Real-time Modification of Music with Dancer's Respiration Pattern

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ABSTRACT
This research aims to improve the correspondence between music and dance, and explores the use of human respiration pattern for musical applications with focus on the motional aspect of breathing. While respiration is frequently considered as an indicator of the metabolic state of human body that contains meaningful information for medicine or psychology, motional aspect of respiration has been relatively unnoticed in spite of its strong correlation with muscles and the brain.

This paper introduces an interactive system to control music playback for dance performances based on the respiration pattern of the dancer. A wireless wearable sensor device detects the dancer's respiration, which is then utilized to modify the dynamic of music. Two different respiration-dynamic mappings were designed and evaluated through public performances and private tests by professional choreographers. Results from this research suggest a new conceptual approach to musical applications of respiration based on the technical characteristics of music and dance.

Keywords
Music, dance, respiration, correspondence, wireless interface, interactive performance

1. INTRODUCTION
Music and dance have existed from the earliest beginning of the history of mankind as principal genres of performing arts. Based on time and rhythm, they have been closely connected to and influenced each other, and evolved together. However, their mutual correspondence has been an unsolved problem with a long history: in spite of being similar to each other, their characteristic differences restrained the synergy and sometimes made their relationship controversial, in which case one of them had to be subordinated to the other at the cost of its own artistic values. In spite of the efforts made by artists from both sides to overcome this discrepancy, it still remains unsolved.

Focusing on structural aspect rather than emotional one, this constraint can be seen in various elements such as form, theatricality, sonority, tempo, etc. [21, 22]. Among these, inclusive dynamic flow of music is of great importance for choreography: here the "dynamics" of music includes tempo, rhythm and emotional impression as well as the physical scale (e.g., amplitude gain) of music and its sound [22]. The result of choreography is desired to be coherent with this dynamics of music. For example, musical accents or beats may require corresponding reactions of the dancer: both the timing and the intensity of the accents of music need to be reflected in dance, so that agile motions with rotation or locomotion must be accompanied by the beats in music [22] and faster motions makes stronger beats.

In this paper, the issue of the relationship between music and dance is dealt with a technical approach, and a new method to improve their mutual correspondence based on the dancer's respiration is introduced. This research was motivated by discussions with a number of professional dancers and dance-majoring students on the role of respiration in dance: virtually every one of them emphasized the importance of respiration with motion and its relationship to music. Based on this fact, we focus on the motional aspect of respiration and developed a system to control selected features of music for dance by breathing. Compared with previous uses of respiration in music and dance, this is distinctive in that the main focus is not on the metabolic aspects of human body but on biomechanics of motion. Specific mapping strategies as well as hardware implementations are also discussed and evaluated.

2. RESPIRATION
2.1 Respiration as an Interaction Modality
Respiration is generally treated as one of the conventional biofeedback factors. These are closely related with the metabolic system and widely used in medicine [9, 13]. This approach developed and applied to emotion [6, 10, 14], game [11, 17], Workload monitoring [20].

Although these applications have different goals, they are commonly interested in the metabolic aspect of the respiration. Within such aspect, the most important thing of respiration is how much air is consumed smoothly. Frequently used features are the average amplitude, frequency, and deviation of the respiration, which corresponds to spectral features.

2.2 Respiration and Music
There are some musical application cases of biofeedback including respiration, and the typical format of them is a bio-music. Filatriau [7] introduced his works that used brainwave, respiration and heartbeat. Main weakness of his first work with EEG-driven sound synthesis was said to be its lack of playability. Respiration and heartbeat signals were used in his second work. Two features of respiration, airflow and thoracic volume, were measured and used to control the center frequencies of different band-pass filters for subtractive synthesis: here respiration events are directly reflected in sound, which is similar to the concept proposed in this paper. Tahiroglu used the skin conductance, electrocardiogram, and

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respiration for sound synthesis [15], in which respiration rate controlled the pitch, modulation points, and amplitude of the frequency modulation. In these two examples it is hard to find deep consideration on the meaning of breathing. Meanwhile, Groux explored the utilization of the emotional aspect of the physiological data to control high-level musical attributes [8]. His research is inspiring for he focused on the higher-level features of the physiological data rather than simply dealing with raw signal.

