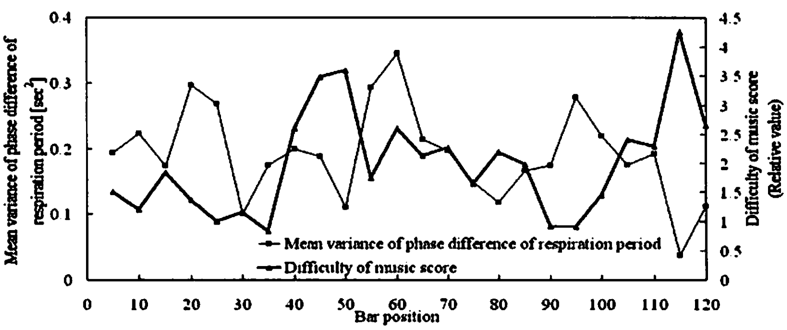


Figure 9. Time course of mean variance of phase difference of respiration period and difficulty of music score

(Player_1-Player_1, Player_2-Player_2, Player_3-Player_3) in all tables show the cross correlation between 1st performance and 5th performance in playing alone. "1st-5th" line of 3rd and 4th row in all tables shows the cross correlation between 5th performance in playing alone and each cooperative performance.

In the 2nd row of all tables, comparing the value of "Alone" line to that of "1st-5th" line, the value of "Alone" is smaller than that of "1st-5th" line. In the 3rd and 4th row of all tables, comparing the value of "Alone" line to that of "1st-5th" line, the value of "Alone" is bigger than that of "1st-5th" line. That is to say, in each player, the time course pattern changed from playing alone to a cooperative performance, and between players, the time course pattern of

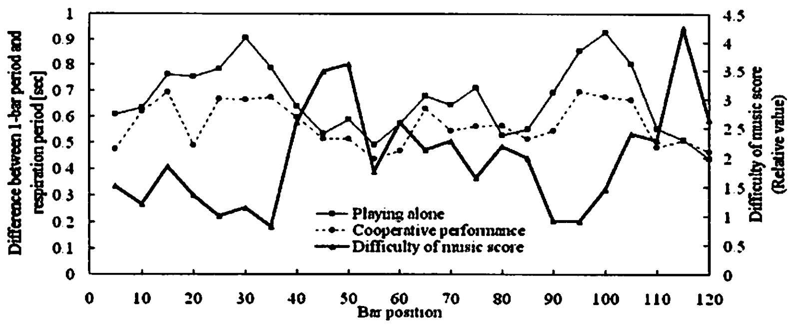


Figure 10. Time course of difference between 1-bar period and respiration period and difficulty of music score

cooperative performances more resemble than that of playing alone.

These results suggested that there is a musical interaction between players, and as a result, the new time course pattern emerged between them.

3.3 Intra-personal relation between musical aspect and physiological aspect

In this subsection, intra-personal relation between musical aspect and physiological aspect is analyzed with the difference between 1-bar and respiration period.

Solid line of Fig.10 shows the time course of mean difference between 1-bar period and respiration period playing alone. The value was calculated with a few steps. Firstly, mean 1-bar period through 5 bars and corresponding mean respiration period were calculated. Secondly, the subtraction was done between mean 1-bar period and mean respiration period. Thirdly, mean difference value was calculated from all data (15 cases).

Dotted line of Fig.10 shows the time course of mean difference between 1-bar period and respiration period of a cooperative performance. The mean difference was calculated from 30 cases.

There is significant difference between each bar positions in all time courses (Kruskal-Wallis ANOVA: $H=47082$ (Solid line), 50.875 (Dotted line), $p<0.005$), therefore there is each difference in each bar position. In Fig.10, the time course of playing alone resembles that of a cooperative performance (The cross correlation between time courses is 0.818.). This result means that the mean difference between 1-bar period and respiration period is affected by the common property in a cooperative performance and playing alone, and that is guessed to be the score information.

