Hierarchical interaction in musical ensemble: Temporal development of bar period and respiration rhythm

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Abstract – **In recent years, music therapy is focused on as a method to care patient who have physical or mental diseases. Music therapy is a kind of musical communication between patient and therapist. To clarify a cognitive mechanism of the musical communication is effective to do this kind of therapy more efficiently. In this research, to clarify the cognitive mechanism of the communication, a cooperative performance was analyzed with temporal musical and respiration rhythms and a dual task method. As a result, there was no effect of a sub-task on musical and respiration rhythms in playing easy music, however in playing difficult music, musical and respiration rhythms were changed by a sub-task. From these results, a hierarchal communication model of a musical performance was proposed.**
Keywords – **Communication, music, cognitive system, respiration**

I Introduction

In recent years, music therapy is focused on as a method to care patient who have physical or metal diseases. Music therapy is a kind of interaction between patient and a therapist. For example, in improvisational music therapy, patient moves body synchronizing the sound, and at the same time, therapist makes sound synchronizing patient movement. This interaction is regarded as musical communication. Although effectiveness of such therapy often is reported, the cognitive mechanism of musical communication is not analyzed enough. To clarify the cognitive mechanism of it is effective to do such kind of therapy more efficiently. In this research, we clarify the cognitive mechanism analyzing interaction between players in a musical performance. Based on the result, we propose a musical communication model of a cooperative performance.

There are two kinds of musical performances. One is a solo performance, and the other is a cooperative performance. Although there is a lot of research about a solo musical performance, there is little research concerning a cooperative performance. One of a few examples of the research about cooperative performances is an analysis of musical synchronization between players [1]. The research revealed that a player of melody part precedes the ones who take other musical parts by 10msec and that there is always 30-50msec desynchronization when the players make sounds at the same time.

The research which clarifies the mechanism of a solo musical performance analyzes the musical tempo (speed of musical performance). ago-gigs (temporal development of musical rhythm) and so on. Of these elements, ago-gigs has most often been analyzed. The representative research about ago-gigs illustrates that ago-gigs is not changed when the players play the same music [2][3], and players use more ago-gigs as a musical expression than the other musical technique [4].

In addition to such research, there are some research which investigates player's physiological aspects clarifying cognitive system of players [5]. In this research, the relationship between 1-bar rhythm and respiration rhythm is analyzed when players play the same music in different music meter. The results showed that the players' respiration period in performance is shorter than that in normal, and the coupling between 1-bar and respiration rhythm playing in a difficult meter of 7/4 and 5/4 is stronger than that of playing in an easy meter of 3/4 and 4/4. Including this research, the relationship between respiration and music has often been analyzed [6][7]. Such research shows that human respiration was changed by listening to music, and the difference depends on musical rhythm. It seems that respiration has no relation to musical perceptions. However, the fact that the respiration changes depending on musical rhythm suggests that respiration influences musical cognitive system, which is an effective element to analyze.

A summary of these researches is as follows: a temporal development of musical rhythm is an important element for an analysis of musical performance, and it has relation to respiration rhythm. As for musical communication between players, only synchronization of musical cooperative performance was analyzed. Therefore, in this research, we analyze an interaction of a cooperative performance with a temporal development of musical and respiration rhythm, and we clarify cognitive mechanism of the interaction. Moreover, we investigate the cognitive aspect of players' interaction in cooperative performance by using a dual task method. With the results of these analyses, we propose a musical communication model of a cooperative performance.

II Method

A. Task and subjects

The task of this experiment was that two players play the same music with two electric pianos at the same time face to face. Subjects were three graduate students (24-31) who had at least 12 years experiences of playing the piano. The music for the experiment was Music A and Music B shown in Fig.1a, 1b. Music A was composed with only quarter notes. Music B was composed with 8th notes and 16th notes. Music B was more difficult to play than Music A because it needed fast finger moving to express fast pitch change.

