

Synchronization and Fluctuation of Rhythm in Musical Cooperative Performance

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Abstract. A live musical performance gives us better impression than recorded music heard from a portable music player. From player's point of view, live performance also gives better impression than playing music with metronome or recorded music. Thus, the difference exists between the live musical performance and the recorded performance that doesn't change in real time. In this research, to clarify the difference, the cooperative performance of the drum and the bass was analyzed from a rhythmical aspect. The results showed that synchronization error between musical rhythms, and fluctuation of musical rhythm became smaller in cooperated performance than in the performance with recorded music.

Keywords: Music, Rhythm, Synchronization, Fluctuation, Cooperative Performance.

1 Introduction

A Portable music player such as an iPod has been widespread recently and people can enjoy music anytime and anyplace. Nevertheless, live musical performance still gives us better impression than recorded music. From player's point of view, live performance also gives better impression than playing music with metronome or recorded sound. These empirical facts suggest that there is qualitative difference between recorded music which never changes at real-time and live musical performance. To clarify this difference contributes not only to develop an artificial musical playing agent but also to understand fundamental human communication mechanism which is quite complicated. In this research, from such point of view, we analyze a cooperative musical performance.

A music player changes musical tempo consciously or unconsciously to give artistic expression to their performance. There are some researches which deal with such temporal change in piano performance [1]-[3]. In those researches, the relation between fluctuation of rhythm and grouping of phrase or artistic expression has been discussed. Recently, not only piano performance but also drum performance has been analyzed. For example, Okuhira et. al. have analyzed sense of groove quantitatively

which possibly determine whole music expression [4]. Watanabe et. al. have analyzed the relation between standard deviation of drum beat and subjective metronome [5].

While these researches have analyzed change of musical tempo of solo performance, our research group has analyzed a musical cooperative performance. In this research, we analyzed the relation between musical aspect and physiological aspect of piano ensemble, and resulted that synchronization between musical rhythm and respiratory rhythm changed depending on difficulty of performance [6]. Werner et. al. have also analyzed the synchronization of musical rhythm of cooperative piano performance and resulted that proper sound feedback is important to synchronize musical rhythm [7]. In addition to these researches, there are some researches which have analyzed non-verbal information in cooperative performance. Katahira et. al. have analyzed the relation between drum performance and visual information. The results showed that visual information contributed to synchronize musical rhythm [8].

Moreover, with the development of information technology, analysis of interaction between a human player and an artificial player has appeared. Horiuchi et. al. have analyzed cooperative performance of solo player and accompanist using multiple regression analysis. From results, they have developed the control model of musical performance [9]. Kobayashi et. al. have analyzed cooperative performance of two piano players, and resulted that time difference of sounding, and change of time difference affected tempo control. From these results, Kobayashi have developed an artificial ensemble system [10].

A Summary of these previous researches is that in researches about solo performance, fluctuation of musical rhythm has analyzed, and the relation between artistic expression and fluctuation has been discussed. However fluctuation of cooperative performance has not been discussed. On the other hand, in researches about cooperative performance, synchronization of musical rhythm and its mechanism, or non-verbal information and physiological aspect have been analyzed. However the difference between performance with recorded music and cooperative performance has never been discussed.

Therefore, in this research, the difference between performance with recorded music and cooperative performance are analyzed from rhythmical aspect. Especially, the cooperative performance of the drum and the bass which is very popular with jazz, rock and pops and needs rhythmical cooperativeness for good performance are focused.

2 Methods

2.1 Task and Subjects

2 kinds of music were prepared for the experiment (Fig.1(a)-(d)). One was simple music, and another was complex music (BPM =120, 16 bars). For the experiment of simple music, 8 subjects (4 armature drummers and bassists who had 3.6 years playing experience in average.) participated. Similarly, for the experiment of complex music, another 8 subjects (who had 3.3 years playing experience in average.)

participated. In both experiments, 2 bassists and 2 drummers were paired (Therefore 2 pairs were prepared in each experiment.). In each pair, there were 4 combinations. Therefore 8 combinations of a drummer and a bassist were prepared in each experiment. All subjects were instructed to have a practice with a score and recorded CD a few days before experiment. Moreover, just before experiment, subjects had a practice to accustom themselves to the environment and playing the music. Therefore, in this experiment, the technical difference between subjects and environmental effects were regarded to be negligible.

