BODY INCLINATION AND MOTION VARIATION OF BODY SEGMENTS IN THE TRIPLE PIROUETTE FOR SKILLED FEMALE DANCERS

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The study investigated body inclination angle and motion variation for skilled dancers in the triple pirouette. Eleven skilled female ballet dancers were asked to perform the triple pirouette. A three-dimensional motion capture system was used to calculate the body inclination angle and direction angles of the body segment vectors for evaluating the motion variation of the body segments. Maintaining a small body inclination angle during the triple pirouette, they showed a high commonality of the segment motions in the left shank and left thigh of the support leg as well as the upper and lower torso, while a high individuality was observed in the upper limbs, which would relate to artistic expression and attribute to the skilfulness of dances.

KEYWORDS: ballet, motion analysis, direction angle

INTRODUCTION: One of the important techniques in ballet, pirouette en dehors (henceforth, pirouette), is a movement of rotation around a vertical axis while supporting the body with one leg (Figure 1). A successful pirouette requires the generation of the angular momentum about the vertical axis in the preparation phase, with the rotation axis aligned to the vertical line to maintain balance during the turning phase (Laws, 2002). It has been said that skilled dancers tend to keep body inclination angle and its variation smaller than those of novice dancers (Lin et al, 2019). However, there is little scientific information on skilled dancers that can help ordinary dancers learn a successful pirouette.
Ae et al. (2007) and Murata et al. (2008) proposed observing motion variation for the evaluation and diagnosis of human motion, i.e., small motion variation observed among skilled performers indicates that the performers moved their body segments in a similar pattern, and that the motion pattern they used may be critical to that technique. Hiley et al. (2013) pointed out that in performing repeated consecutive giant circles or high bar the more elite gymnasts had less variability in the mechanically important aspects of technique and more variability in some of the less mechanically important aspects. From these remarks, observing motion variation of the body segments during the triple pirouette for skilled dancers would provide insights into how they move the body segments to maintain a small body inclination as an index of performance.
The purpose of this study was to investigate the body inclination angle for skilled dancers in the triple pirouette and to identify body segments with small motion variations. The hypotheses of this study are as follows: 1) the body inclination angle for the skilled dancers varies less during the turning phase than that during the starting (push off and turn1) and ending phases, 2) the body segments with less motion variability in the triple pirouette are the thigh of the support leg and torso.

METHODS: The participants were 11 skilled female classical ballet dancers (age, 27.3 ± 3.4yrs; height, 1.60 ± 0.03m; mass, 46.6 ± 2.6kg; ballet experience, 22.4 ± 3.0 yrs) who were active on the stage domestically and internationally. They were asked to perform the triple pirouette as if they were dancing on a real stage as much as possible. All participants used the left leg as the support leg, which was the preferred leg.
A motion capture system with 12 cameras (Arqus A5, Qualisys, 250 Hz) was used to collect three-dimensional coordinate data of 67 reflective markers on the dancers performing the triple

pirouette. All participants were asked to evaluate on a 5-point scale after performing the triple pirouette until at least three trials with a score of 4 or higher were obtained. A right-handed coordinate system was defined as follows: the vertical direction for the positive Z-axis, the forward direction for the positive Y-axis, and the right direction for the positive X-axis. The three-dimensional coordinate data of 25 body segment endpoints were smoothed using a Butterworth digital filter after determining the optimal cut-off frequencies (Winter, 1990), i.e., 7.5-17.5 Hz for coordinate X, 7.5-17.5 Hz for coordinate Y and 10 -17.5 Hz for coordinate Z, depending on the body segment endpoints.
The motion phases were defined as shown in Figure 1: the preparation phase was from 1) the starting position to 2) the instant when the gesture leg left the floor; the turning phase was from 2) through 3) the instant when the gesture leg entered the passé, 4) the instant of the second turn to 5) the instant when the gesture leg left from the knee of the support leg for touching the floor; the ending phase was from 5) though6) the instant when the foot of the gesture leg touched the floor to 7) the instant of 100 frames after 6). The time series data of direction angles of body segments were normalised by mean time ratios of motion sub-phases and phases (30, 9, 18, 17, 13, 13%), in which the duration from the start to the end of the trial was set as 100%.