In this experiment, players repeated the music 7 times (28 bars). Two experimental conditions were prepared. One was a normal condition (N condition) in which players play music normally. Another condition was a dual task condition (D-condition) in which players play music with performing word-memory task.

The dual task method was that subjects have to perform a main-task (playing the piano) and a sub-task at the same time. If subjects

(a) Music A

(b) Music B

Fig. 1 Music for the experiment

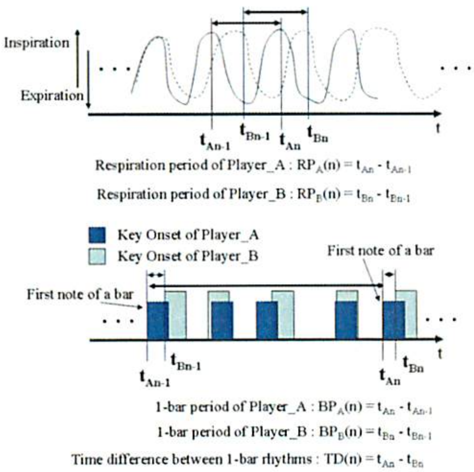


Fig. 2 Indices for analysis

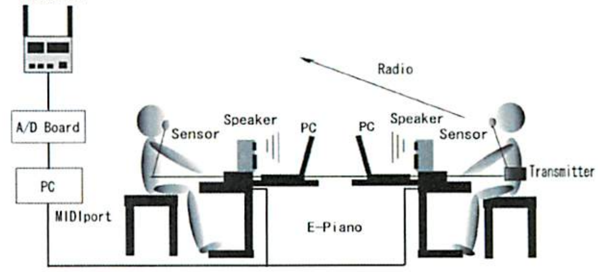


Fig. 3 Measuring system of a cooperative performnce

could perform each task normally, these tasks would be processed in different cognitive systems. If the subjects could not perform the main-task, these tasks were shared in the same cognitive system. Using this method, it was possible to determine the cognitive system of main-task to some extent. In this research, the main-task was playing the piano, and the sub-task is memorizing 5 words which are presented as visual information. Word-memory task is performed with laptop computer which is placed in front of the subjects. The subjects memorize 5 words (Example: Children, Lemmon, Noodle, Tokyo, Bed) before playing the piano and answer the words on the paper right after playing the piano.

Experimental procedure is as follows:

1-1. Playing Music A (4 bars * 7 = 28 bars) 5 times in N-condition

1-2. Playing Music B (4 bars * 7) 5 times in D-condition

2-1. Playing Music A (4 bars * 7) 5 times in N-condition

2-2. Playing Music B (4 bars * 7) 5 times in D-condition

Players were assigned to practice playing the music enough and rehearsed to adjust each tempo a couple of times before the experiment. Before the experiment, the players were told only to play the music cooperatively.

B. Experimental system

Fig.2 shows experimental system. The electric piano (Roland: RD-600) and speakers (ONKYO: GX-R3) were used for the experiment. Players sat down 2.7m apart face to face. The musical performance was recorded in music sequence software (emagic• FLogic Audio platinum Ver 3.5) by MIDI signal. Time resolution of MIDI instruments is 0.96msec. Player's respiration is measured by a thermistor sensor (NIHON KODEN: TR-511G) attached in the nasal cavity. All the measured respiration data are sent from transceiver (TR-511G) to receiver (Multi Telemeter System WEB-5000), and the data are digitalized by A/D board (ADTEK: AXP-AD02). Measured digitalized data finally stored in PC. Time resolution of respiration measurement is 7.8msec. A laptop computer is placed in front of the subjects for word-memory task. All experimental system is synchronized, which makes it possible to compare the musical data and respiration data.

C. Data analysis

To analyze musical synchronization between players, time difference between 1-bar rhythms and period of 1-bar rhythm is used for indices (shown in Fig.3). To analyze temporal development of respiration rhythm, the period of respiration rhythm is used for indices. In Fig.3, if the value becomes bigger, it means inspiration. If the value becomes smaller, it means expiration. In this analysis, 24 bars of the 28 bars are analyzed and the last 4 bars are deleted, because it is impossible to calculate the last 1-bar period.