In this experiment, 4 conditions were prepared and 5 performances were conducted in each condition.

- Condition 1: Performance with click sound (BPM =120) from a speaker
(Click Condition)
- Condition 2: Performance with the music which was recorded in Click condition
(Rec Condition)
- Condition 3: Cooperative performance without visual information which was realized to stand screen between players (Live1 Condition)
- Condition 4: Cooperative performance with visual information
(Live2 Condition)

Experiment was conducted from 1 to 4 condition. Performance order affected experiment results were also regarded to be negligible because subjects had a practice enough before experiment. Between condition, subjects had enough rest. Therefore fatigue did not affect the experiment results.

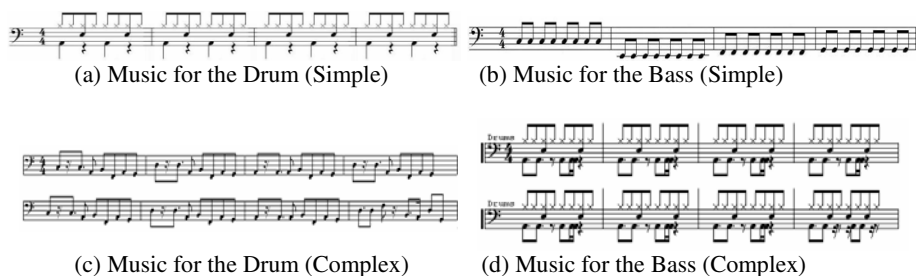


Fig. 1. Music for Experiment

2.2 Experiment System

Fig.3 shows the experiment system. Musical performance was recorded by “Cubase4” (Steinberg). The silent MIDI drum “DTXPROLER” (YAMAHA) and the subjects’ own bass were used for experiment. Performed data of the drum (MIDI data) and the bass (raw wave data) were captured through digital mixer “01X” (YAMAHA). In Rec condition, to play back recorded drum performance, “MOTIF RACK” (YAMAHA) and a Speaker (GX-D90, ONKYO) was used.

In this experiment system, latency (the time delay in each recording device) might occur. Therefore latency of each device was measured. As a result, under 1 msec of latency was observed. This result indicated that latency of this system was negligible.

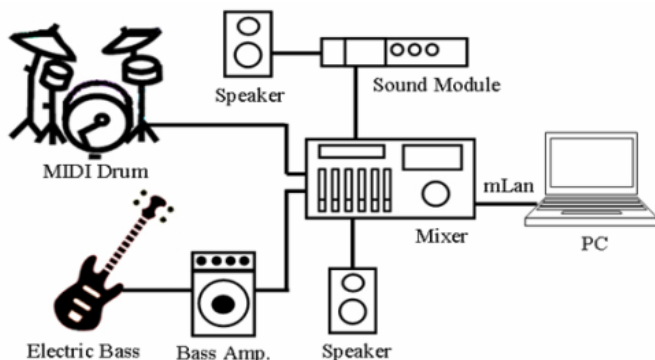


Fig. 2. Experiment System

2.3 Data Analysis

In this research, to clarify the difference between performance with recorded music and cooperative performance, rhythmical aspect of musical performance was analyzed. Concretely, fluctuation of periodical rhythm and synchronization error (S.E.) between 2 players (or between a player and click or recorded music) was analyzed. In addition to this analysis, subjective evaluation to musical performance was conducted by questionnaire.