2.3 Mechanism and Control

Mechanically, respiration process is operated with numerous thoracic and abdominal muscles. Functions of these muscles results in thorax deformation and the pressure gradient in the respiratory organs, and it causes the airflow for gas exchange [4].

The respiratory center that controls ventilation is designed to alternate inspiration and expiration rhythmically. The rate and amplitude of these ventilator movements is under the direct control of the respiratory center, which are stimulated by the increase of CO_2 increase in blood.

Meanwhile, neural input from the motor cortex stimulates the ventilation during the exercise. Also, it enables the voluntary control of breathing that allows an individual speaking, singing, or playing a wind instrument. The motor cortex also allows the motion and breathing to be integrated during exercise. It is the uniqueness of respiration comparing to other biofeedback factors, and we can expect different approach to utilize the respiration.

2.4 Respiration and Muscular Activity

Compared to metabolic correlation of breathing, relation between the respiration and muscle activity has been a minor research interest [3]. Still, some researches show the meaningful correlation between the respiration and muscle activity. They focused on how breathing influences the instantaneous strength and flexibility of muscles [3, 12] and smoothness of motion [5]. These correlations can be considered to be the result of structural change of bones and muscles during the respiration process rather than an influence of the oxygen and energy consumption, and it is supposed to be anatomically related to the performance of other skeletal muscles [12].

The principle of the breathing is explored by dancers with their sense from early history of dance, and their experiences are adopted and accumulated to the technique and education of dance.

3. SYSTEM DESIGN

3.1 Basic Concepts

3.1.1 Why Respiration?

For the homeostasis of the body, most biofeedback features are generally autonomous and not voluntarily controllable. Respiration is one of the exceptions in this aspect: it can be controlled voluntarily and instantly in some degree (up to a certain degree). Considering that a number of interactive musical pieces with biofeedback suffers from the common problem of controllability [7, 16], this is of great importance. The fact that respiration mechanism is more closely connected to the inclusive mechanical state than other types of biofeedback is another benefit.

In terms of low- (or zero-) latency controllability, respiration is less advantageous than typical gesture detection methods using accelerometers, IR marker, computer vision, Kinect, etc., which generally provide faster, more responsive control features as well as more detailed information on the movements of dancers. However, in the unique area of dance and performing arts, they may expose their limitations: as the goal of this research is to find the correspondence between music and dance, the inclusive flow or energy of entire body is more important than motion data of each body segments. In this context, respiration becomes a more direct and efficient approach with less restraints on the dancer's movement and more expressivity on the stage.

3.1.2 Spectral vs. Temporal Approach

In general, previous applications of respiration focused on its spectral feature only; this approach is advantageous for long-term status of the body which provides the metabolic information. Considering the uniqueness of respiration and its use in dance, however, we take a temporal approach to detect the instantaneous changes of breathing for the following reasons:

- Respiration is a very slow activity compared to other physiological features, which makes system latency too long with the spectral approach.
- As dancers always control their respiration intentionally depending on his/her movement (as mentioned before), the process is hardly periodic and spectral approach becomes less useful.

3.1.3 Score-based Musical Interface

The musical mappings for this system are designed with the score-level control [18] in mind. In this structure, we can consider two dimensions of feature control – tempo and other instantaneous parameters (e.g., pitch, loudness, and timbre).

While improvisatory variation of tempo gives more excitements to music [22], it can be confusing for dancers in a traditional paradigm because they are trained to dance to "regular" rhythms [2]. Therefore, we leave the control of tempo as a future work and focus on dynamic features of music.

