The Application of Entrainment to Musical Ensembles

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Abstract. We introduce a new viewpoint of "entrainment", which refers to a sort of synchronization among oscillators. Entrainment, originally found in a physical context, shows very complicated characteristics under high-level conditions, as with living organisms, behaviors, the mind, and so on. We found entrainment plays an important and subtle role in musical performance from a series of our experiments. As a result, it could also be connected with the phrasal structure of music, based on the analysis of asynchronization (or deviation) among performers, which shows the existence of both synchronization and deviation in a given phrase.

1 Introduction

Lots of models or rules in performances have been proposed by many researchers, since Seashore mentioned that beauty in music lies largely in artistic deviation from the exact or rigid. Therefore, the synchronization and asynchronization among multiple performers have certain significance for creating vivid expression through musical performance. In this paper we examine this concept by combining physical and musical notions. To illustrate this approach, we begin with some remarks about the background of our study.

1.1 Background

First, it has been found that small fluctuations of rhythm or stress, which are not described in the score, play an important role in musical performances. In addition, this fact is fundamentally concerned with all sorts of expression or communication involving some time span, including not only music but also dance, play, and speech. Generally speaking, expression depends on the contrast between the explicit meaning expressed by words or scores and the implicit feeling or nuance. Although in general the main content is the explicit meaning, we often experience the opposite phenomenon in which the additional nuances play a crucial role in communication. Clearly feeling and nuance are very important in artistic expression.

In spite of this, the subject of performance has not been adequately discussed. Specifically, it is very difficult to determine the fundamental essence of artistic expression, although it is possible to analyze some general patterns of emotional information. There have been some important studies that have influenced our ideas: (1) A musical phrase can be explained in terms of a basic, common two-part structure such as “expectation-confirmation” or “implication-realization” [1, 2], the connection with linguistics [3], the philosophy of form in music as examined by researchers of Gregorian chant, and so on. (2) There are some rules when specific phrase patterns are performed [4, 5], and they are also connected with the generative theory [6]. (3) There are several useful Eastern viewpoints relative to time such as “ma” (a characteristic remark of a pause), “kan” (a kind of intuition), and so forth. (4) We have also found interesting research on spoken language, claiming that there are very typical fluctuations made of the strongest vowels, which the researchers call “Nu waves” [7].[1]

Second, most previous studies have dealt with only one performer, while there are just a few papers analyzing multiple performers playing simultaneously, such as Rasch’s work [8, 9]. He analyzed time lags among three performers. In this case, one person played the main melody and thus led the ensemble. This causes certain time lags between his/her onset times and those of the other performers. In the case of a typical ensemble with several performers, however, the relationships among their onset times become fundamentally complicated; the time lags among them are not clear and have not been well studied. In fact, the performers either try to minimize the time lags as much as possible or are not conscious of this matter.

The reasons there have been few studies with multiple performers are as follows:

1. It is not easy to experiment with and get data for multiple subjects.
2. It is difficult to scientifically analyze a large amount of complex data from multiple performers.
3. The relationship among multiple performers is too complicated for the subjects and experimenter to control.

The first hurdle has been partly overcome by contriving new experimental methods based on improvements in mechanical and electronic technology. It is always difficult, however, to find enough subjects with sufficient ability, especially in the case of multiple subjects playing simultaneously. The second and third hurdles are more essential and require us to clarify the fundamental relations between consciousness and unconsciousness of these phenomena, or between given (passive) and spontaneous (active) expressions.

Finally, there are also physical approaches to music, based on chaos, fractals, 1/f fluctuation, and so on [10]. We feel it is somewhat difficult to apply these scientific models directly to actual music. Music in terms of chaos is very interesting from a mathematical viewpoint. However, chaos theory is originally based on the results of numerical calculations, so that chaos-modeled music becomes like computer-simulated music. Such models prevent composers from developing creative phrases.

Music in terms of fractals is also very interesting for both scientists and artists and results in the viewpoint of simple, beautiful geometrical structures. Although this approach can explain fugue, canon, and Bach’s works in particular, music considered

[1] This paper is written in Japanese, but deals with conversations in both English and Japanese.

as fractals is potentially changed to a special structure from the original temporal structure. The new structure may not be suitable for analyzing music as a dynamic temporal series.

Music in terms of 1/f fluctuation holds great wonder for those who feel some kind of mysterious atmosphere in music. This approach is very attractive but has not been developed sufficiently. We can say nothing about the music when it is of the type based on 1/f fluctuation. The weakest point of such a power spectrum method is that it misses the phase information, preventing us from comparing the fluctuation and the musical structure.

