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Movement Characteristics of Entire Bodies in Dancers' Interaction

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Abstract: The purpose of this research is to show movement characteristics of bodies during dance performance. We examined bodily characteristics of dancers when moving and conforming to other dancers. Specifically, we analyzed paired dancer movements through motion capture and compared all body-part characteristics based on data derived from cross-correlation analysis and variance-covariance matrix using an exponential map. We found that the correlation coefficients of speed between the head, shoulders, and knees of dancers were significantly high. The values of variance-covariance through the exponential map based on velocity were positively high between the shoulders vertically, and the hips and knees in a front-back direction. The results indicated that not only the legs but also the shoulders of both dancers move at a similarly fast rate when they coordinate and synchronize with one another.

Keywords: Dance, Movement, Interaction, Motion Capture, Cross-correlation, Variance-covariance Matrix, Exponential Map

1. INTRODUCTION

Recent human-computer interaction research using robots and avatars has focused on nonverbal elements. Eye contact and gaze direction are used effectively for communication, not only between humans but also between humans and robots [1]. Furthermore, for good communication it is important to use not only eye contact but also hand gestures and body movements [2-5].

Investigating the essential elements of human-to-human nonverbal interaction is critical. Previous research on human interaction [6] has examined temporal and spatial relationships of two people playing a game in which they were required to carry a bar to a goal without verbally communicating. The two players exchanged roles several times during the game, and their communicative relationship was demonstrated by observing each partner's bodily movements and eye contact. Other research [7] has investigated how two players conform during a piano duet. The results showed that pairs coordinate movements when playing the piano as when taking a breath in unison. In addition, when the players reached a difficult section of music that required a carefully unified performance, they followed not only each partner's facial expressions and eye contact but bodily movements as well.

Coordinating and synchronizing paired movements in a dance performance is another topic worth considering. Dancers must communicate with their dance partners in order to coordinate and synchronize movements. When dancers perform, they rarely use verbal communication except during training and practice.

Previous research on dance movements showed relationships between certain characteristic movements and audience impressions [8–10]. They showed that a dancer can express emotions and audience can recognize a dancer's intended emotions through his or her expressions. In other words, the dancer is communicating with the audience. However, these researches focused on the movements of individual dancers and their effects on the audience. Dance performances can include any number of dancers.

We examine dancer interaction during dance performance by analyzing communicative features of bodily movements between dancers, and review results from three-dimensional coordinate and rotation data, and evaluate the utility of each type of motion data.

2. METHODS

2.1 Dancers

Six male dancers (mean age of 22.5 years), all experts in street dance, especially hip-hop, locking, and soul dance (mean of 5.2 years of dance experience), participated in this research.

2.2 Apparatus

We used a 3D motion capture system (Motion Analysis Corporation, California) with 15 cameras to capture and record bodily movements at a sampling rate of 120 Hz. Thirty-two reflective markers were attached to the body of each dancer (Fig. 1).

2.3 Procedure

In the experiments, two dancers were randomly paired. First, both dancers stood 2.0 m apart and performed down-up dance movements, i.e., repetitive motions of knee bends and knee extensions with steps. These are basic dance exercises that help dancers establish a sense of rhythm.

The follower was requested to synchronize with the leader. A single task included eight counts or beats.

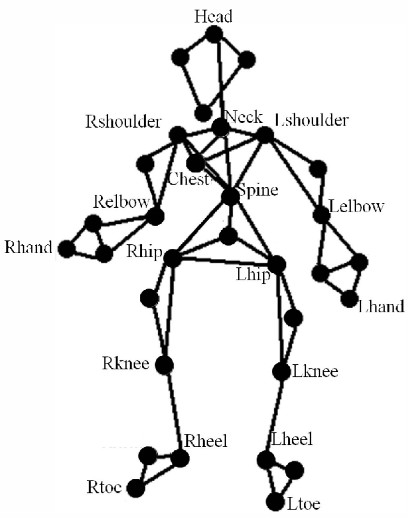

Fig.1 Position of reflective markers

Dancer pairs performed each task four times. In other words, data were captured on 32 counts for each task. The tasks began after a short practice session.

2.4 Cross-correlation for data analysis

Three-dimensional coordinate analyses were conducted by using reflective markers attached to the dancers. In addition, the speed of each joint in motion was calculated based on the rhythmic count of the dance. The mean speed for each count was calculated. Cross -correlation coefficients of speed between the leaders and their followers for each count were calculated and compared.

2.5 Exponential map for data analysis

Motion captured data are time series of high-dimensional data. The many motion capture data formats in use today can be divided into two major types, which are three-dimensional coordinates and skeleton hierarchy. Motion capture data formats, such as C3D and TRC, store motion data in a 3D coordinates system, while formats such as ASF/AMC, HTR and BVH store motion data as hierarchical skeleton data.