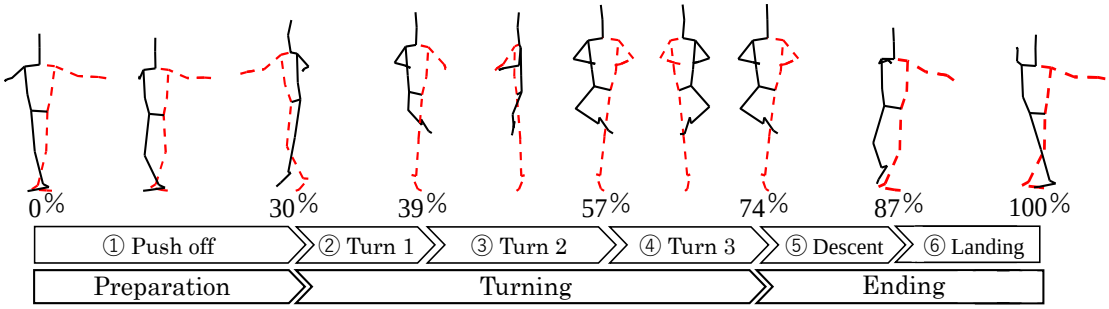

Figure 1: Motion phases of the triple pirouette.

The following parameters were calculated from the obtained data: 1) body inclination angle was calculated using the method of Lott et al. (2019) as an index of performance of the triple pirouette during turn; 2) standard motion model was created using the method of Ae et al. (2007) as the averaged motion of 11 dancers; 3) direction angles of the body segment vectors relative to three axes of the right-handed global coordinate system were calculated using the method of Ae et al. (2021); 4) motion variation was evaluated by the standard deviation (SD) of the time normalized direction angles of body segments. We evaluated a motion variation of the body segment whose SD was larger than mean + 1SD of all segments as a body segment with a large motion variation and that was smaller than the mean - 1SD as that with a small motion variation. All calculations were performed using MATLAB software (R2021a, MathWorks).

RESULTS: Figure 2 shows the average body inclination angle during the triple pirouette as a performance index with those for two typical dancers (A and B) as examples. The average inclination angle of the 11 dancers during the turn was 3.9 ± 1.0°. Dancer A (grey line) with the smallest body inclination angle had an average body inclination angle of 2.6 ± 1.3°, whereas dancer B (dotted line) with the largest body inclination angle had an average body inclination angle was 5.4 ± 2.3°. The average inclination angle (black line) and those of the two dances during the Turn 1 and descending phases decreased and increased, although those of the average one and dancer A showed smaller changes during the Turn 2 and 3 phases than dancer B.

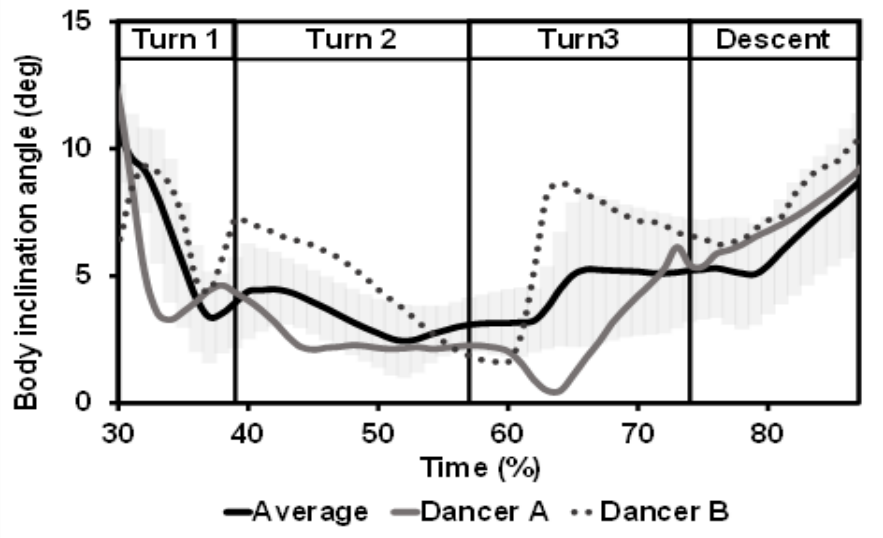

Figure 2: Changes in average body inclination angle with those of the two dancers as examples.