III Results

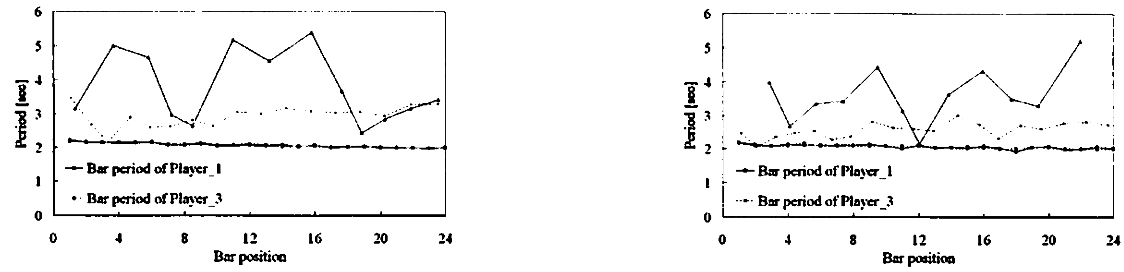
A. Change of time course of 1-bar and respiration period

In this section, the temporal development of 1-bar and respiration period and the relationship between them are analyzed qualitatively in all experimental condition.

The results of dual task are as follows: correct answer rate of Music A is 92.0% (138/150), and that of Music B is 85.3% (127/150). These results mean that in D-condition, players performed the word-memory task properly.

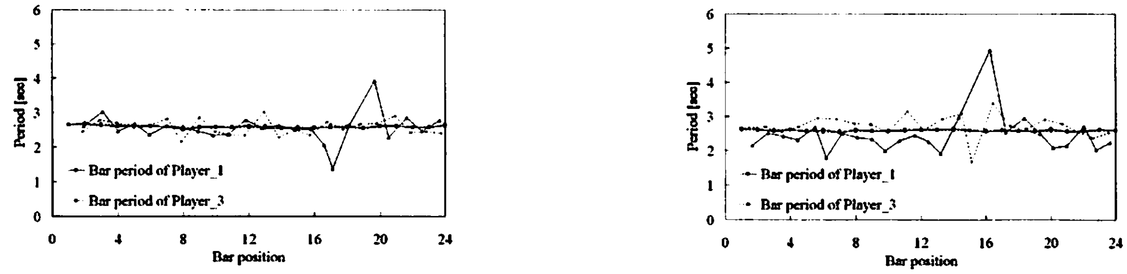
Fig.4a is one example of Player_1 and Player_3's results which shows temporal development of 1-bar and respiration period in Music A and N-condition. Fig.4b shows a result of Music A and D-condition. Fig.5a shows a result of Music B and N-condition. Fig.5b shows a result of Music B and D-condition. Comparing temporal developments of Fig.4a to that of Fig.5a, the respiration period has a big fluctuation in Fig.4a. However in Fig.5a, it has a very small fluctuation. In all figures, 1-bar period has a very small fluctuation. Comparing temporal developments of Fig.4a to that of Fig.4b, there are no significant differences between each temporal development. Comparing temporal developments of Fig.5a to that of Fig.5b, respiration period of Fig.5b has a moderate fluctuation.

In the following section, the relationship between 1-bar rhythms of



(a) N Condition (b) D Condition

Fig. 4 Time course of 1-bar and respiration period (Music A)



(a) N Condition (b) D Condition

Fig. 5 Time course of 1-bar and respiration period (Music B)

players, the relationship between respiration rhythms of players, and the relationship between 1-bar and respiration rhythm of a player are analyzed qualitatively in all experimental conditions.

B. Relation between 1-bar rhythm of players

In this section, the relationship between 1-bar rhythms of players is analyzed quantitatively in all conditions.

