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Article

Rotational movement of Chinese dance based on the analysis of kinematic mechanics

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Abstract: Objective: Rotation is a fundamental movement in Chinese dance, and many dancers are difficult to control the smoothness and stability of their movements during rotation, resulting in low completion rates. To better grasp the key points of rotational movements, this article started from a biomechanical perspective and studied the differences in completing rotational movements among dancers of different skill levels. **Methods:** Twenty dancers were divided into group A (high level) and group B (ordinary level). The dancers' movements were recorded using two Casio cameras and analyzed using the APAS System. The center of gravity displacements, joint angles, and other kinematic mechanical indicators were compared between the two groups. **Results:** Group A demonstrated faster completion for a 360° rotation than group B. Group A exhibited larger torso angles during the preparation stage, rotating 180° and rotating 360°, with values of 84.67° ± 1.36°, 85.41° ± 0.65°, and 84.91° ± 0.78°, respectively. Significant differences in hip and knee angles were also observed at each stage in group A ($p < 0.05$). Furthermore, when rotating 1080°, group A consumed the longest time in the first lap, followed by the second and third laps, and had more stable center of gravity displacement and velocity. **Conclusion:** Group A shows superior body control and higher rotation quality when performing rotational movements in Chinese dance.

Keywords: kinematic mechanics; Chinese dance; rotation; knee joint; torso angle

1. Introduction

Dance, as a fundamental form of human expression [1], has evolved to various styles such as ballet and Latin dance [2]. Throughout its long history, China has preserved a rich repertoire of original dances [3]. Chinese dance embodies unique cultural elements and emotions [4], incorporating techniques from opera, martial arts, and ballet. It encompasses different genres, including classical and folk dances. With the increasing competitiveness in the field of dance, the risk of injuries among Chinese dancers has also risen [5]. Consequently, teaching and training of dance skills have been researched more and more. Rotational movement is a fundamental and crucial component of Chinese dance, connecting elements between different movements. It directly impacts the sense of rhythm and coordination of the dance. Continuous rotation can lead to a climax in dance, making it highly enjoyable. Therefore, rotational technique is an important indicator for assessing the quality of dance. Rotation accounts for a relatively high proportion in various dance exams and has a significant impact on the overall score. When dancers rotate, their heads play a role in maintaining balance and driving body movement. At the same time, they increase rotational inertia through arm swings and generate power from the waist and hips by alternating leg movements. The upper body coordinates to complete the rotation. In this process, any shaking or loss of balance can easily lead to falls and cause physical injuries. Rotation mainly tests the dancer's balance and stability. To better understand the key points of force generation in rotational movements, it is necessary to start with biomechanics. This approach can provide targeted guidance for dancers' practice, improve the quality of rotational movements, enrich theories related to Chinese dance rotations, reveal movement patterns, and provide technical references and theoretical basis for training. Currently, kinematic analysis is a common research method in sports studies [6]. For instance, Jordan et al. [7] analyzed data on ground contact time and foot-to-center-of-mass displacement during linear deceleration of male athletes using the inertial measurement unit system. Moreover, they validated the effectiveness of this system in assessment. de Avelar et al. [8] explored the effects of neuromuscular training on knee and ankle stability in handball players. They observed significant improvements in ankle mobility and decreased frequency of excessive anterior tibial translocation. Harris et al. [9] analyzed the impact of patellar tendinopathy (PT) on long jump athletes and found that athletes with PT exhibited similar knee dorsiflexion and hip extension but landed with a lower loading rate. Snyder et al. [10] investigated the effects of fatigue on the landing performance of female soccer players. They discovered that knee extension strength during sidestep cuts decreased, peak ground reaction force (GRF) increased, and both anterior and lateral tibial shear forces significantly increased after multiple games, suggesting that fatigue increased the risk of knee injuries. In terms of dance, Kulis et al. [11] analyzed the significant characteristics of swinging movements in world-class dancers based on kinematic variables and found that the mean square difference between hip and thoracic angular rotational velocity signals is a good indicator for evaluating swinging movements. Wells et al. [12] conducted a biomechanical analysis of the triple step in recreational swing dancers and discovered higher peak vertical ground reaction forces during the first step and second step, providing some guidance for understanding swing dance-related injuries and improving performance. Tsubaki et al. [13] analyzed the differences in rotational axis during rotations performed by professional and amateur ballet dancers wearing pointe shoes, discovering that professional dancers exhibited superior control ability. Zhang [14] introduced a dance motion recognition model utilizing bioimage visualization technology, offering practical insights for dance instruction. Chang et al. [15] conducted research on complex dance sequences in ballroom dancing by collecting three-dimensional kinematic data from 36 joint angles. Their findings revealed that with skill improvement, kinematic degrees of freedom become unfrozen, resulting in more organized structure of motions. Kawano et al. [16] investigated the impact of upper limb rotational movements on the aesthetics of ballet. They found that five factors, including the magnitude of rotational motion and the speed of arm elevation, significantly affected the aesthetic appeal of ballet movements. In comparison to Latin and ballet dances [17], there has been relatively little research conducted on Chinese dance thus far. Wilcox [18] delved into the process by which specific folk-dance techniques and aesthetic styles are adapted and incorporated into Chinese dance, offering a comprehensive analysis of its dynamic heritage. Chang et al. [19] assessed how participating in Chinese square dancing affects cognitive function and quality of life in elderly women with mild cognitive impairment, as well as investigated potential underlying mechanisms. Danny [20] pointed out that Chinese dance could be combined with the learning of Chinese language and culture for teaching and performance and analyzed the possibility of using Chinese dance to teach Chinese language and culture. Zhou [21] analyzed the significance of “jumping” movements within Chinese dance, emphasizing that dancers can deliver a more impressive stage performance by skillfully incorporating jumps into their routines. Based on electroencephalogram signals, Li et al. [22] recognized cross-subject aesthetic preferences for Chinese dance poses using transfer learning and convolutional neural networks. They found a greater involvement of the right hemisphere in visual aesthetic processing of Chinese dance poses. It is evident that there remains a substantial void in the integration of Chinese dance with biomechanics research, as well as a reliance on teachers’ instructional experience without sufficient objective theoretical support during actual teaching of Chinese dance, resulting in some shortcomings when guiding and training dancers. In order to further enrich the research on Chinese dance and assist dancers in better understanding the key points of spinning movements, based on kinematic analysis, this study investigated rotational movements in Chinese dance and compared the variations in performing these movements among dancers of different proficiency levels. The results provide a theoretical foundation for instructing rotational dance movements and lay a basis for further research in this domain.