S.E. was calculated by the method below; at first, the sounded time (or Click sound in condition 1) of the drum was calculated from MIDI data. And the sounded time (or Click sound in condition 1) of the bass was calculated from wave data (In each sound, the first peak of wave form was selected as sounded time.). Next, as shown in Fig.3(a), absolute value of the time difference between corresponding sounded times was calculated as S.E..

In this research, high hat cymbal, snare drum and bass drum were used for performance. However in cooperative performance, a bassist tends to play with the sound of snare and bass drum. Therefore these two drums and corresponding bass sound were used for data analysis (In analysis of Click condition, similar analysis process was adopted.).

Fluctuation of periodical rhythm was calculated by the method shown in Fig.3(b). The formula (2) was for calculation of standard deviation of period, and it was used for index of fluctuation.

For subjective evaluation, questionnaire was conducted after experiment. Question items were “Easiness of performance”, “Enjoyment of performance”, “Subjective synchronization error”. After experiment the drummers and bassists answered these items by 5 grades, and next, they commented about each experiment condition freely.

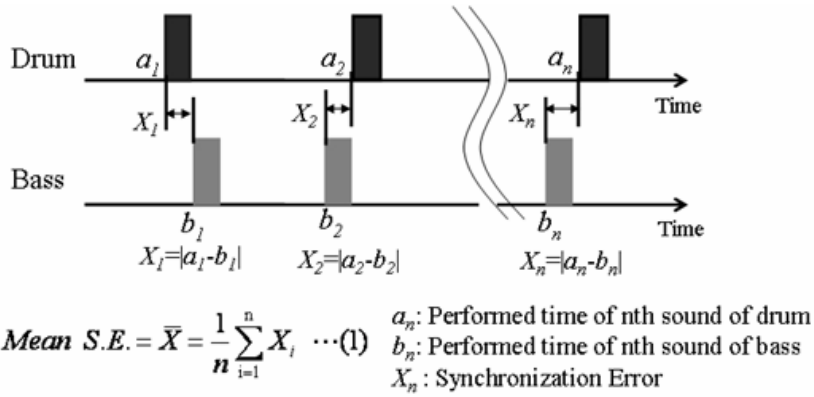


Fig. 3(a). Calculation of synchronization error

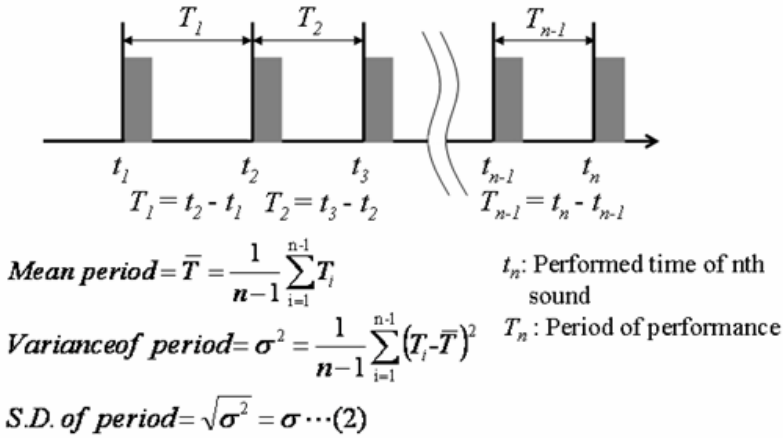


Fig. 3(b). Calculation of fluctuation of periodical rhythm

3 Results

3.1 Results of Simple Music

Fig.4(a) shows mean and S.D. of fluctuation of periodical rhythm which is calculated from data of all 8 pairs (5 performances * 8 pairs = 40 data). In this research, at first, Levene's test was conducted to analyzed data. As a result, the equality of variance was not confirmed. Therefore, including not only data of subsection 3.1 but also data of 3.2, significant difference between medians is tested by Kruskal-Wallis test.

The result of drum performance shows that there is no significant difference between conditions ($X^2(3) = 1.746$, n.s.). This result means that drum's fluctuation of periodical rhythm is mostly same in all conditions.