The three-dimensional positional coordinates posed a problem because they lacked the directional information needed to process the difference in position of the marker size and the physique of the representation's data acquisition. In our research, we had to consider each set of pairs, each articulating the dance motion; we then analyzed the coordination between the bodies of the two dancers, including the direction of movement. To consider the direction of movement, there are many methods, such as: 3x3 rotation matrices, Euler angles, Quaternions, and an exponential map [11, 12]. Essentially, rotations are non-Euclidean in nature because rotating far in any direction will bring you back to the starting point. The use of Euler angles will suffer from gimbal lock, and the loss of rotational degrees of freedom. In order to avoid the aforementioned problems, there are two solutions: (1) the set of unit quaternions embedded in four-dimensional space and (2) the exponential map in three-dimensional space. The second solution is suitable for this research because we are interested in parameterizing a three degrees of freedom (DOF) rotation without the gimbal lock, and this interpolates rotations well, using Euclidean interpolates, such as cubic splines.

The exponential map maps a vector in R^3 describing the axis and magnitude of a 3-DOF rotation to the corresponding rotation. We can calculate the exponential map by using the Rodrigues' Formula [11] as follows:

$$e^{[0,0,0,1]^T} \text{ if } v = 0$$

$$e^{v} = \left[\sin\left(\frac{1}{2}\theta\right)\hat{v}, \cos\left(\frac{1}{2}\theta\right)\right]^T \qquad \text{if } v \neq 0$$

where $\theta = |v|$ and $\hat{v} = v/|v|$.

2.6 Motion capture data

Motion capture data used in our research comprised three-dimensional position coordinates in a TRC format (Motion Analysis Corporation). First, converting the exponential map was necessary. Therefore, we acquired three-dimensional coordinate values using EvaRT software (Motion Analysis Corporation) in conjunction with the motion capture system. In addition, we created kinematic model calculations from the coordinate value data using a Calcium plugin (Motion Analysis Corporation) for EvaRT. We then obtained body segment data in HTR format. The HTR is the original format used by the Motion Analysis Company. In addition, we converted HTR data to BVH format in order to generate animation using MotionBuilder software (Autodesk Inc., California). The BVH format is originally developed by the BioVision Company (California). It is represented by the configuration data in a "MOTION" section describing the behavior in joint angle values and a "HIERARCHY" section describing the link structure of the target. The coordinate system is based on a right-handed rotation using the Euler angles format. In addition, we converted the BVH data to an exponential map.

3. RESULTS AND DISCUSSION

3.1 Results of cross-correlation analysis

We calculated cross-correlation coefficients for the speed of each body part between dancers when a follower attempts to synchronize movements with a leader. We analyzed cross-correlations for the same body parts of both dancers and constructed a matrix. The results related to Dancers A and B are shown in Table 1.

The vertical and horizontal axes represent Dancers A and B, respectively. When changes in the speed of a body part between each frame are similar, the correlation is high. These correlation coefficients are

Table 1 Cross-correlations of body movements between a pair of dancers

	Head	Lshoulder	Lelbow	Lhand	Rshoulder	Relbow	Rhand	Neck	Spine	Lhip	Rhip	Lknee	Lheel	Ltoe	Rknee	Rheel	Rtoe
Head	0.73																
Lshoulder	0.60	0.40															
Lelbow	0.25	0.52	0.55														
Lhand	0.20	0.27	0.29	0.36													
Rshoulder	0.56	0.47	0.13	0.16	0.60												
Relbow	0.33	0.56	0.36	0.08	0.25	0.16											
Rhand	0.20	0.0	0.32	0.44	0.11	0.22	0.35										
Neck	0.73	0.39	0.10	0.10	0.59	0.17	0.14	0.57									
Spine	0.53	0.50	0.17	0.07	0.55	0.13	0.09	0.59	0.45								
Lhip	0.31	0.22	0.22	0.17	0.22	0.26	0.17	0.26	0.23	0.42							
Rhip	0.33	0.24	0.11	0.08	0.21	0.19	0.15	0.22	0.19	0.48	0.44						
Lknee	0.53	0.54	0.56	0.33	0.59	0.39	0.34	0.45	0.42	0.45	0.49	0.72					
Lheel	0.31	0.36	0.33	0.33	0.36	0.19	0.39	0.22	0.34	0.14	0.13	0.82	0.71				
Ltoe	0.20	0.22	0.23	0.25	0.32	0.34	0.37	0.33	0.31	0.12	0.20	0.20	0.29	0.13			
Rknee	0.46	0.40	0.22	0.16	0.45	0.26	0.04	0.46	0.34	0.44	0.45	0.73	0.76	0.24	0.77		
Rheel	0.37	0.33	0.26	0.16	0.37	0.27	0.09	0.35	0.23	0.11	0.22	0.80	0.78	0.27	0.84	0.75	
Rtoe	0.25	0.29	0.24	0.13	0.39	0.38	0.09	0.31	0.14	0.11	0.26	0.26	0.26	0.27	0.24	0.24	0.17