2. Subjects and methods

2.1. Research subjects

Twenty dancers majoring in dance performance at Nanjing University of the Arts were recruited for this study and divided into groups based on their training duration. Ten dancers with a training duration of over five years are assigned to Group A (including six females and six males), while ten dancers with a training duration of less than five years were assigned to Group B (including five females and five males). All dancers were proficient in the rotational movements of Chinese dance, had good physical health without any major medical history of heart or skeletal diseases, had no history of injuries or illnesses in the three months before the experiment, and had good mental health. They understood the purpose and procedures of the study and provided informed consent by signing a consent form. The basic information of the dancers in both groups is presented in **Table 1**.

Table 1. Basic information about the dancers in the two groups.

	Group A (n = 10)	**Group B (n = 10)**
Age/years	20.12 ± 2.12	20.33 ± 2.07
Height/cm	165.77 ± 1.68	166.32 ± 1.15
Weight/kg	50.12 ± 1.36	50.34 ± 1.28
Training time/years	8.67 ± 1.12	2.77 ± 0.64

2.2. Movement for study

The movement under study in this research is the rotational movement in Chinese dance. The rotating route is a straight line. Rotating 360° in one circle can be divided into three stages.

1) Preparation phase: The dancer positions their left foot in front and places the right foot behind. The left leg serves as the motion leg, with the instep of the left foot tensed and toes pointing towards the ground. The dancer's gaze is directed toward the upcoming rotation direction, and the weight is predominantly on the left leg (**Figure 1**).
2) 180° rotation: The dancer utilizes the left leg as the axis and shifts the center of gravity to the right leg to turn the body 180° (**Figure 2**).
3) 360° rotation: The dancer shifts their weight slightly onto the right foot, steps forward with the left foot, followed by the right foot, completing a 180° turn and ultimately facing the initial direction of the turn (**Figure 3**).

Figure 1. The preparation phase.

Figure 2. 180° rotation.

Figure 3. 360° rotation.

2.3. Experimental methods

1) In order to reduce the impact of clothing on dancers, such as movement restrictions caused by inappropriate attire (previous research has shown a potential causal relationship between shoe selection and injury likelihood in dance performance [23]), the dancers in both groups were dressed uniformly and underwent a warm-up session. They also practiced rotational movements as arranged by the experimenter.
2) The experimental site was set up in a specific layout. Two Casio cameras with a frame rate of 50 frames per second were used for synchronized fixed-point shooting. The angle between the main optical axes of the two cameras is set to 100°. The distance between the cameras was 12 m, and the height of the camera lens from the ground was 1.3 m. One camera was placed in front of the dancers at a distance of 9.12 m, while the other camera was positioned on the side of the dancers at a distance of 11.25 m. The camera was calibrated and the focus was adjusted to ensure correct focusing. A preliminary experiment was performed to ensure accurate image capture.
3) Both groups of dancers were instructed to perform three consecutive single rotations of 360°. After a one-minute break, they then completed three consecutive rotations of 1080°.
4) The highest-quality movement of each dancer was selected for analysis. The APAS system [24] was used for movement analysis. Due to the uneven mass distribution and irregular shape of the human body, it is difficult to calculate accurately. Therefore, in the study of biomechanics, human body models are often used for analysis. The Hanavan human body model is currently widely used in biomechanical analysis [25]. Although there are still some discrepancies between the calculated values of the model and actual values, it can effectively reflect individual characteristics and has great advantages in simulating and analyzing technical movements on computers [26]. The Hanavan human body

model was employed in the analysis of this paper. Digital filtering with a cutoff frequency of 7 was used for data smoothing. The center of gravity displacement, velocity, joint angles, and other kinematic mechanical indicators were calculated.