Fig.6a shows a histogram of all time differences ((Combination of subjects = 3)*(5 trail)*(24 bars) = 360 data are illustrated) between 1-bar rhythms of Music A and N-condition. Fig.6b shows a histogram of Music A and D-condition, Fig.7a shows that of Music A and D-condition, and Fig.7b shows that of Music B and D-condition. There is no significant difference between shape of histogram of Music A and N-condition and that of Music A and D-condition. However, the histogram of Music B and N-condition lean to Y-axis comparing to that of Music B and D-condition.Fig.12 shows the mean value of each histogram. The black bar of left column shows the mean value of Fig.6a and the gray bar of left column shows the mean value of Fig.6b. The black bar of right column shows the mean value of Fig.7a and the gray bar of right column shows the mean value of Fig.7b.

There is no significant difference between the mean time difference of Music A and N-condition and that of Music B and N-condition ($t(718)=0.0262$, $p>0.25$). These results indicate that there is musical desynchronization between players in both Music A and Music B condition. Moreover there is no significant difference between the mean time difference of Music A and N-condition and that of Music A and D-condition ($t(718)=1.71$, $p>0.25$), however there is significant difference between the mean time difference of Music B and N-condition and that of Music B and D-condition ($t(718)=3.49$, $p<0.001$). These results suggest that there is no effect of the sub-task on musical synchronization in Music A, however in Music B, musical synchronization was changed by the sub-task.

C. Relation between respiration rhythm of players

In this section, the relationship between the respiration rhythms of players is analyzed quantitatively in all conditions.

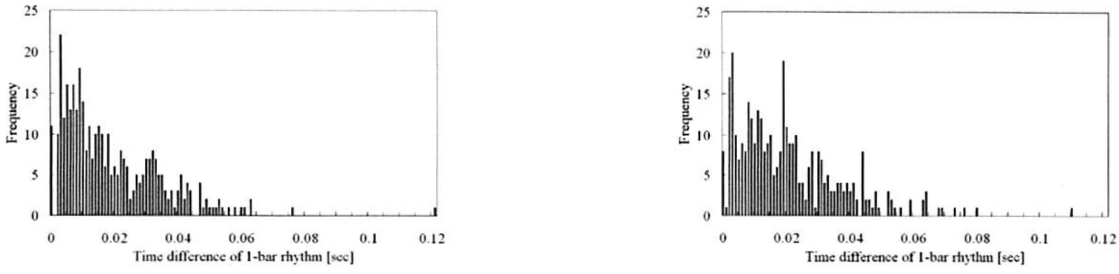
Fig.8a shows a histogram of the differences between the mean respiration periods of players ((Combination of subjects = 3)*(5 trail) = 15 data are illustrated) in Music A and N-condition. The difference between the mean respiration periods of players is calculated by the absolute difference between them in one trial. Fig.8b shows a histogram of Music A and D-condition, Fig.9a shows that of Music B and D-condition, and Fig.9b shows that of Music B and D-condition. In Fig.12, the black bar of left column shows the mean value of Fig.8a and the gray bar of left column shows the mean value of Fig.8b. The black bar of right column shows the mean value of Fig.9a and the gray bar of right column shows the mean value of Fig.9b.

There is no significant difference between the mean difference of respiration period of Music A and N-condition and that of Music B and N-condition ($t(28)=3.03$, $p<0.001$). These results indicate that the mean difference of respiration period in Music B become smaller than that of in Music A.

D. Relation between 1-bar and respiration rhythms of a player

In this section, the relationship between the 1-bar and respiration rhythm of a player is analyzed quantitatively in all conditions.

