Analysis of the triple pirouette of professional classical ballet dancers

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Classical ballet pirouette is difficult technique to master even for professional dancers. Little research has been conducted on the pirouette. The purposes of this study were to analyse the pirouette movement of professional classical ballet dancers, and to search critical viewpoints for instruction focusing on their averaged motion (Ae et al.,2007) and motion variation of body segments. The participants were 11 professional female classical ballet dancers performed the triple pirouette. The motion capture system with 12 cameras (Qualisys, Sweden, 250 Hz) was used to collect three-dimensional coordinate data. The coefficient of variation (CV) and standard deviation of the body segments were used to represent the variability of body segment movement. There were smaller motion variations in the shank, thigh, head, and torso of the top dancers, which indicated that the similar motion patterns appeared in the triple pirouette in these segments. On the other hand, the larger variation of the left foot in the preparation and turning phase indicated that ankle adjustment may be employed to maintain balance. The upper extremity with large variation may also function as an angular momentum generator and balance adjustor and may be an indicator of difference in teaching methods.

KEYWORDS: ballet, pirouette, three-dimensional motion analysis, coefficient of variation,

INTRODUCTION: The turn is a technique that is included in all genres of dance, and the pirouette of classical ballet is one of the most essential rotation techniques. In recent years, the number of biomechanical studies on the pirouette have increased, and most of the studies focusing on angular momentum generation (Kim et al., 2014; Imura & Iino, 2018) and balance regulation (Laws & Swope, 2002; Lott & Xu, 2020; Lin et al., 2019). These have pointed out the importance of trunk and arm (lead arm) movements that contribute to angular momentum generation (Kim et al., 2014), as well as the ankle joint and pelvis for balance regulation (Lott & Xu, 2020). The triple pirouette is not so easy to perform even for professional dancers. In many sports, movements of skilled athletes have been used to provide motion models as a tool for skill acquisition (Hay & Reid, 1982; Ae, 2020; Glazier, 2021). However, little biomechanical studies on the pirouette movement in ballet have been conducted for the preparation of a template used for instruction.

There are many teaching methods in the area of classical ballet, which all may be appropriate and effective from the viewpoint of instructional experience. A biomechanical analysis on the pirouette technique of the skilled ballet dancers can provide scientific information for designing teaching methods and preventing injuries.

The purposes of this study were to analyse the pirouette movement of professional classical ballet dancers, and to search critical viewpoints for instruction focusing on their averaged motion (Ae et al.,2007) and motion variation of body segments. Averaging motion and movement parameters would be expected to remove or reduce noise or error inherent in the movement of the individual dancers.

METHODS: The participants were 11 professional female classical ballet dancers (age, 27.3 ± 3.0 years; height, 1.60 ± 0.03 m; weight, 46.6 ± 2.6 kg; years of experience, 22.4 ± 3.0 years), including soloist dancers who had won top prizes in competitions. After their own warming up, they performed the triple pirouette en dehors on the dance floor. They wore their own favourite ballet shoes and performed at demi-pointe. The participants performed it until three trials with a self-reflection rating of more than 4 on a 5-point scale were obtained. Only pirouettes rated 5 by each dancer and a dance teacher were used for the detailed analysis.

The motion capture system with 12 cameras (Qualisys, Sweden, 250 Hz) was used to collect three-dimensional coordinate data of 67 reflective markers on the body. A right-handed coordinate system was defined: vertical direction as the Z-axis, the forward direction as the Y-axis, the lateral direction as X-axis. The three-dimensional coordinate data of 25 body segment endpoints were smoothed using a Butterworth digital filter (8-15Hz) after determining the optimal cut-off frequencies (Winter, 1990). The averaged motion of the participants was calculated often the method of Ae et al., (2007).
According to the method of Lott et al., (2020), the pirouette movement was divided into three phases: 1) preparation phase until the right toe-off, 2) turning phase with a single leg support, and 3) ending phase where the rotation was completed toward the pose. The time series data were normalized to the time of each motion phase, 100 % in total. The motion analysis software written in MATLAB (Math works) was used for the calculation of direction angles of each body segment (Ae, 2021). The coefficient of variation (CV) used for an indication of the variation in body segment motion was calculated by dividing the standard deviation (SD) of the direction angle by the mean and multiplying by 100, as well as SD of the direction angle itself.