The result of bass performance shows that there is significant difference between conditions ($X^2(3) = 51.4$, $p < .05$). Therefore, multiple comparison (Steel-Dwass test) is conducted between conditions. As a result, there is significant difference between Click and Live1, Click and Live2, Rec and Live1, Rec and Live2 ($t = 5.102, 5.881, 4.278, 4.783$, $df = 78$, $p < .05$). This result means that fluctuation of periodical rhythm in Live1, 2 condition is smaller than fluctuation in Click and Rec condition in which musical rhythm do not change interactively.

Fig.4(b) shows mean and S.D. of S.E. which is calculated from data of all 8 pairs. The results of Kruskal-Wallis test is that there is significant difference between conditions in drum and bass performance ($X^2(3) = 55.202, 34.339$, $p < .05$). Therefore multiple comparison is conducted between conditions. The result of drum performance is that there is significant difference between Click and Live1, Click and Live2, Rec and Live1, Rec and Live2 ($t = 3.494, 3.696, 6.376, 6.554$, $df = 78$, $p < .05$).

The result of bass performance is that there is significant difference between Click and Rec, Click and Live1, Click and Live2, Rec and Live1, Rec and Live2 ($t = -2.637, 2.695, 3.504, 4.437, 4.749$, $df = 78$, $p < .05$). The value of Live2 is smallest in all conditions. These results show that S.E. of cooperative performance is smaller than that of Click and Rec condition in which players play according to static musical tempo.

Fig.5 shows the result of subjective evaluation. It is easy to understand that Live2 gets the highest point. The results of Kruskal-Wallis test is that there is significant difference between conditions in all question items ($p < .05$). The result of multiple comparison is that in "Easiness of performance", there is significant difference between Click and Rec, Click and Live1, Click and Live2, Rec and Live1, Rec and Live2 ($p < .05$). In "Enjoyment of performance", there is significant difference between Click and Live1, Click and Live2, Rec and Live1, Rec and Live2 ($p < .05$). In "Subjective S.E.", there is significant difference between Click and Rec, Click and Live2, Rec and Live1, Rec and Live2 ($p < .05$).

These results suggest that cooperative performance give better subjective evaluation, and visual information contribute to get higher value.

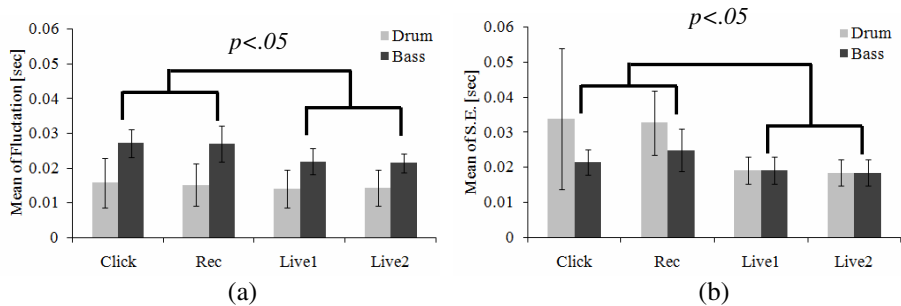


Fig. 4. Mean and S.D. of (a) fluctuation of period, (b) synchronization error

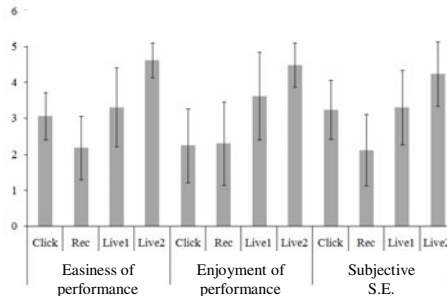


Fig. 5. Mean and S.D. of Subjective evaluation

3.2 Results of Complex Music

Fig.6(a) shows mean and S.D. of fluctuation of periodical rhythm which is calculated from data of all 8 pairs (5 performances * 8 pairs = 40 data). The result of drum performance shows that there is significant difference between conditions ($X^2(3) = 10.786, p < .05$). The result of multiple comparison is that there is significant difference between Rec and Live2 ($t = 3.438, df = 78, p < .05$). This result means that fluctuation of periodical rhythm in Live2 condition is smaller than fluctuation in Rec condition in which musical rhythm does not change interactively.