Fig.10a shows a histogram of the differences between the mean 1-bar period and the mean respiration period of a player ((Combination of subjects = 3)*(5 trail)*(Number of subjects = 2) = 30 data are illustrated) in Music A and N-condition. The difference between the mean 1-bar period and the mean respiration period of a player is calculated by the absolute difference between them in one trial. Fig.10b shows a histogram of Music A and D-condition, Fig.11a shows that of Music B and D-condition, and Fig.11b shows that of Music B and D-

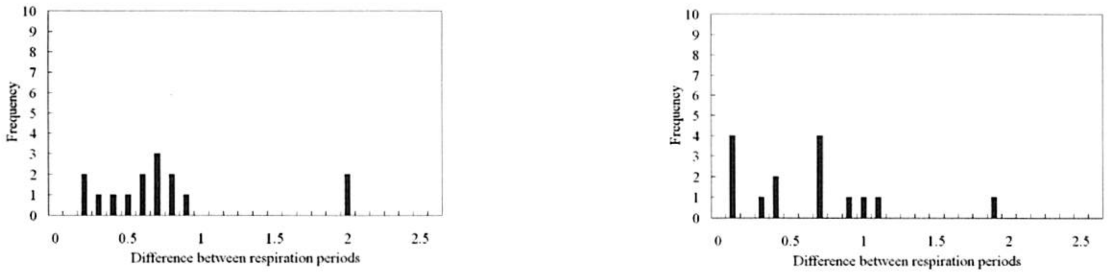


(a) N Condition **(b)** D Condition

Fig. 6 Histogram of time difference of 1-bar rhythm (Music A)

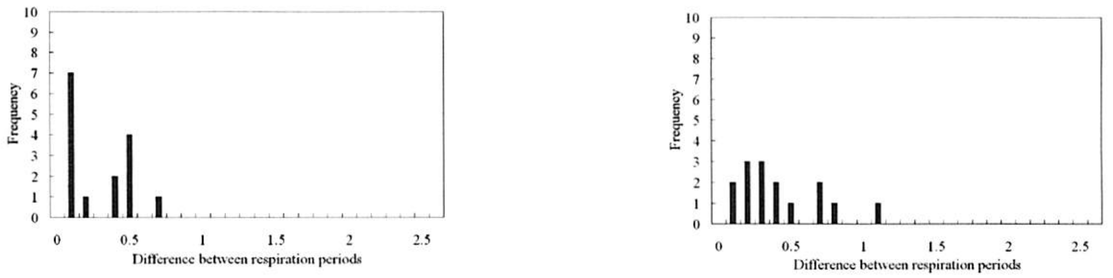
(a) N Condition **(b)** D Condition

Fig. 7 Histogram of time difference of 1-bar rhythm (Music B)



(a) N Condition **(b)** D Condition

Fig. 8 Histogram of difference between respiration periods (Music A)



(a) N Condition **(b)** D Condition

Fig. 9 Histogram of difference between respiration periods (Music B)

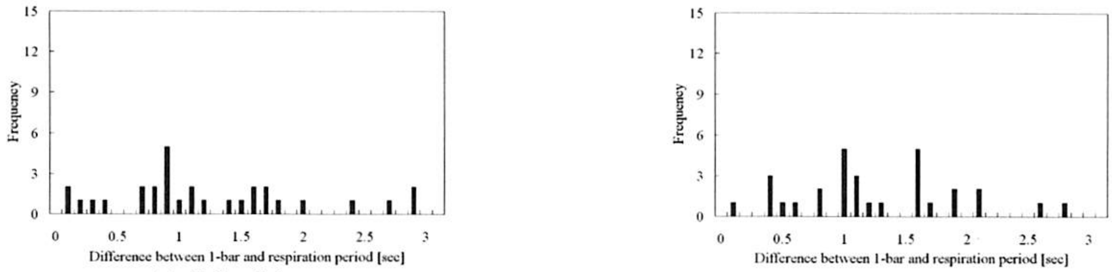
condition. In Fig.14, the black bar of left column shows the mean value of Fig.10a and the gray bar of left column shows the mean value of Fig.10b. The black bar of right column shows the mean value of Fig.11a and the gray bar of right column shows the mean value of Fig.11b.