3.2 Structure

Basic structure of the system is the real-time modification of pre-defined or randomly generated music sequence in progress by means of respiration of user. Respiration signal is measured with a gauge pressure sensor on the mouth of the dancer (Figure 1), and it is amplified and transmitted to a computer wirelessly in real-time. For sampling and transmission of the signal, Arduino FIO was used. Sampling and transmission rate was set to 200Hz, which would be big enough for respiration detection.

MAX/MSP is used as a main platform. The pressure signal is sent to a MAX/MSP patch and preprocessed with digital filters to eliminate DC-offset and reduce noise. The filtered signal is mapped to musical parameters considering the correlation between respiration, dance motion and musical parameter. The mapping strategy is the key point of this research. The interpreted music parameters modulate given MIDI music sequence. The modified MIDI note is sent to the virtual instrument Ableton Live to synthesize the sound.

The goal of this research is the correspondence between the motion and music. Therefore, two correlations are needed to be considered in mapping design: correlation between the motion and respiration, motion and music. Musical parameters are designed considering these correlations. Two versions of mapping were attempted, and details of those mapping strategies and evaluations will be discussed in the next chapter.

Figure 1. Respiration sensor device

4. MAPPING STRATEGIES AND EVALUTATIONS

4.1 First Version

Inhalation and exhalation is said to be related to the tension and relaxation of the body, which are dynamic characteristics of dance. As the pulmonary volume is an accumulation of airflow and velocity of the airflow is proportional to the pressure [19], integration of the sensor pressure was used as an index of the pulmonary volume.

In fact, musical dynamics is a complicated term that is affected not only by loudness but also rhythm, pitch and etc. [21] However, as the main goal of this research is to improve the correspondence of given music, control feature is limited to the dynamic. The ventilation state is connected to the music loudness to raise it as the pulmonary volume increase (inhalation). In addition to the over-all loudness control, loudness of accompaniment part was controlled separately to change the affluence of music. It was easily implemented with use of multi-track MIDI file.

The first mapping system was demonstrated on stage at HANPAC Performing Art Center as a part of a new-media performance piece 'ADC Project - Don't Imagine'. A dancer was requested to choreograph with variety in motion with respect to the tempo and energy. Music was given with a pre-defined piano MIDI score, and it was played and modulated with the aforementioned mapping strategy. And visual effect was displayed with projection and modulated with raw pressure signal.

After the performance, a brief interview with some audiences was made. Audiences said they could not recognize the linkage between the music and dance. With the additional interview with the dancer, the problems of the first mapping strategy were discussed. First, loudness control with the pulmonary volume exposed conceptual error. Although the pulmonary volume is related to the tension and relaxation of the body, the two states are static characteristic rather than dynamic. Hence it came out to be inappropriate to map the tension with the musical dynamics. It would be more appropriate to think the dynamic event of the body to occur with the transition between the tension and relaxation.

Another problem seen in the dynamic control is latency. Inhalation or exhalation process is quite slow enough for human to recognize the time that pulmonary volume reach the peak with perceptible latency. It is critical to the correspondence of dance and music.

4.2 Second Version

4.2.1 Structure

Another mapping strategy was designed after the evaluation of the first one and exposed problems were taken into account. First, basic concept of dynamic control changed. As aforementioned, a dynamic event of motion occurs with transition between the tension and relaxation. It corresponds to the respiration event rather than pulmonary volume. It means that it is more appropriate to use pressure value that is proportional to the airflow [19] rather than the estimated pulmonary volume.

Another problem was latency. Use of pressure value instead of pulmonary volume provides less latency. Still, the respiration is so slow that perceptible latency happens while reaching the pressure peak. To reduce it even more, the concept of jerk is adopted.

Jerk is a physical term that represents the rate of change of acceleration, or force [1]. As the jerk is the derivative of the force, physically corresponding dimension must be the derivate of the pressure assuming that the areal dimension is constant. Hence it was decided to use this jerk as a basic factor for music loudness control. Simple peak detection algorithm is applied to detect and figure out the height of the jerk peak.