The result of bass performance shows that there is no significant difference between conditions ($X^2(3) = 1.501, n.s.$). This result means that bass's fluctuation of periodical rhythm is mostly same in all conditions.

Fig.6(b) shows mean and S.D. of S.E. which is calculated from data of all 8 pairs. The results of Kruskal-Wallis test is that there is significant difference between conditions in drum and bass performance ($X^2(3) = 29.493, 45.997, p < .05$). Therefore multiple comparison is conducted between conditions. The result of drum performance is that there is significant difference between Click and Rec, Rec and Live1, Rec and Live2 ($t = -4.378, 4.888, 3.666, df = 78, p < .05$).

The result of bass performance is that there is significant difference between Click and Rec, Rec and Live1, Rec and Live2 ($t = -6.274, 5.494, 4.496, df = 78, p < .05$). These results shows that S.E. of cooperative performance is smaller than that of Rec condition in which players play according to static musical tempo.

Fig.7 shows the result of subjective evaluation. From results, Live2 gets the highest point in terms of "Easiness of performance" and "Enjoyment of performance". However in terms of "Subjective S.E.", Live1 gets the highest point.

The result of Kruskal-Wallis test is that there is significant difference between conditions in all question items ($p < .05$). The result of multiple comparison is that in "Easiness of performance", there is significant difference between Click and Live2, Rec and Live1, Rec and Live2 ($p < .05$). In "Enjoyment of performance", there is significant difference between Click and Live1, Click and Live2, Rec and Live2, Live1 and Live2 ($p < .05$). In "Subjective S.E.", there is no significant difference between conditions.

These results suggest that cooperative performance give better subjective evaluation, and visual information contribute to get higher value in easiness and enjoyment

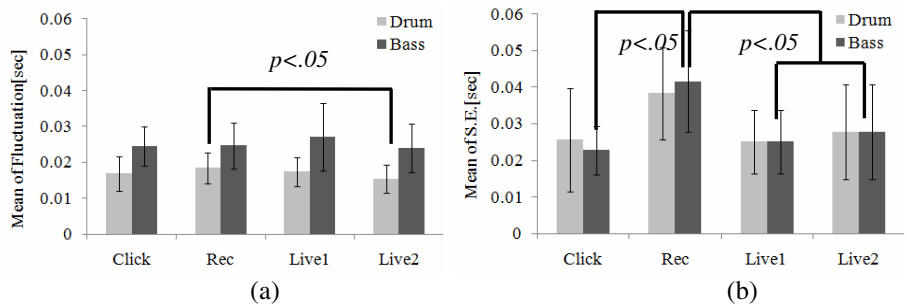


Fig. 6. Mean and S.D. of (a) fluctuation of period, (b) synchronization error

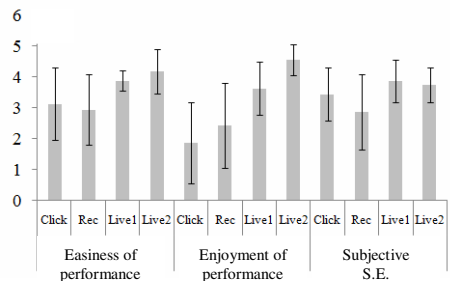


Fig. 7. Mean and S.D. of Subjective evaluation

of performance. However, playing complex music, visual information not always contributes to get higher value.

3.3 Comparison between Simple and Complex Music

The results of simple music and the results of complex music come from different subjects. However, for just reference, these two results are compared in this section.