There is significant difference between the value of Music A and N-condition and that of Music B and N-condition ($t(58)=7.07$, $p<0.0001$), and its absolute difference is big. These results indicate that the mean 1-bar and mean respiration period of a player of Music B is much smaller than that of Music A. There is no significant difference between the mean difference between the 1-bar and respiration period of Music A and N-condition and that of D-condition ($t(58)=0.117$, $p>0.25$), however there is significant difference between them of Music B and N-condition and that of Music B and D-condition ($t(58)=3.05$, $p<0.05$). These results suggest that in Music B, the mean difference between the 1-bar and respiration period was changed by the sub-task.

IV Discussion

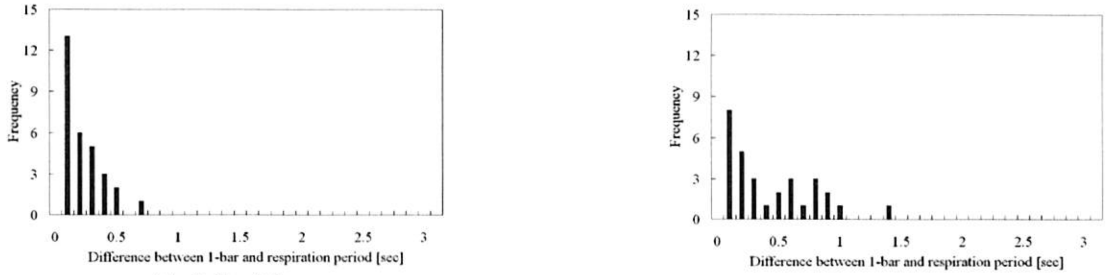
Summary of results is as follows:

1. The analysis of the relationship between the 1-bar rhythms



(a) N Condition (b) D Condition

Fig. 10 Histogram of difference between 1-bar and respiration period (Music A)



(a) N Condition (b) D Condition

Fig. 11 Histogram of difference between 1-bar and respiration period (Music A)

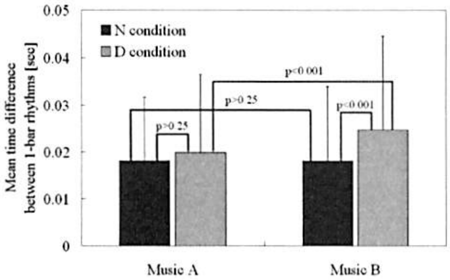


Fig. 12 Mean time difference between 1-bar rhythms

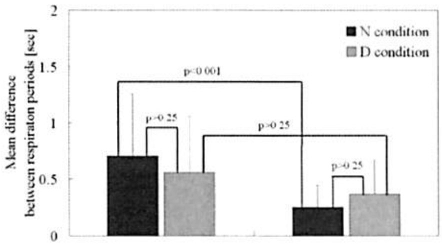


Fig. 13 Mean difference between respiration periods

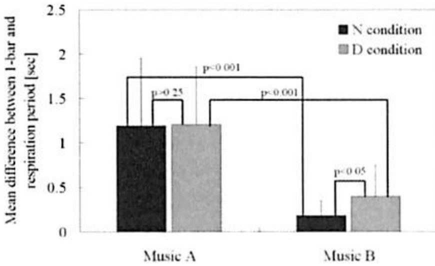


Fig. 14 Mean difference between 1-bar and respiration period

of players revealed that there is musical desynchronization between players in any condition, and there is no effect of the sub-task on musical synchronization in Music A, however in Music B, musical synchronization was changed by the sub-task.

2. The analysis of the relationship between the respiration rhythms of players revealed that the mean difference of respiration period of Music B become smaller than that of Music A.

3. The analysis of the relation between the 1-bar and respiration rhythm of a player revealed that the mean 1-bar and mean respiration period of a player of Music B is much smaller than that of Music A, and in Music B condition, the mean difference between the 1-bar and respiration period was changed by the sub-task.