Control parameter is designed like an ADSR envelope. Magnitude of a jerk peak decides attack level. Attack and release time is fixed to 0.4second. Release and decay part is made by adding raw pressure signal (Figure 2).

The biggest advantage of using the jerk is the minimized latency. Comparing to the estimated pulmonary volume and pressure, it has very short latency within 20ms. Another advantage is achieved by the physical meaning of the jerk. Jerk is the rapidness of pressure, and it represents the rapidness of breathing. Breathing is not only categorized with deep and shallow, but also with rapid and smooth. Deep breath is mainly related to the big or relatively smooth motions while the short breath is related to the more rapid movement. This short breath shows the bigger jerk value that we can achieve appropriate music accent for it.

As the dynamic event of the motion happens with both direction of the transition, from relaxation to tension and vice versa, both of them were regarded as a positive factor for music dynamics. In other word, absolute value of the signal was connected to the music loudness.

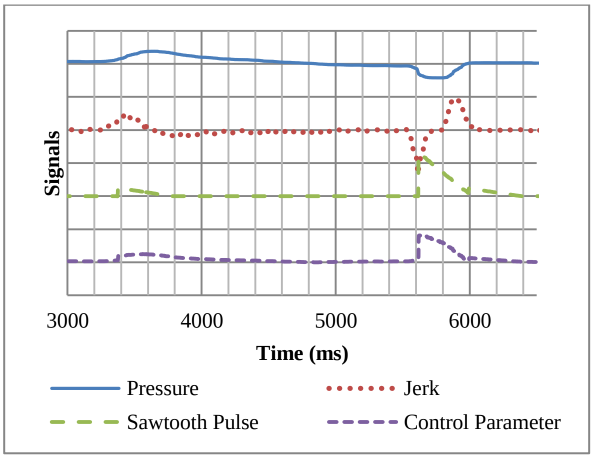

Figure 2. Signal flows of each step of the musical mapping

4.2.2 Evaluation

The second mapping strategy was tested by a veteran contemporary choreographer who was thought to be well experienced in respiration control with improvised movement and musicality as a dancer, which are important abilities for this research. Music sequence was replaced with a simple algorithmic random percussion rhythm to minimize bias of dynamic in original music. Recorded data includes video, filtered pressure signal, jerk, control parameter and modulated music data. Finally, through the interview, he was asked about his inclusive impression and opinion about the system.

Through the observation of those recorded data, we could see that, generally, respiration accent was corresponding to the dynamic of motion such as rise and fall of body, contraction of torso, extension of torso and agility of the movement. Especially, such a pattern appeared remarkably during the dancer was doing athletic techniques like jump, kick and turn. The control parameter that derived from the pressure modulated the loudness of the music. However, modulated accent was frequently not big enough to overwhelm bias of the initial accents of the rhythm sequence. Further adjustment of the mapping strategy might be required.

In addition to the data recording, we interviewed the choreographer about the performance and expectation of the system. In conceptual aspect, as other many dancers, he emphasized the importance of the coupling between the motion and breathing. He agreed with that his movement had been generally well reflected to the music and the signal flow.

On the other hand, he claimed that the mask made him more breathless after he moved a lot, and it made him hard to control the respiration, which caused the respiration pattern more fluctuating and irregular.

5. CONCLUSION

In this research, musical application methodology of biomechanical aspect of the respiration to improve the correspondence between the music and dance has been explored. While the prior researches dealt with the respiration with spectral approach in metabolic aspect, motional aspect of the respiration can be more properly explored with temporal approach. Consequently, this research showed the potential of the new conceptual approach to utilize the respiration for musical use.

There are still unexplored motional features of the respiration. While the test result of pulmonary volume and difference between the inhalation and exhalation was undesirable, those are very important features that every dancer emphasizes. It has large potential if proper corresponding musical features are found. Through the motional approach that takes the respiration technique and pattern of performer into account, more various and meaningful musical utilization of the respiration is expected.

Supplemental materials for this paper can be found at: http://aimlab.kaist.ac.kr/~badclown/respiration

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