Consequently, it is necessary to combine music and science in a more practical way. The essence of music should be explained correctly, but the secret of creativity in musical performance must also be understood; that is, it is crucial to analyze music meaningfully so that performers can play more vividly. Moreover, communication among performers or between performers and the audience is also important artistically. Here we try to analyze such ensembles from the viewpoint of rhythm.

1.2 Asynchronization in Ensemble

Asynchronization [2] among performers is a very subtle parameter for musical performance. Performers usually try to minimize asynchronization while playing music, but in real performances they can not completely avoid it. This can in fact be regarded as a significant artistic factor in music, rather than considering it to simply be a technical problem. In other words, we can say that a "perfect" performance is not necessarily artistic.

Asynchronization is caused by an unconscious and spontaneous process when playing without any conscious deviation. Compared to the temporal fluctuation of a single performer, the unconscious mind plays a more essential role in asynchronization. The reason is that it is impossible to control the time lags among multiple performers without a prescribed scenario, whereas a single player can control the tempo during most parts of a piece of music, assuming he/she has enough technique.

These characteristics of asynchronization make musical performances more vivid and impressive because the unconscious process can create spontaneous, active feelings in the music. Performers do try to synchronize with other performers, but they are also motivated to express artistic phrases by themselves at the same time. We thus believe that good balance between synchronization and asynchronization produces effective ensembles.

1.3 Application of Entrainment

We propose that synchronization (and asynchronization) in music should be regarded as "entrainment", which means a kind of synchronization among non-linear

[2] We often use the word "deviation" with the same meaning as "asynchronization" in this paper. It should not be confused with the statistical meaning, as in "standard deviation".

oscillators. This originated as a physical concept, especially in studies dealing with non-linear phenomena such as chaos. Now, this notion is being applied to a wide variety of fields, including biology, medicine, sociology, and computer science.

Entrainment also has characteristics of the unconscious, especially in the sociological case. For example, the behaviors of close friends are likely to be synchronized with the movements of their hands or feet. This is an important factor in how well they get along. While the process of synchronization in music is not easily explained (we discuss this problem later), the new notion of entrainment should thus be applied to high-order phenomena like music.

In addition, we need to explain entrainment more completely in order to prevent misunderstandings caused by research suggesting the effectiveness of entrainment in music therapy conducted simply by listening to specific musical pieces. We use the concept here to analyze music very precisely and scientifically, rather than to emphasize the atmosphere of music. Our main focus is on analyzing performed music, which produces artistic feelings in both performers and listeners.

2 Entrainment in Natural Science

Entrainment is defined as the phenomenon in which multiple oscillators, which had previously oscillated with different periods and phases, gradually become synchronized and finally come to share a common period. Basically, it is immaterial whether the phases are common. The main factor causing this phenomenon is the non-linear interactions among the oscillators. Various fields, such as physics, chemistry, biology, and psychology, are concerned with entrainment in terms of formal generality. Under appropriate conditions, fairly simple systems can experience entrainment, as with, for example, multiple interacting pendulums and the clustered flow of salt water [11].

In the case of higher-level systems, entrainment has different characteristics from simple synchronization. Subtle fluctuations are often crucial to various activities of life. For example, heartbeats fluctuate all the time due to the effects of the brain and hormones. This fluctuation is clear when the body is well conditioned but decreases when the body is sick [12].

EEG also fluctuates considerably. The brain needs a somewhat chaotic situation in order to maintain the body’s health, while perfect synchronization indicates some kind of brain disease. That is, entrainment due to unnatural outside stimuli could be harmful, while we think that natural entrainment should involve proper synchronization and proper asynchronization.

There are two types of entrainment distinguished by the proportion of activity. The circadian rhythm is a good example of asymmetrical entrainment, requiring organisms to adjust to the period of a day. This type of entrainment of course concerns the flexibility of living systems. We are more interested in the second type, symmetrical entrainment, because the relationship among oscillators is more complicated. The musical ensembles analyzed in our study experience this type of entrainment.

3 Soft Entrainment and Physical Model

In dealing with the entrainment of musical rhythms, it is necessary to consider the rise and fall of asynchronization in detail, instead of simply examining the degree of synchronization. Here we introduce some terms to facilitate more precise understanding. Synchronization is defined as the situation in which multiple oscillators share a common period. Entrainment means both the process of developing from the initial conditions to synchronization and the synchronization itself. “Anti-phase” means out of phase at 180 degrees. “In rhythmical phase” is defined as “out of phase” at a simple value like 120 or 90 degrees, while “micro-out-of-phase” refers to synchronization with very small time lags.