There is the musical desynchronization between players in any condition. In the cooperative performance, the players are always interact each other through music to make the desynchronization small. On the other hand, the respiration period is changed depending on the kind of music. In Music A condition, the difference between mean respiration periods between players is big, however in Music B condition, that is small. Moreover the difference between the 1-bar and respiration period of a player is big in Music A condition, however it is very small in Music B condition. These results of this research suggest that the coupling between 1-bar and respiration rhythm becomes stronger depending on type of music as Ebert showed in his work. It is suggested that there is interaction between a physical and respiration rhythm, and a finger movement is generated by the coordination of physical and respiration rhythms [8][9]. These results suggest that the interaction between players in a cooperative performance is composed of not only a sound element but also a physiological element such as respiration. Therefore these elements should be analyzed to clarify the entire cognitive system.

In this research, a visually presented word-memory task is selected as the sub-task of the dual task method. When performing this subtask, broca area, supramarginal gyrus and supplementary motor area are activated (e.g. [10][11][12]). These areas are related to speech production. In this research, the effect of sub-task appeared in only Music B condition. This result suggests that when playing Music A, the areas of speech production are not activated, however when playing Music B the areas are activated.

The difference between Music A and Music B is difficulty of finger

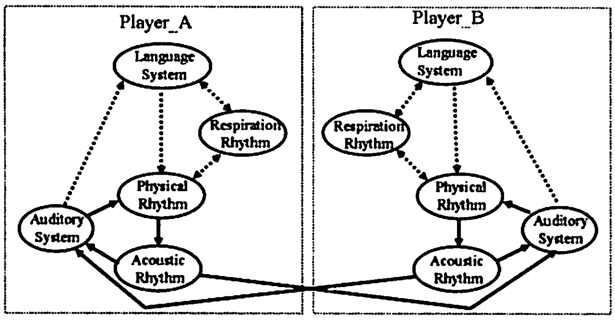


Fig. 15 A musicl communication model of a cooperative performance

movement and changing speed of pitch. Recent research about brain activity in musical perception revealed that the music that have the slow pitch change and slow rhythmical change is processed in a auditory area of right hemisphere [13][14]. Contrary, the music that have the fast pitch change and fast rhythmical change is processed in not only the auditory area of right brain but also a language processing area of left hemisphere [15][13][14].

These researches can explain the difference desynchronization of 1-bar rhythms between Music B and N-condition and Music B and D-condition. When playing music such as Music A, the musical signal is mainly processed in the auditory system of right hemisphere. Therefore, if the sub-task occupied language system, there was no effect on the musical synchronization. However, when playing music such as Music B, if the sub-task occupied language system, players could not control the 1-bar rhythm as well as normal condition. This activation of language system can also explain the change of respiration period. Language system is an area for speech production. Therefore it has a strong relationship to respiration system. When playing Music B, the language system is more activated than when playing Music A. It is speculated that the change of respiration rhythm is generated by this activation. Especially the result that the difference between 1-bar and respiration period became very small suggest that melody of 1 meter is generated as if speech production. Moreover in this research players play the same music, therefore players respiration is tend to synchronize.

We propose a communication model from these discussions (shown in Fig.15). This hierarchal model is composed of two layers: one is the lower layer which has the auditory and physical feedback system, and the other is the higher layer which has the language and respiration system. General music has both essence of Music A and Music B. Therefore it is speculated that lower layer and higher layer work synergically in general musical performance.

In future works, it is necessary to verify this model and analyze the temporal development of 1-bar and respiration rhythm to propose the model which considers dynamics of each system. Moreover, to approach to the problem of music therapy, we have to investigate a subjective aspect of musical communication.

V Conclusion

In this research, a musical performance is analyzed by 1-bar and respiration rhythms and dual task method to clarify the cognitive mechanism of a cooperative performance. As a result, there are two types of cooperative performances: one is a performance of playing music of slow pith and rhythm change which is not effected by word-memory task. The other is a performance playing music of fast pith and rhythm change which is affected by word-memory task. From these results, the hierarchical communication model of a cooperative performance is proposed. In future works, it is necessary to analyze the temporal development of the 1-bar and respiration rhythm to propose the model which considers dynamics of each system.

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