The score information that affects respiration is supposed to be the rhythm information. However, if there is the entrainment with the 1 to 1 ratio between music rhythm and respiration rhythm, the difference between 1-bar period and respiration period is stable. In subsection 3.1, we used the difficulty of music, and again, we focus on it as score information. The cross correlation between the time course of the mean difference in playing alone and the time course of the difficulty of music is -0.617. The cross correlation of a cooperative performance is -0.460. There is negative correlation between them. These results mean that where the difficulty of music score is high, the difference between 1-bar period and respiration is small, and where the difficulty of music score is low, the difference between 1-bar period and respiration is big.

These results suggest that the relation between musical aspect and physiological aspect was changed by the effect of music.

4. Discussion

The summary of results is as follows: in subsection 3.1, where music difficulty is high, performances do not synchronize, however respiration rhythms are likely to synchronize. Conversely, where music difficulty is low performances synchronize, however respiration rhythms are not likely to synchronize. In subsection 3.2, there is musical interaction between players, and the new tempo pattern emerged between them. In subsection 3.3, where the difficulty of music score is high, the difference between musical aspect and physiological aspect became small, and where the difficulty of music score is low, the difference between musical aspect and physiological aspect became big.

To interpret these results, we hypothesize that where the difficulty of music score is high, players have to pay attention to music, and where the difficulty of music score is low, players do not have to pay attention to music so much.

With this hypothesis and the communication model between players shown in Fig.11, the results are interpreted as follows; whether the difficulty of music score is high or low, there is musical interaction between players, and new musical tempo pattern is emerged by the interaction. Some researches [7][9] showed that there was a correlation between musical rhythm and respiration rhythm, therefore it is suggested that musical aspect is coupling to physiological aspect. Where the difficulty of music score is high and players have to pay attention to music, the synchronicity of music become low. However the coupling between musi-

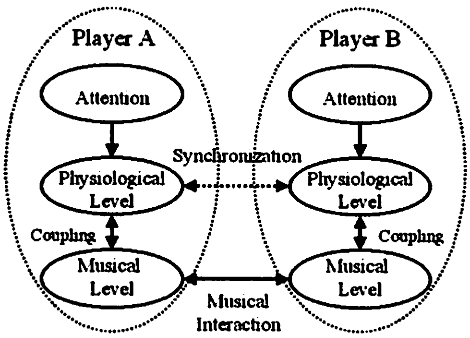


Figure 11. Communication model of a musical cooperative performance

cal aspect and physiological aspect become strong, and respiration rhythms of players who play same musical tempo synchronize. Conversely, where the difficulty of music score is low and players do not have to pay attention to music so much, the synchronicity of music become high. However the coupling between musical aspect and physiological aspect become weak, respiration rhythms of players do not synchronize.

Based on this model, the results of I.Koura's and T.Nakamura's researches are interpreted as follows: when difficult music is played, or when armature play music, or at long pose part, players have to pay more attention. As a result, the coupling between musical aspect and physiological aspect become strong, and respiration rhythms were likely to synchronize.

As this research shows, musical aspect and physiological aspect have a relation. Here, we correspond musical aspect to verbal or symbolic aspect of communication, and physiological aspect to nonverbal or embodied aspect of communication. When we consider or develop the communication system between human and artificial agents, we tend to focus on only verbal or symbolic aspect of communication. As a result, trivial discommunication often occurs. Moreover, although we consider nonverbal or embodied aspect, if we do not consider the relation between verbal or symbolic aspect and nonverbal or embodied aspect, we deal with only primitive communication. To realize true communication between human and artificial agent, we have to consider both aspects of communication and also consider their dynamics.

5. Conclusion

In this paper, we measured the musical level and physiological level of a cooperative performance at the same time, and analyzed the communication between players. The results showed that (a) where music difficulty is high, performances do not synchronize, however, respiration rhythms are likely to synchronize. Conversely, where music difficulty is low performances synchronize, however respiration rhythms are not likely to synchronize, (b) there is musical interaction between players, the new tempo pattern emerged between them, (c) where the difficulty of music score is high, the difference between musical aspect and physiological aspect became small, and where the difficulty of music score is low, the difference between musical aspect and physiological aspect became big.

To interpret these results, we hypothesize that players pay more attention in difficult music part, and propose the new communication model that consist of musical level, physiological level and attention level. In the future works, we will investigate the relation between the mechanism of respiration and cognitive mechanism of music in dynamics level, and will develop a fine model.

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