RESULTS: Figure 1 shows the averaged motion of the classical ballet dancers performing the triple pirouette (n=11). The upper figure (a) is a stick picture from the front view and the lower figure (b) is the lateral. Black lines indicate the right limbs and dotted lines (red) indicates the left limbs. In the preparation phase (0~30%), the ankle, knee and hip joints flexed about 20% time and the upper limb rotated in the counter-clockwise direction. The trunk tilted forward a little after 20% time. Then the upper limb rotated clockwise, and the gesture leg (right) broke the contact (toe-off), 30% time and the left shoulder aligned with the line of the foot. During the turning phase, the gesture foot was placed on the knee of the support leg (left), and the passé placed before the first rotation (40% time). At the end of the first rotation, the whole body tilted a little from the vertical. In the ending phase, about 70% time, with the gesture foot separated from the support leg, the trunk faced forward and the left heel contacted with the floor about 80% time. After the contact of the left heel, the trunk rotated until reaching the 4th position (85% time).

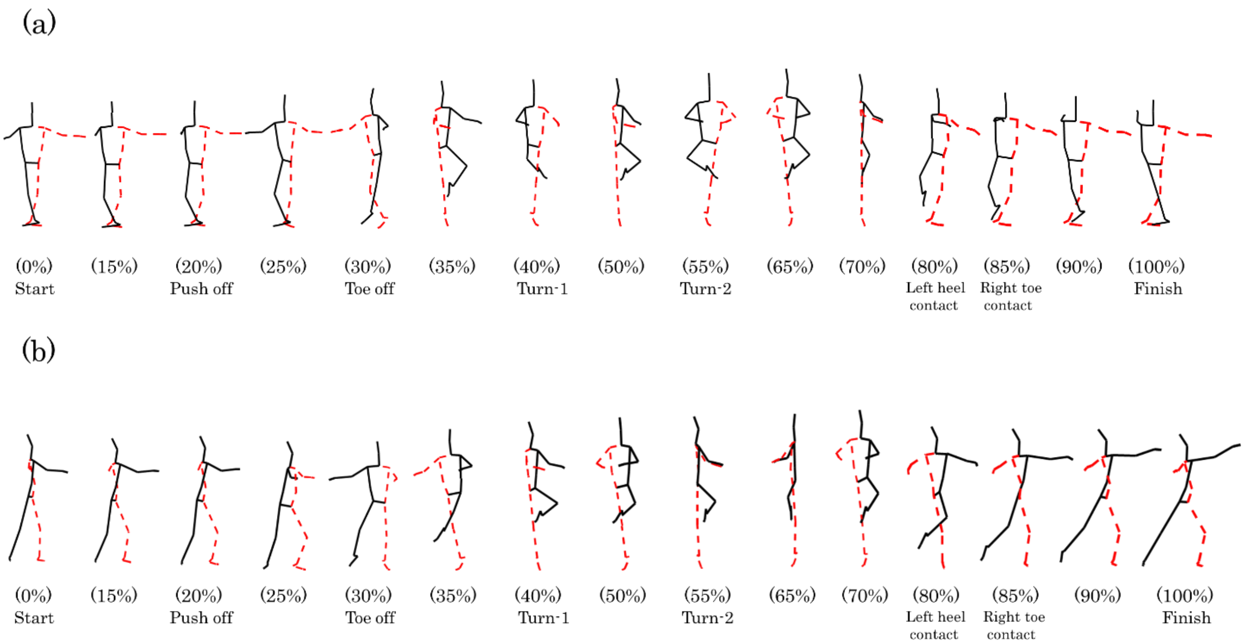

Figure1: Front view (a) and lateral (b) of stick pictures of the averaged motion of the triple pirouette for dancers(n=11). The black line indicates the right side of the body, and the dotted line (red), one indicates the left side.

Figure 2 shows average CVs of the direction angles X (a) and Y (b) of the body segments for three phases in the triple pirouette. In the preparation phase, the CVs were smaller for the torso, head, left thigh, shank and right foot in the X direction angle, and for the torso, head, left shank, right shank, and thigh in the Y direction angle.
In the turning phase, the CVs were smaller for the left thigh, shank, and torso in the X direction angle, and for the left thigh, shank, and torso in the Y direction angle.
In the ending phase, the CVs of the upper torso, left shank and thigh in the X direction angle, and those of the upper torso, left thigh and shank in the Y direction angle were small.