indicated with a score of 0.70 or higher. Red cells in the matrix in Table 1 indicate those correlation coefficients that are greater than 0.60, whereas those less than 0.60 but greater than 0.40 are shown as orange cells in the matrix.

As shown in Table 1, the correlation coefficients of the head and neck with the head, spine, right shoulder, and knees were high in Dancers A and B. In addition, the correlation coefficients between the knees and shoulders were relatively high. For the hips, the correlation coefficients between a knee and its opposite hip were relatively high. The correlation coefficients between the heels and knees were high. However, the correlation coefficients of the elbows and hands to all other body parts were low. In addition, the correlation coefficients between the toes and all other body parts were low.

The results showed that the correlation coefficients between the hips and knees and among the head, shoulders, and knees were high, despite the fact that the dance movements evaluated in the study were primarily foot-step movements. The results of correlation coefficients between parts of the leg were expected. In other words, we expected that the movements of each dancer's legs would synchronize when dancers conformed to one another's movements. However, the results indicated that dancers used mainly the head, shoulders, and knees to conform to the movements of another dancer.

3.2 Results of variance-covariance matrix using exponential map

We analyzed the variance-covariance matrix between dancers. Table 2 shows these results in relation to each body part of Dancers A and B.

The vertical and horizontal axes represent Dancers A and B, respectively. If the value of the variance-covariance is positively high, the matrix cell is red. If the value of the variance-covariance is negatively high, the matrix cell is blue. These variance-covariance values are based on the velocity of each dancer's body part. Therefore, if a body-part movement of Dancer A is fast and the corresponding body-part movement of Dancer B is similarly fast, the value is positively high. In addition, if a body-part movement of Dancer A is slow and the corresponding body-part movement of Dancer B is slow, the value is positively high. By contrast, when a body-part movement of Dancer A is fast but the corresponding body-part movement of Dancer B is slow, the value is negatively high.

The variance-covariance value of the head and left shoulder in the x-axis was positively but only slightly high. The variance-covariance value of the head in the z-axis and left shoulder in the x-axis was negatively high. The variance-covariance value of the left shoulders in the z-axis was positively high. The variance-covariance value of the right shoulders in the z-axis was positively but only slightly high. The variance-covariance value of right shoulders in the z-axis and right hip in the x-axis was slightly high. The variance-covariance value of the left hips in the x-axis and values of the left hip and left knee and right knee in the x-axis were positively high. The variance-covariance value of the right hips in the x-axis and value of the right hip and right knee in the x-axis were positively high. The variance-covariance values of the left and right knees in the x-axis were positively high.

Values of the left and right shoulders in the z-axis were positively high to the corresponding body parts in the same axis. In addition, values of the left and right hips and the left and right knees in the x-axis were positively high to the corresponding body parts in the same axis. In other words, the shoulders of both dancers moved vertically and at a similar rate of speed. The same were true for the hips and knees of both dancers when moving in a front-back direction.

In addition, values of the left hip and the left and right knees in the x-axis were positively high, and value of the right hip and right knee in the x-axis was positively high. In other words, when the hips of one dancer were moving in a front-back direction at a fast rate, the legs of the other dancer were moving similarly fast.

The results of the variance-covariance matrix indicated that not only the legs of the paired dancers but also the shoulders move at a similarly fast rate during synchronized dance.

Table 2 Variance-covariance matrix using the exponential map of body movements between a pair of dancers

