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Dynamics and Sociality of Synchronized Arousal between Dancer and Audience in Breakdance Battle Scenes

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Abstract

This study investigated heart rate synchronization (synchronized arousal) between performers and audience in a real-life dance battle. Although similar phenomena have been observed in some rituals, no studies have been conducted on art performances, such as dance and music. We organized a dance battle and measured the heart rate of both the dancers and the audience during the actual performance. The degree of heart rate synchronization was calculated using cross-recurrence plot/cross-recurrence quantification analysis. The results show that 1) heart rate synchronization between the dancers and audience does occur in dance battles, 2) the degree of heart rate synchronization varies depending on the social relationship between the dancers and audience, and 3) the degree of heart rate synchronization dynamically changes as the performance progresses. These findings suggest that embodied, physiological, and social aspects are involved in the process of performance sharing and appreciation.

Keywords: synchronized arousal; synchronization; multi-channel coordination; heart rate; dance battle; audience; CRP/CRQA; field work

Introduction

This study focuses on a dance battle as an example of a performance scene and quantitatively investigates the synchronization and coordination of the heart rate between performers and the audience.

In performing arts, such as dance and music, people in situations such as performers and audience actively interact with each other to create attractive performances. Some argue that a fascinating aspect of performance lies in the interaction among performers, and performers and the audience (Bailey, 1993). The importance of this interaction has been increasingly emphasized from the perspective of the social origins of dance and music (Merker et al., 2015). It has been suggested that people deepen their relationships by sharing their actions and emotions through dance and music. In addition, it is suggested that dance and music have become ubiquitous in diverse societies and cultures because the above mentioned aspects of dance and music have been effective in maintaining and developing communities.

Recent studies have quantitatively investigated this interaction among people in performance scenes. For example, in music, a study statistically examined the leader–follower relationship between parts of an orchestra based on the physical movements of musicians (Badino et al., 2014). Another study used synchronization analysis to examine the coordination of physical movements and performance details between performers in a paired jazz performance (Walton et al., 2018). In dance, the coordination of multiple body parts among dancers in performance scenes has also been studied (Washburn et al., 2014). Shimizu and Okada (2021) proposed a multichannel coordination dynamics framework. They argued that complex interactions between performers, such as synchronization and coordination, occur for multiple behavioral aspects, such as gestures, facial expressions, and dance steps. They also suggested that the aspects of these interactions changes dynamically as the performance progresses, and that these dynamic changes of interaction contain a fascinating point in the art performance.

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As described above, several studies have focused on behavioral interactions among people in performance scenes. They attempted to quantitatively understand the aspects of their interactions. However, it is not sufficient to investigate only the behavioral aspects of people to fully understand the complex interactions in a performance scene. In addition, it is necessary to comprehensively examine the internal physiological and emotional states of performers and audience. Konvalinka et al. (2011), who focused on the synchronization of heart rates between performers and the audience, is a good example. Konvalinka et al. (2011) attempted to directly investigate the sharing of arousal and excitement between performers and audience in performance scenes. They measured heart rate synchronization between performers and the audience during a fire-walking ritual performed in Spain every year. The results of this study suggested that synchronization and coordination of heart rates between performers and audience were observed. Furthermore, they showed that the degree of synchronization and coordination varies depending on the social relationship between the performers and the audience (audience with close social relationships, such as family and friends, or those with distant relationships, such as tourists). These findings are stimulating in that shared arousal between the performer and audience in a performance scene actually occurs and that the psychological distance between the performer and audience influences the degree of this arousal sharing. However, the authors noted that this study dealt with a firewalking ritual that easily generated arousal, excitement, and sharing. It is necessary to carefully consider whether these findings can be widely applied to other performance situations, such as dance and music.

The present study focuses on other performance situations (dance battles) and examines the same questions investigated by Konvalinka et al. (2011). Furthermore, following Shimizu and Okada's (2021) framework of multichannel coordination dynamics, it is expected that the synchronization and coordination of physiological and emotional states, such as heart rate (synchronization of arousal), will also indicate dynamic changes as performance proceeds. This study also investigated dynamic changes in heart rate synchronization (dynamics of synchronized arousal). Based on this discussion, the following three questions were investigated:

1. Does heart rate synchronization between the performer and audience occur in performance situations (dance battle situations) other than the fire-walking ritual?
2. Does the degree of heart rate synchronization change depending on the social relationship between the performer and the audience?
3. Does the degree of heart rate synchronization change dynamically throughout the performance?