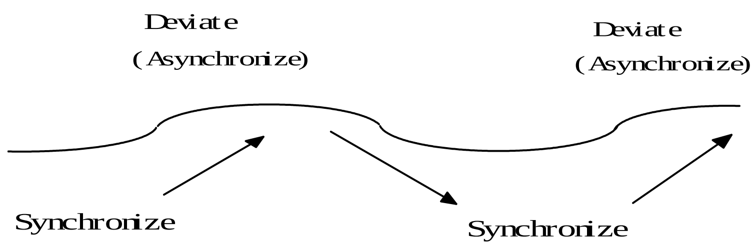

Fig. 1. An illustration of soft entrainment. The higher the line is positioned, the larger the asynchronization becomes. In soft entrainment, synchronization and deviation occur alternately.

In the case of a higher-level complex system, the rhythm is synchronized but also deviates, without achieving perfect synchronization. We call this situation “soft entrainment”, which includes the complicated characteristics of synchronization. Soft entrainment consists of partial synchronization and partial asynchronization (Fig. 1). Musical rhythm is a typical example of soft entrainment. Although it is supposed to be in phase, it actually experiences micro-out-of-phase entrainment.

How can we develop an appropriate physical model to describe such a subtle phenomenon? This is a very challenging problem, but one of our future goals is to develop a model that will enable us to simulate soft entrainment by numerical experiments. A potential candidate is the globally coupled map (GCM) proposed by Kaneko and its “chaotic itinerancy” in a “partially ordered phase” [13]. Although this idea is very attractive, right now it is probably still difficult to explain the phenomenon of soft entrainment.

4 Soft Entrainment in Music

It is very difficult to clarify the essence of rhythm. It is a kind of pattern cognition; that is to say, it is the interpretation of a temporal event series. Moreover, the length of time is limited to a specific range in which the phenomenon is experienced as musical rhythm. A rhythm with too fast a tempo is recognized as the pitch of a tone. This becomes a different kind of pattern recognition, similar to timbre or the discrimination of vowels, when the pitch becomes much higher. On the other hand, with too long a time span, the series is experienced as independent events, rather than as a rhythm. We can, however, unconsciously recognize a series with a very long time span as a kind of rhythm pattern.

In discussing the structure of rhythm, we can focus on the typical two-part structure and the mix of layers of rhythms at different levels, like expectation-confirmation or implication-realization. We can also consider arsis-thesis in Gregorian chants, which means the same structural characteristics as previous combinations. These concepts can not only be used to formulate various rhythms but are also meaningful for interpreting rhythms and examining the essence of rhythms.

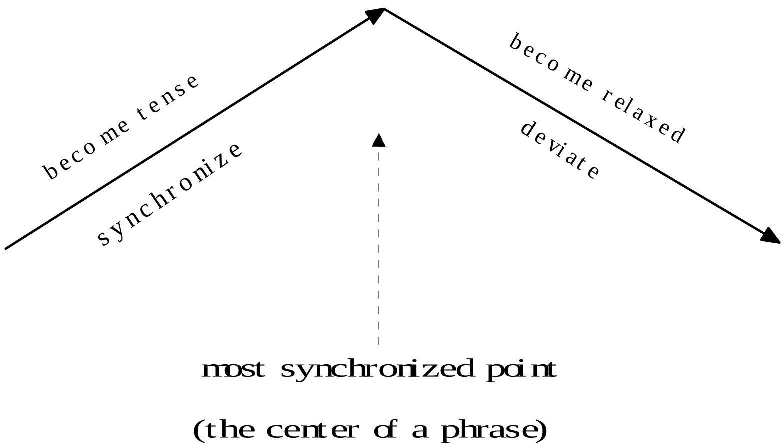

Fig. 2. The basic pattern of soft entrainment in music. In this model, synchronization indicates tenseness and deviation indicates relaxation.

Now we explain the outline of these rhythm theories. In this paper, a “phrase” means every level of a grouping unit of rhythm (or including melody). A phrase is divided into two parts, with the transition point at the middle of the phrase. This transition point is variously called a “climax”, “peak”, “accent”, “ictus”, “point”, etc. The first part is characterized by tenseness, rise, acceleration, and strengthening, while the second part is characterized by relaxation, fall, deceleration, and weakening. This is just like the rise and fall of the feet while walking, or the situations before and after a goal at a horse race. This pattern is important as a basis for making performances involving temporal rhythm (like music) vivid, and it is also known as a practical guide for performance.