Comparing Fig.4(a) and Fig.6(a), fluctuation of complex music is bigger than that of simple music without bass performance in Click and Rec condition. The result of Mann Whitney U test between simple and complex music shows that there is significant difference between Rec conditions, and Live1 conditions in drum performance ($U = 489, 511, p < .05$). In base performance, there is significant difference between Click, Rec, Live1, Live2 conditions ($U = 568, 578, 525, 567, p < .05$).

Comparing Fig.4(b) and Fig.6(b), S.E. of complex music is bigger than that of simple music without drum performance in Click condition. The result of Mann Whitney U test between simple and complex music shows that there is significant difference between Click, Live1, Live2 conditions in drum performance ($U = 582, 448, 438, p < .05$). In base performance, there is significant difference between Rec, Live1, Live2 conditions ($U = 199, 448, 438, p < .05$).

4 Discussion

In this research, to clarify the difference between performance with recorded music and cooperative performance, the cooperative performance of the drum and the bass were analyzed from rhythmical aspect. The summary of results is below;

- In most case, fluctuation of periodical rhythm in Live condition is smaller than fluctuation in Click or Rec condition.
- S.E. of Live condition is smaller than that of other conditions.
- Live condition get highest point in subjective evaluation.
- In most case, fluctuation of periodical rhythm in simple music is smaller than fluctuation in complex music.
- In most case, S.E. of simple music is smaller than that of complex music.

The results of S.E. show that two players most synchronize in cooperative performance. If just synchronizing mutual sounds, it is assumed that to synchronize a sound to repetitive click sounds is easiest than other conditions. However cooperative performance whose musical tempo may change gives best results. The reason why S.E. of cooperative performance get good result is that human cannot keep perfect constant rhythm, and as a result fluctuation should be appeared. In cooperative performance, both players predict mutually musical tempo listening partner's fluctuated performance. In this situation, if prediction of players matches, their musical tempo will more synchronize than in playing with repetitive click. In playing with recorded music, mutual prediction never happens, and recorded music has bigger fixed fluctuation than click. As a result, less synchronization is observed.

The results of fluctuation show that cooperative performance which do not have a pace maker give better result than performance with Click. This result is very interesting. This kind of results demands the control mechanism which realizes interaction between players, and at the same time, realizes stability of musical tempo. One possible mechanism is entrainment of nonlinear oscillators. However it cannot explain the result of Click condition which is enforcement entrainment and should give best result in S.E. and fluctuation. In future, it is necessary to develop a dynamical system which explains this phenomenon for modeling.

In the result of subjective evaluation, Live2 condition gets highest point in terms of "Easiness of performance", "Enjoyment of performance". However, in terms of "Subjective S.E.", Live1 gets highest point. These results correspond to the results of S.E., and means that in complex music, visual information do not contribute synchronization error. Moreover these results mean that in Live2 condition, players enjoy their performance, although synchronization error become bigger. The reason of this result is that in Live2 condition, visual information might enhance tension or sense of coexistence. As a result, it affected subjective evaluation of performance.

The result of this research shows that synchronization and fluctuation of cooperative performance is smaller than that of performance with fixed tempo, and at the same time cooperative performance gives better impression than performance with fixed tempo. Described above, it depends on success of mutual prediction of players. To predict timing of sounding is realized by referring past information about performance. This referring ability is for not only musical performance but also general

human activity. For example, in conversation, human predict subsequent utterance by past utterances and speak. In future, we would like to analyze the relation between general communication and musical performance.

5 Conclusion

In this research, to clarify the difference between performance with recorded music and cooperative performance, the cooperative performance of the drum and the bass are analyzed from rhythmical aspect. As a result, (a) in most case, fluctuation of periodical rhythm in cooperative performance is smaller than fluctuation in performance with recorded music, (b) S.E. of cooperative performance is smaller than that of performance with recorded music, (c) cooperative performance get highest point in subjective evaluation.

In future works, experiment with the music composed of simple and difficult music or including adlib part will be conducted. Moreover, with the results of experiment, model of cooperative performance will be developed.

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