By investigating these three questions, we aimed to clarify the complex and dynamic interactions between performers and audience in a performance scene from a physiological perspective.

Fig. 1. Performance Scene from the Dance Battle

Methods

Dance Battle Competition as the Study Field

This study measured data from a real-life dance battle "Sweet Coast Breaks"; held on September 17, 2022. This dance battle was planned and executed to conduct this study in collaboration with the authors and other dance experts who had considerable experience in holding dance battles. The people who participated in the battle (organizers, MC, DJ, dancers, judges, and audience) and the battle rules were almost similar to those usually held in the field.

Here, we provide an outline of the dance battle. Dance battles often include the following two phases: A) Preliminary round to determine the top dancers in the tournament (top 16 in this battle), and B) Main round of the tournament with the top 16 dancers. This study measured and analyzed battles in the main tournament (B); in particular battles after the top eight were selected, in which we could perform the measurement appropriately. Specifically, we analyzed data from

- Dancer A and Dancer B's battles in the Top eight,
- Dancer A and Dancer B's battles in the Top four (semifinals)
- Dancer A and Dancer B's battle in the final.

Given this background, we carefully consulted with the organizers of the dance battle. Therefore, we could extract the dancers most likely to win the tournament in advance, and it was possible to measure the winning Dancer A runner-up Dancer B. To avoid influencing their evaluation, we did not consult the judges regarding which dancers should wear heart rate sensors.

Fig. 1 shows the battle scene. In a dance battle, dancers perform their dances in turn. In this dance battle, dancers' performances were conducted two turns. Although the rules did not define the duration of each performance, our previous studies showed that it was often in the range of 30–60 seconds (Shimizu & Okada, 2018, 2021). To ensure the ecological validity of the data, the order of performances was not predetermined, as is usually the case in dance battles. After the DJ played the music, the dancers determined the order of their performances through nonverbal interactions (facial expressions, gestures, and positioning). This study investigated the synchronization and coordination of heart rates between dancers and the audience during the dance battle.

Participants

We selected three dancers and 11 audience for heart rate measurements. Among them, we used data from the two dancers who reached the finals (hereafter referred to as Dancer A and Dancer B) and 10 audience members whose data showed no significant deficits (hereafter referred to as audience 1 to 10) in the analysis. Data from the third dancer were not used in the analysis because they did not reach the final round. Audience members 1–3 were friends with Dancer A, and audience members 4–6 were friends with Dancer B. The remaining audience (7–10) were undergraduate and graduate students who had no social relationships with the two dancers.

Apparatus

A wearable heart rate sensor (MyBeat: WHS-1, Union Tool Inc.) was used to measure the heart rate. This device measures heart rate activation at 1,000 Hz and records the time interval of activation (RRI: R-R Interval). We prepared the device according to the number of participants and placed it on their chest. Each device was connected to a smartphone via Bluetooth. We adjusted the measurement time for each device according to the time of the smartphone and the timing of the chest tapping just before each battle.

Analysis

Heart rate synchronization and coordination between performer and audience

First, we preprocessed the heart-rate data. The recorded data were heart rate (RRI), which required several adjustments to apply the analysis of synchronization and coordination. We converted the measured event-based time series data (RRI data) to equal-interval time series data (e.g., Kodama et al., 2018). Here, the data were downsampled at 1-second intervals. When no corresponding data existed, we completed the data by conducting a third-order spline completion. The completed data were standardized based on mean and standard deviation, which was used in subsequent analyses.

Using this preprocessed data, we calculated the degree of heart rate synchronization and coordination between specific dancers and the audience. This study applied cross-recurrence plot/cross-recurrence quantification analysis (hereafter referred to as CRP/CRQA) for synchronization analysis. CRP/CRQA is used to investigate the synchronization between the two time-series data. It is developed based on RP (Recurrence Plot), a method for embedding one-time series data in a high-dimensional phase space and visualizing its recurrence state on a two-dimensional plane, and Recurrence Quantification Analysis (RQA), a method for quantifying the recurrence state. This method can be applied to a wide variety of data and is not limited by data size and distribution. This analysis was used by Konvalinka et al. (2011) to verify heart rate synchronization between performers and the audience.