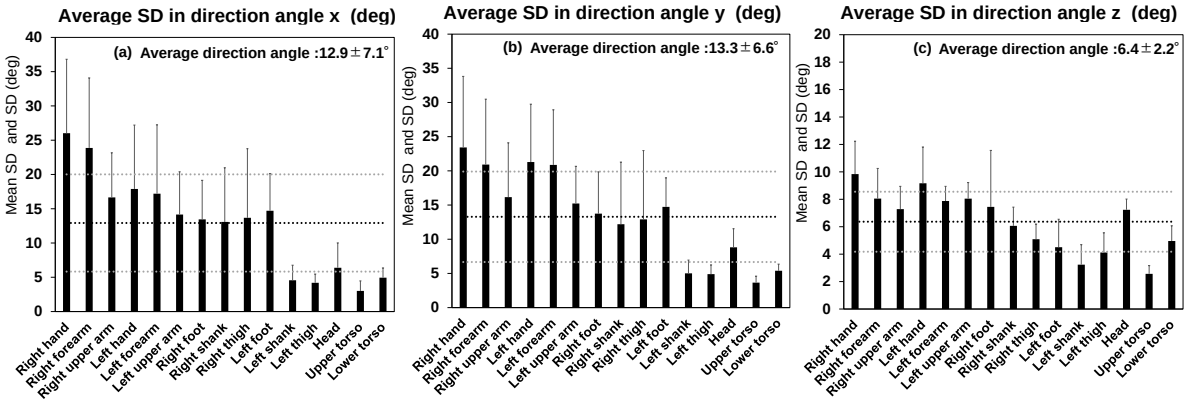

Figure 3: Mean standard deviations of body segment direction angles x(a), y(b), and z(c) during the triple pirouette for skilled dancers.

Figure 3 shows mean SDs of the body segment direction angles(x(a), y(b), and z(c)) during the triple pirouette. The mean SDs of the direction angles for the skilled dancers tended to be larger in the distal segments of the upper limb such as the right hand and right forearm, and smaller in the torso followed by the support leg such as the left shank and thigh. The head tended to show smaller SD than the extremities but larger than the upper and lower torsos.

DISCUSSION:

The body inclination angle of the skilled dancers was 3.9 ± 1.0°, which was similar to that reported by Lott et al., (2019) (4.5 ± 2.0°). Dancer B 's body inclination angle tended to vary larger than the average +1SD range during the turning phase (30%-74%). An increased body inclination angle was observed in the average and two dancers during the Turn 1 and descending phases. Comparison of changes in the body inclination angle and direction angles of the right arm segments revealed that the direction angle z for the right hand in the starting and descending phases changed more than in the Turn 2 and 3 phases, where the change in the body inclination angle was smaller than that during the Turn 1 and descending phases. This implied that the increased body inclination angle in these phases was caused by the motion of the upper extremities for the increase in the angular momentum about the vertical axis in the starting and Turn 1 phases, and for the decrease in angular velocity for the preparation of landing of the gesture leg.

The skilled dancers in this study may use their upper extremities to control body inclination in the starting and ending phases of the triple pirouette. The sharp increase in the body inclination angle for dancer B (dotted line in Figure 2) seen in Turn 3 would be a sign that she was losing her balance a little, which might be one of the reasons for her large average body inclination angle ($5.4 \pm 2.3^{\circ}$).

In the triple pirouette for the skilled dancers, the mean SDs of the direction angles of the left shank, left thigh, upper torso, and lower torso tended to be smaller than mean-1SD of all segments. Assuming that body segments with a small motion variation are important in performing a certain movement (Ae et al.,2007; Murata et al.,2008; Hiley et al.,2016), the left shank, left thigh, upper torso, and lower torso are likely to be key body segments for a successful triple pirouette. This means that dancers and instructors should focus on these segments in the ballet lesson. In the present study, changes in direction angles for the upper limbs and their SDs were larger than those of other body segments, implying that there were individual differences in the motion patterns of the upper limbs. In the ballet world, body motions for artistic expression are crucial and vary from dancer to dancer (Kawano et al., 2019).

CONCLUSION: The skilled female classical ballet dancers during the triple pirouette showed a small body inclination. Maintaining the small body inclination angle during the triple pirouette, they showed a high commonality of the segment motions in the left shank and left thigh of the support leg as well as the upper and lower torsos, which means that these segments are critical for a successful pirouette. On the other hand, a high individuality was seen in the upper limbs, which would relate to the artistic expression and be attributed to the skilfulness of the dancers.

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