Now, we assume that during the tense part the rhythm becomes more synchronized, while in the relaxed part it deviates more and more. Thus, the structure of soft entrainment can be described as having the greatest deviation at the first point of a phrase the greatest synchronization at the tensest point in the middle of the phrase, and once again the greatest deviation again at the end of the phrase. This basic soft entrainment structure is referred to as "deviate-synchronize-deviate" (Fig. 2).

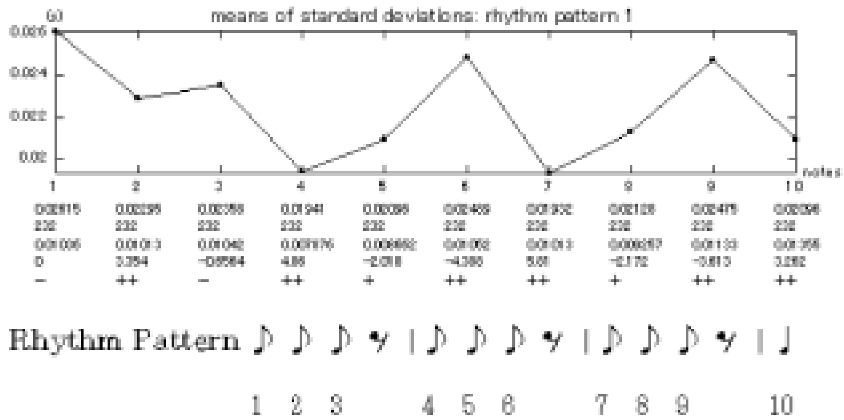

Fig. 3. The fluctuation of the standard deviation of tapping times among five subjects for the mean value of many sessions. As the line falls, the more the phrase is synchronized. The rhythm is a traditional Japanese pattern (san-bon-jime).

We show a sample of a soft entrainment pattern from our experiments (Fig. 3)[3]. Five subjects tapped specific rhythm patterns according to a traditional Japanese pattern ("san-bon-jime"). The vertical axis represents the standard deviation of tapping times among the subjects, which is a parameter corresponding to asynchronization (the data is based on the mean values of many sessions). The 4th, 7th, and 10th notes are the most synchronized points of this phrase and have accents at the same time. The figure also shows the deviation both at the beginning and at the end.

Moreover, the first note of a phrase needs to be synchronized to some degree in order to start the music smoothly, while Fig. 5 shows the result of a simple rhythm pattern with little musical context. Therefore, we should assume that there is a

[3] The paper including this figure has not been published yet.

synchronizing part before the beginning of a phrase. This is usually shown as a “preparation beat”, often by a conductor. Thus, typical music phrases begin by being somewhat tense. We should also mention that very often the tensest point of a phrase is nearly at the end, instead of the center; in other words, the climax of a musical work is likely to be near its end.

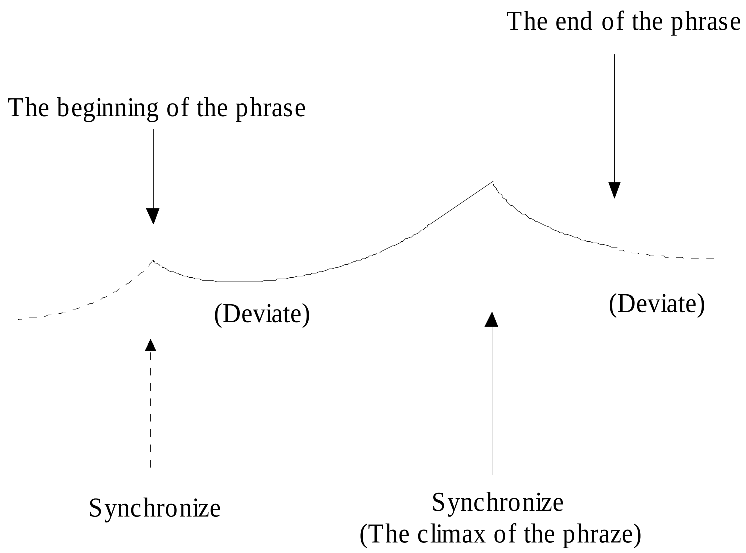

Fig. 4. An image of actual soft entrainment in music. There is a synchronizing part before the beginning of the phrase, and the peak is located near the end.