This analysis was conducted in the following order: A) embedding the time series into the state space; B) identification and visualization of the recurrent state of the embedded time series (in CRP, the coordination state between two time series); and C) quantification of the identified recurrent and coordination states. For page numbers, we abbreviated the details of the embedding method (see Kodama et al., 2021; Webber & Zbilut, 2005 in detail). In this study, the embedding parameters were calculated by applying the commonly used average mutual information and false nearest neighbor methods. The state in which the trajectories of the embedded time series were closer than a certain threshold was defined as recurrence (or coordination in the case of two time series). The state of recurrence/coordination was visualized on a two-dimensional plane. For a single time series, the embedded data were aligned vertically and horizontally. For the two time series, one embedded data was aligned vertically, and the other horizontally. Then, the RP/CRP was generated by filling in the corresponding vertical and horizontal time points where recurrence/coordination occurred. This RP/CRP could be considered as a two-dimensional visualization of the point in the time series at which recurrence/coordination occurred.

Based on the RP/CRP, the RQA/CRQA index was calculated to represent the degree of overall recurrence/coordination. Although various indices have been proposed, this study used the following three indices that were often used in synchronization studies: DET (%Determinism), MaxL (Maxline), and L (MeanLine) (Kodama et al., 2021; Webber & Zbilut, 2005). The continuation of the coordination between one or two time series was considered important for synchronization. This continuity was represented by a continuous diagonal line in CRP, where DET was the ratio of consecutive diagonal coordination points to all the coordination points, MaxL was the maximum length of the diagonal line, and L was the average length of the diagonal line. These three indices were considered to have strong relationships with synchronization. In this study, we investigated the aspects of heart rate synchronization between dancers and the audience by focusing on these three indices. For a detailed theoretical background to this analysis, please refer to Marwan et al. (2007) and Webber and Zbilut (2005).

We applied the calculation of heart rate synchronization to various combinations of dancers and audience to test the three questions mentioned in the Introduction. First, to investigate whether heart rate synchronization actually occurred in the dance battle, we calculated the heart rate synchronization between the dancers who actually performed during the dance battle and the audience who watched this performance (hereafter, we refer to this pair as the Real pair).

However, apparent synchronization can occur by chance, even if the two people do not interact. Therefore, this study also calculated the degree of synchronization that occurred by chance in the same pair and compared it with that of the Real pair. For this purpose, we shuffled the heart-rate data of the same dancers and audience in different battles and calculated their synchronization. For example, the heart rate data of Dancer A in the Top eight and audience members 1–10 in the top four (semifinals) were combined. The degrees

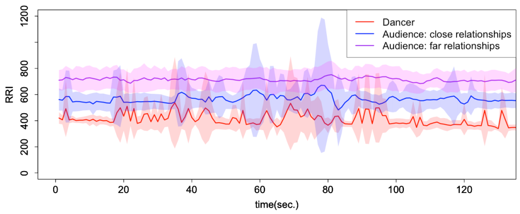

Fig. 2. Mean and SD of the Heart Rate Interval (RRI)

of synchronization and coordination were calculated using CRP/CRQA (this pair was referred to as a Virtual pair).

By comparing the degree of these synchronizations with those of the Real pair, we investigated whether the two people's interactions actually caused heart rate synchronization. We conducted Linear Mixed Modeling (LMM) with the type of Pair (Real/Virtual) as a fixed effect and dancers (Dancer A/B), audience (Audience 1–10), and battles (Top eight/Semifinals/Finals) as random effects to examine the synchronization differences among the Pairs.

Influence of social relationships on heart rate synchronization and coordination

To investigate the second question, we divided the audience into two groups based on their social relationships with the dancers. One group comprised the dancers' friends (Dancer A: Audience members 1–3; Dancer B: Audience members 4–6), and the other group had no direct social relationships with the dancers (Audience 7–10). We compared the degree of heart rate synchronization between the two groups. LMM was conducted with social relationships (near/far) as a fixed effect and dancers, audience, and battles as random effects.

Dynamical transition of heart rate synchronization and coordination

To investigate the third question, the time of each battle was divided into four turns (i.e., the time at which each dancer performed their dance). Using the heart rate data divided by these turns, we calculated the degree of synchronization/coordination using CRP/CRQA. LMM was performed with turns (turns 1–4) and social relationships (near/far) as fixed effects and dancers, audience, and battles as random effects. We investigated the effects of turns, social relationships, and their interactions.

Results

Heart Rate Synchronization and Coordination between Performer and Audience

Fig. 2 shows the *mean* and *SD* of the heart rate interval (RRI). We also visualized differences in social relationships, which are described in the next section. This figure shows that the RRI of the dancers was consistently shorter than that of the audience (a shorter heart rate cycle). Furthermore, we can observe that the fluctuations of the RRI generally match those of the audience, especially those who have close relationships with dancers.