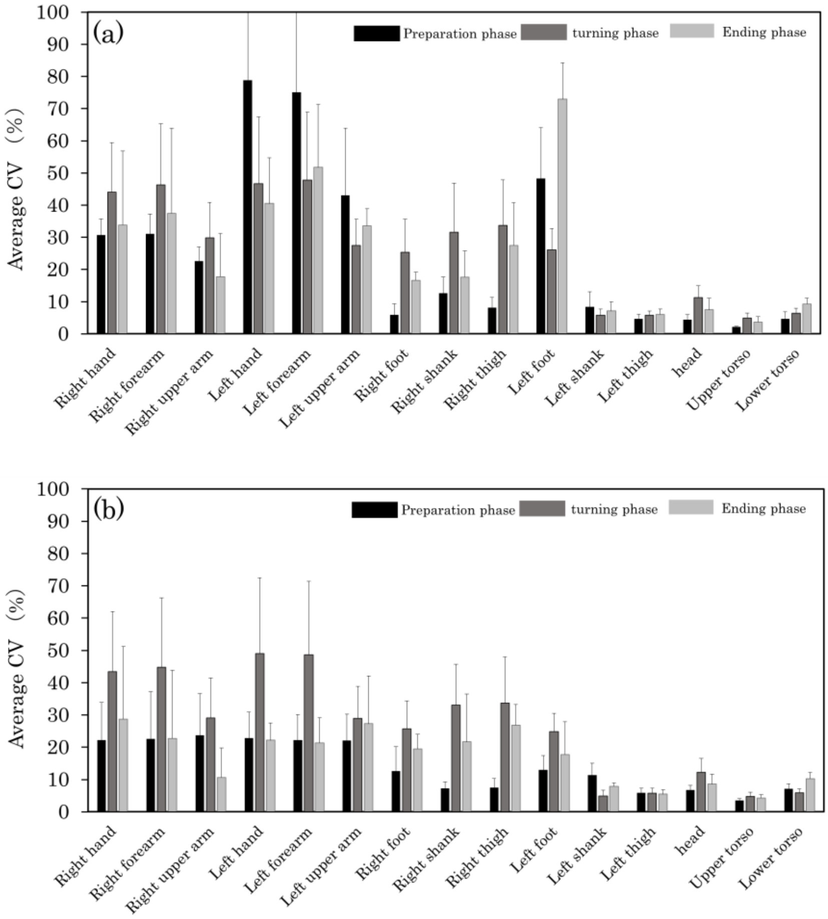

Figure 2: CVs in X (a) Y (b) direction angles of the body segments for three phases in the Triple pirouette.

DISCUSSION: The preparation phase is an important phase because most of the angular momentum for the triple pirouette is generated in the preparation phase (Laws & Swope, 2002). The thigh in the preparation phase seemed to be responsible for the torque generation for turning (Imura & Iino, 2018). In the present study, the CVs were small in the thigh and the left shank, which indicated the individual differences in these segment movements were small. It revealed that these segment movements of the support leg prior to rotation might be highly common in successful rotation.
In the upper limb, only the right forearm showed the small variation. Therefore, the CV of the lead arm as an important part was small because the dancers would employ a similar movement. The movement of the lead arm (right) has been often emphasized in teaching, although such emphases are not automatically eligible to be considered as a cause of movements.
The lower limbs and the torso moved less in the turning phase, which was why the CVs of these segments small. It is said that dancers would adjust their body segments in two or more turns (Lin et al., 2019). However, although top dancers have used the pelvis and ankle

strategies to adjust balance during rotation (Lin et al., 2019), the left foot showed greater variation than the left shank and thigh. Ankle adjustment, primarily in the support leg, is important for vertically adjusting the centre of pressure under the centre of mass to maintain balance (Lott & Xu, 2020). Based on this remark, it is likely that each dancer in the present study adjusted the foot at times, and the lower leg, thigh, and trunk had the similar motion pattern with small variation. However, the temporal adjustment of the foot needs to be further examined because the foot motion varied from individual to individual.

The upper extremity with large CVs may also function as a balance adjustor as well as the ankle. It is inferred that differences in teaching methods might come out as large motion variation in the upper extremity.

The top dancers are likely to have smaller left-right motion in postural adjustment. The support foot (left) with a small CV would have moved in a high commonality among top dancers because the process of reaching the passé after foot-off would be essential for maintaining balance (Lin et al., 2019).

CONCLUSION:

There were smaller motion variations in the shank, thigh, head, and torso of the top dancers, which indicated that the similar motion patterns appeared in the triple pirouette in these segments. On the other hand, the larger variation of the left foot in the preparation and turning phase indicated that ankle adjustment may be employed to maintain balance. The upper extremity with large variation may also function as an angular momentum generator and balance adjustor and may be an indicator of difference in teaching methods.

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