		Head			Lshoulder			Lelbow			Rshoulder			Relbow			Neck			Chest			Spine			Lhip			Rhip			Lknee			Rknee		
		x	y	z	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z	x	y	z
Head	x	0.01																																			
	y	0.01	0.01																																		
	z	0.00	0.00	0.01																																	
Lshoulder	x	0.03	0.00	-0.05	0.01																																
	y	0.01	0.01	-0.01	0.01	0.02																															
	z	0.00	-0.01	0.01	-0.01	-0.03	0.04																														
Lelbow	x				0.00	0.00	0.00																														
	y	0.00	0.00	0.00	0.00	-0.01	0.01		0.00																												
	z			0.00	0.00																																
Rshouder	x	0.00		0.00	-0.01	-0.01	0.01		0.00	0.00	0.01																										
	y	0.00		0.00	-0.01	-0.01	0.01	0.00	0.00	0.00	0.01	0.01																									
	z	0.01	0.00	-0.01	0.01	0.02	-0.01	0.00	0.00	0.00	-0.01	-0.01	0.03																								
Relbow	x	0.00	0.00	0.00	0.00	0.00	0.00		0.00		0.00	0.00	0.00																								
	y	0.01	0.00	-0.01	0.01	0.02	-0.02	0.00	0.00	0.00	-0.01	-0.01	0.02	0.00	0.02																						
	z	0.00	0.00	0.00	0.01	0.01	-0.01		0.00		0.00	-0.01	0.01	0.00	0.01	0.01																					
Neck	x	0.00		0.00	0.00	0.00	0.00			0.00	0.00	0.00	0.00		0.00	0.00	0.00																				
	y	0.00	0.00		0.00	0.00	0.00				0.00	0.00	0.00		0.00	0.00																					
	z	0.00	0.00	0.00	0.00	0.00	0.00				0.00	0.00	0.00		0.00	0.00																					
Chest	x												0.00																								
	y	0.00	0.00		0.00	0.00	0.00				0.00	0.00	0.00		0.00	0.00																					
	z			0.00		0.00	0.00				0.00	0.00	0.00		0.00																						
Spine	x	0.00	0.00	0.00	0.00	0.00	0.00		0.00		0.00	0.00	0.00	0.00	0.00	0.00							0.00														
	y	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00					0.00			0.00													
	z	0.00	0.00		0.00	0.00	0.00				0.00	0.00	0.00	0.00	0.00	0.00							0.00		0.00												
Lhip	x	0.00	0.00	0.01	-0.01	-0.01	0.00	0.00		0.00	0.00	0.00	-0.01	0.00	-0.01						0.00		0.00	0.00		0.06											
	y	0.00	0.00	0.00	0.00	0.01	-0.01		0.00		0.00	0.00	0.00	0.00	0.01	0.00					0.00		0.00		0.00	0.00	0.01										
	z			0.00	0.00	0.01	-0.01	0.00	0.00		0.00	0.00	0.00		0.01	0.00					0.00		0.00	0.00		0.00	0.00	0.01									
Rhip	x	0.01		-0.01	0.02	0.01	-0.01	0.00	0.00	0.00	-0.01	-0.02	0.03	0.01	0.03	0.01				0.00	0.00	0.00	0.00	0.01	-0.01	0.02		0.01	0.07								
	y	0.00		0.00	0.00	0.00	0.00				0.00	0.00	0.00		0.00	0.00								0.00		0.00	0.00		0.00	0.00							
	z	0.00	0.00	0.00	0.00	0.00			0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00					0.00			0.01	0.00	0.01	0.00	0.00	0.03	0.00	0.01						
Lknee	x	0.00	0.00	0.00		0.00		0.00	0.00	0.00	0.00	0.00	-0.01	0.00	-0.01	0.00				0.00	0.00	0.00	0.00	-0.01	0.00	0.04	0.00	0.00	0.02		-0.02	0.04					
	y				0.00		0.00						0.00								0.00			0.00		0.00			0.00		0.00	0.00	0.00				
	z	0.00	0.00	0.00			0.00				0.00		0.00		0.00								0.00	0.00	0.00	-0.01	0.00	0.00	0.00		0.00	0.01	0.00	0.01			
Rknee	x	0.00		-0.01	0.01	0.01	0.00	0.00	0.00	0.00	-0.01	-0.01	0.02	0.00	0.02	0.00					0.00		0.00	0.01		0.04	0.00	0.00	0.04	0.00	0.01	0.00	0.00	0.00	0.06		
	y	0.00	0.00	0.00	0.00	0.00	0.00		0.00		0.00	0.00	0.00		0.00	0.00								0.00		0.00			0.00		0.00				0.00		
	z			0.00	0.00	0.00	0.00	0.00		0.00			0.00		0.00	0.00					0.00		0.00			0.02	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	-0.02	0.00	0.01

4. CONCLUSION

This research examined dancer interaction during dance performance and analyzed the characteristics and relationships of body movement between dancers. We obtained results from cross-correlation analysis using three-dimensional coordinate data and from a variance-covariance matrix with an exponential map using rotation data. We found that the correlation coefficients of speed for the head, shoulders, and knees of dancers were significantly high. The values of variance-covariance in the exponential map based on movement velocity were positively high between dancer shoulders vertically and between dancer hips and knees in a front-back direction. These results indicated that not only the legs of paired dancers but also the shoulders move similarly fast during synchronized dance.

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