Figs. 3 and 4 show the degree of heart rate synchronization between the dancers and the audience in Real and Virtual pairs. The CRP shows that the Real pair has more black dots,

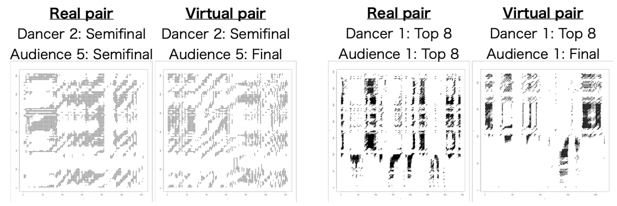

Fig. 3. Cross Recurrence Plot of the Real and Virtual Pair

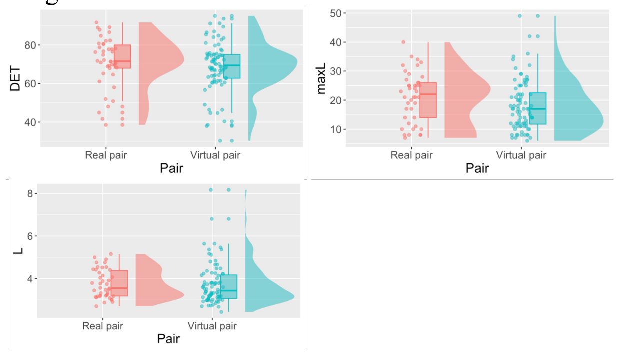

Fig. 4. CRQA Values of the Real and Virtual Pair

indicating recurrence/coordination, and more long black diagonal lines, indicating synchronization and coordination over time (Fig. 3). The CRQA values were as follows: For DET, Real: 71.21, Virtual: 68.86; for maxL, Real: 1782.21, Virtual: 1050.83; and for L, Real: 21.12, Virtual: 18.01. These results exhibited high synchronization and coordination values for the Real pair (Fig. 4).

The results of LMM suggest that the pair type had a significant effect on maxL. For DET, the standardized coefficient of Pair type was 0.023, p = .108; for maxL, 3.11, p = .020; and for L, 0.013, p = .93. Although there was no clear significant effect of pair-type difference on all indicators, the effect is clearly seen in maxL, which is considered to be one of the most important indicators of synchronization/coordination. Furthermore, considering both the CRP and CRQA values, the degree of synchronization and coordination was higher in the Real pair than in the Virtual pair. These results suggest that heart rate synchronization and coordination occurred between dancers and the audience in battle scenes.

Influence of Social Relationships on Heart Rate Synchronization and Coordination

Next, we investigated the degree of synchronization and coordination between dancers and the audience with different social relationships. Fig. 2, 5, and 6 present the results. Fig. 2 shows that the audience with close relationships with the dancers had a shorter RRI (shorter heart-rate cycle). In addition, we can observed that the fluctuations of the RRI seemed to match higher with the dancers' RRI than the audience with far relationships.

CRP shows more black dots (representing recurrence/coordination) and black diagonal lines (representing synchronization and coordination over time) in audiences with closer social relationships (Fig. 5). The CRQA values were as follows: For DET, 1810.83 for close

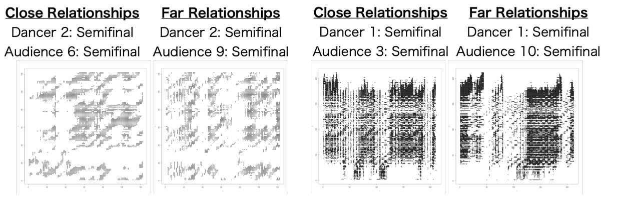

Fig. 5. Cross Recurrence Plot of Close/Far Relationships

Fig. 6. CRQA Values of Close/Far Relationships

audience and 1760.75 for far audience; for maxL, 22.89 for close and 19.79 for far audience; and for L, 22.89 for close and 19.79 for far audience (Fig. 6). These results suggest that there was a higher degree of synchronization between dancers and the audience with close social relationships than between dancers and audience members with far relationships. Additionally, the LMM results suggested significant effects of social relationships on DET, maxL, and L. For DET, the standardized coefficient of social relationships was 0.053, p = .010; for maxL, 3.10, p = .014; and for L, 0.42, p = .028. These results suggest that the heart rate synchronization occurred more strongly between dancers and a socially close audience in actual battle scenes than between dancers and a far audience.