Based on these concepts, we should change the basic soft entrainment pattern to a more realistic model with a small synchronization at the beginning of the phrase, the most synchronized point near the end, and a somewhat deviating part in the middle (Fig. 4). Smaller clusters of soft entrainment can also occur during the main phrase.

5 Discussion

This section deals with a few topics related to entrainment in music. First, we consider the psychological structure of musical expression. In playing music we of course have the relevant emotion in mind to be expressed through the music, which causes us to try to play more spontaneously. On the other hand, the ensemble situation tends to force us to cooperate with other players, namely through synchronization or just entrainment. As a result, expression based on emotion would tend to have an effect opposite to that of entrainment. In fact, to “express” means to bridge the gap between emotion and entrainment. That is, expression is subject to the conflict between emotion and entrainment, in terms of creating entrainment and making musical phrases vivid. We call such a connection in an ensemble the “EEE” model, which stands for emotion, expression, and entrainment. We think that in this model the expression is the most artistic activity.

Second, the relationship between entrainment and consciousness is a bit troublesome. Some people might say that entrainment does not exist in a musical performance because performers tend to synchronize clearly and consciously. Synchronization in music can not be achieved so easily, however. Imagine how we can synchronize our rhythms. We need some kind of sign to indicate the time to play. Although one might suggest that the “preparation beat” performs this function, it is not sufficient if the beat sign is indicated by an independent point in time. At least two beats are required to predict the playing time precisely, and moreover, people are not as punctual as computers. Consequently, we need a more sensitive way to feel the right time instead of a mechanical calculation.

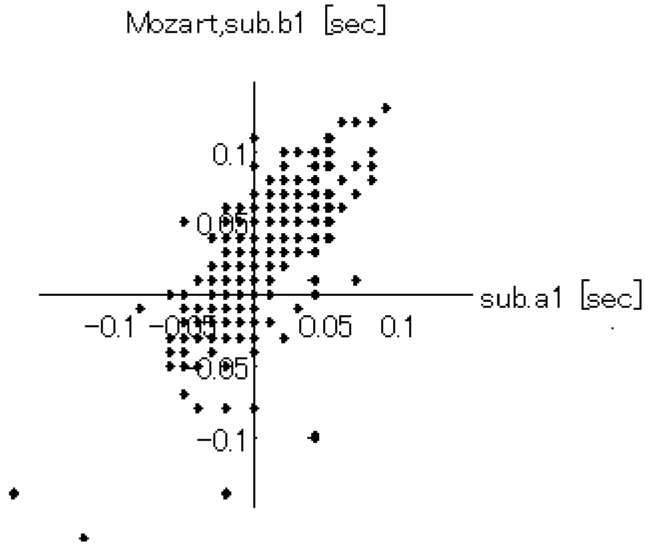

Fig. 5. The correlation of time lags between two subjects tapping with a musical sound. This correlation implies the presence of entrainment, aside from the subjects’ intention.

We think that a natural phenomenon like entrainment can create synchronization, even aside from players’ intention. We show a sample of such entrainment from our study (Fig. 5) [14]. In this experiment, two subjects tapped with a musical sound, and we precisely measured their tapping times. The figure indicates the correlation of the time lags to the stimuli time between the subjects. Such time lags are so spontaneous that they can not be consciously fit with each other. The correlation thus implies the existence of entrainment between the subjects.

Finally, soft entrainment should be considered as the result of our concentration or attention interacting with external rhythms. As a performer there are three kind of rhythms to consider: the external rhythm created by the performer, the external rhythms created by other performers, and the internal rhythm. The connection between the external and internal rhythms was discussed carefully by Jones in terms of a basic notion of entrainment [15], and the ideas of a limit cycle and attentional energy are very motivating to us. Although our model is currently insufficient to express these ideas, we agree that attention plays an important role during performance in an ensemble. The question is whether the attentional energy and emotional (expressional) energy have the same tendency or not. In our model, the level of attention focused on synchronization is maximized at the synchronized point, while the emotional energy explodes during the deviating part. We should investigate this idea more thoroughly.

6 Conclusion

We proposed and introduced a new concept of entrainment for rhythmic ensembles. We should conduct more advanced investigation of this notion. We need to test the practical effect of entrainment in music and consider the connection between external information in a rhythm ensemble and the internal workings of the mind. This should include an experimental study measuring biological parameters such as EEG, heartbeat, and breath. Above all, it is important for us to study the factors that produce deep musical impressions while playing and listening to all kinds of music.

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