Dynamic Transition of Heart Rate Synchronization and Coordination

Finally, we investigated dynamic changes in the degree of synchronization by turns and social relationships. The results are shown in Fig. 7. The CRP shows a change in the frequencies of the black dots and black diagonal line with turns (Fig. 7). CRQA values were calculated as follows: In the audience at close social relationships, for DET, turn 1: 76.00, turn 2: 82.16, turn 3: 71.37, and turn 4: 81.60; for maxL, turn 1: 91.92, turn 2: 74.08, turn 3: 89.08, and turn 4: 40.25; and for L, turn 1: 10.58, turn 2: 11.83, turn 3: 11.17, and turn 4: 8.42 (Fig. 8). These results suggest that the degree of synchronization changes with turns. Specifically, the degree of synchronization was slightly lower at the beginning of the battle, higher in the middle, and lower again at the end. However, for audiences with far social relationships, for DET, turn 1:75.88, turn 2: 70.53, turn 3: 67.41, and turn 4: 80.86; for maxL, turn 1: 96.00, turn 2: 54.00, turn 3: 73.94, and turn 4:50.38; and for L, turn 1: 10.44, turn 2: 7.63, turn 3: 8.06, and turn 4: 7.75, indicating that the degree of synchronization decreased with the number of turns.

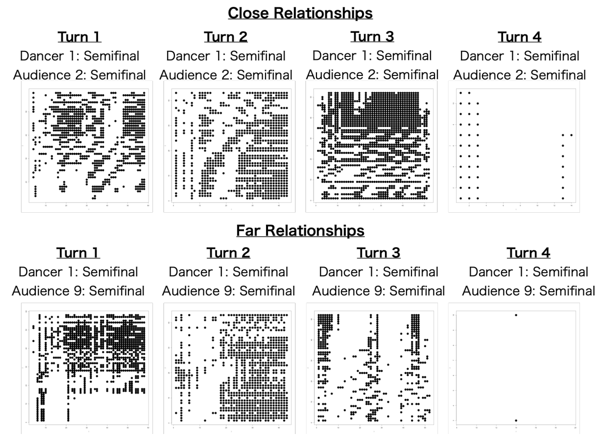

Fig. 7. Cross Recurrence Plot of Turns 1–4 with Close/Far Relationships

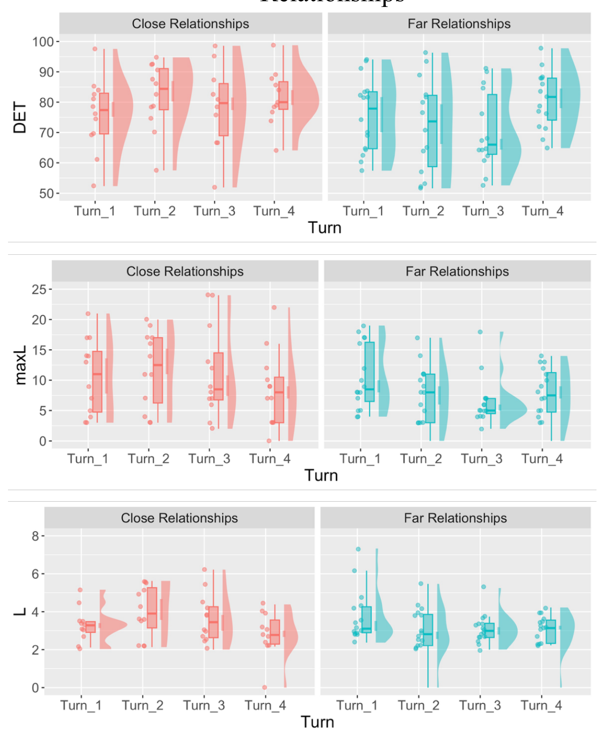

Fig. 8. CRQA Values of Turns 1–4 with Close/Far Relationships

The LMM results suggest significant effects for DET and L. For DET, the standardized coefficients for turn 3 were -0.085, p = .078, and for L, turns 2–4 were -1.05, -0.96, and –1.10, p = .034, .054, and .027, respectively. An interactive effect was also confirmed for turn 2 and social relationships, with a standardized coefficient: 1.36, p =.072. These results suggest that, overall, heart rate synchronization between the dancers and audience decreased with the number of turns. However, a different trend was observed between the dancers and audience with close social relationships, suggesting that the degree of synchronization may increase during the battle and decrease at the end.

Discussion

This study focused on people's internal aspects (physiological and emotional states) and investigated the complex interactions between performers and the audience during performance scenes. We organized a dance battle competition and measured the heart rates of the winning and runner-up dancers and the audience who watched their performances. We calculated the degree of heart rate synchronization between the dancers and audience using CRP/CRQA. The results revealed the following three findings:

1: In the dance battle, heart rate synchronization (synchronized arousal) occurs between the dancers and the audience.

2: The degree of synchronization varies depending on the social relationship between the audience and dancers. Stronger heart rate synchronization is observed when the audience and dancers have a close relationship.

3: The degree of synchronization changes dynamically throughout the performance. This change depends on the social relationship between the audience and dancer. Specifically, for the audience and dancers with close relationships, synchronization increases in the middle of the battle and then weakens at the end. Conversely, synchronization between the audience and dancers with far relationships consistently weakens throughout battles.

A previous study argued that heart rate synchronization occurs between performers and the audience during a fire-walking ritual (Konvalinka et al., 2011). This also suggests that careful consideration is needed when generalizing to other performance situations. Considering the findings of previous studies and the results of the present study, heart rate synchronization, which indicates the sharing of excitement, can be considered a phenomenon that occurs widely in other art performances such as dance and music. From the audience's perspective, this phenomenon provides fascinating insights. Studies on performance and artwork appreciation have focused mainly on higher-order cognitive processes (e.g., Pelowski et al., 2016). However, the findings indicate that the embodied, physiological, and social processes of heart rate synchronization with the performer may be intensely involved in the appreciation process. How these physical, physiological, and social processes relate to emotional experiences and cognitive evaluations during appreciation warrants further investigation. We are currently conducting an exploratory study of this aspect using heart rate and cognitive evaluation data of judges.

Another finding worth discussing is that the degree of heart rate synchronization (shared arousal) varies depending on the relationship between the audience and dancer. Konvalinka et al. (2011) discussed the background of this change in terms of the degree to which the audience could mentally overlap themselves with the performers. The audience subjectively experiences the tension and excitement faced by the performers. The results shown in Fig. 2 may support this explanation; the RRI value of the audience with close social relationships had shorter cycles and was closer to that of the performer's. Further, based on studies on imitation, intention comprehension, and empathy, the above processes of superimposition and empathy may occur (e.g., Meltzoff & Moore, 1983). Based on this discussion, we can infer that the appreciation of performances, such as dance and music, involves a social process that goes beyond the perception and cognitive processing of objects. This aspect is considered to strongly influence emotional experiences such as being moved. In the future, it will be necessary to comprehensively investigate the process of performance sharing from embodied and social perspectives.

Although the third finding is interesting, some aspects are difficult to interpret. This can be explained by the process that heart rate synchronization (synchronized arousal) usually peaks at the beginning of a battle and then declines consistently throughout the performance. We can also explain that the degree of this decline is mitigated/complemented by the close social relationships between the dancer and audience. This complementation of social relationships can also be explained by assuming the above processes, such as intention, comprehension, and empathy. However, we cannot provide a sufficient explanation for the consistent decline in heart rate synchronization throughout the battle. Heart rate synchronization may weaken as dancers continue to perform, and their heart rate variability becomes strong. It is also possible that the performance was not sufficiently interesting, and that the audience's arousal was out of sync with that of the dancers. However, further investigation is required.

The limitations of this study include, first, the small sample size, which limits the generalizability of our findings. While this study had high ecological validity by targeting natural dance battle scenes, the number of dancers and audience that could be measured was limited because of the large amount of equipment and researchers. In the future, verification based on a sufficient number of dancers and audience members is necessary to generalize the findings.

Furthermore, this study focuses on specific dancer–audience pair interactions. We could not examine the interactions among diverse and extensive groups of people who participated in the dance battle scene. For example, the MC who provided the play-by-play commentary, the DJ who played the music, and the judges who evaluated the performances may have influenced the interactions between the performer–audience pairs. We also could not investigate the interaction between multiple audience members sharing the same scene, as verified by Nomura et al. (2015). Although this study created virtual pairs, and effects other than pair interactions were controlled for in the comparison, it is necessary to include the participants mentioned above in the model and examine their effects. Future studies should go beyond these specific two-party interactions, focus on interactions among various people at the battle scene, and comprehensively examine them. Through the above examination, we hope to clarify the overall picture of the complex and fascinating interactions that exist throughout dance battles and art performances.

Acknowledgments

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