2.4. Statistical analysis

Statistical analysis was conducted using SPSS software [27]. The independent samples *t*-test [28] can be used to infer whether there is a difference in two mean values. Dancers' kinematic data in both groups A and B have passed tests for normality and homogeneity of variances, making it suitable for analysis using the independent samples *t*-test. The significance level was set at 0.05. The charts were created in Excel.

3. Results

A comparison of the time taken to rotate 360° in a single turn for the two groups is shown in **Figure 4**.

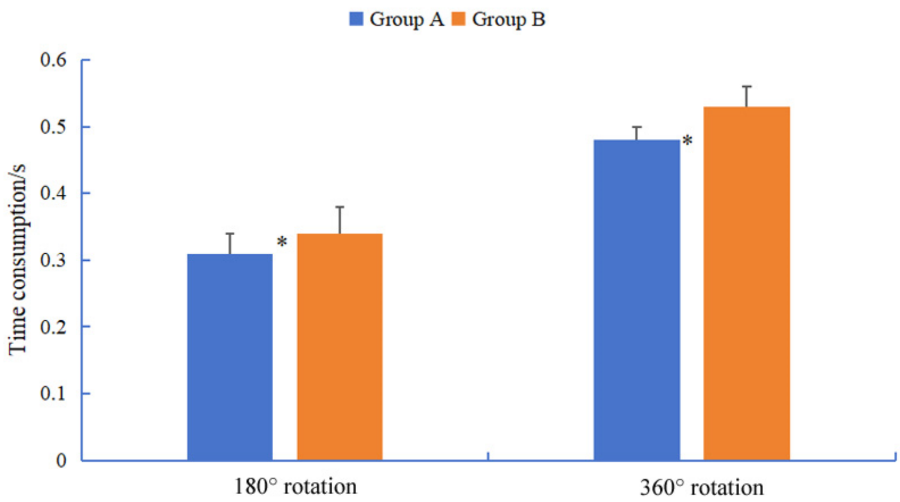

Figure 4. Comparison of time taken to rotate 360° in a single circle between the two groups.

Note: *: $p < 0.05$ compared to group B.

From **Figure 4**, it can be observed that when rotating 180°, group A took an average of 0.31 ± 0.03 s, while group B took 0.34 ± 0.02, i.e., the time taken by group A was significantly shorter than that of group B ($p < 0.05$). Furthermore, when rotating 360°, group A took an average of 0.48 ± 0.04 s, while group B took 0.53 ± 0.03 s. Group A again completed the rotation in significantly less time than group B ($p < 0.05$). These results indicated that when rotating a single circle of 360°, dancers from group A were faster and took significantly less time compared to those from group B (0.48 ± 0.04 s vs. 0.48 ± 0.04 s) ($p < 0.05$), suggesting that group A dancers were more efficient in completing the 360° rotation.

Table 2 compares the torso angles at each stage between the two groups.

Table 2. Comparison of torso angles.

	Preparation phase	180° rotation	360° rotation
Group A (*n* = 10)	84.67 ± 1.36*	85.41 ± 0.65*	84.91 ± 0.78*
Group B (*n* = 10)	82.33 ± 1.14	84.21 ± 0.61	82.31 ± 0.72

Note: unit: °; *: $p < 0.05$ compared to group B.

Based on **Table 2**, significant differences in torso angle between the two groups were observed during the rotation of 360°. In the preparation phase, group A exhibited a torso angle of 84.67° ± 1.36°, which was significantly greater than 82.33° ± 1.14° in group B. During the 180° rotation, group A displayed a torso angle of 85.41° ± 0.65°, which was also significantly greater than 84.21° ± 0.61° in group B. Similarly, during the 360° rotation, group A had a torso angle of 84.91° ± 0.78°, which was significantly greater than 82.31° ± 0.72° in group B. This finding suggested that group A demonstrated stronger vertical stability of the torso and more accomplished rotational movement than Group B during the 360° rotation.

Table 3 compares hip and knee angles in the preparation phase between the two groups.

Table 3. Comparison of hip and knee joint angles in the preparation phase.

		Group A (*n* = 10)	Group B (*n* = 10)
Hip joint angle	Left	176.54 ± 0.45*	174.21 ± 1.26
	Right	174.36 ± 2.12*	172.15 ± 1.67
Knee joint angle	Left	166.22 ± 1.89*	172.77 ± 0.12
	Right	172.36 ± 1.45*	170.48 ± 1.36

Note: unit: °; *: $p < 0.05$ compared to group B.

As shown in **Table 3**, in the preparation phase, the left hip joint angle was 176.54° ± 0.45° in group A, which was significantly greater than group B (174.21° ± 1.26°) ($p < 0.05$). The right hip joint angle in group A was 174.36° ± 2.12°, which was also significantly greater than group B (172.15° ± 1.67°). Moving on to the knee joint, the left knee joint angle in group A was 166.22° ± 1.89°, significantly smaller than group B (172.77° ± 0.12°) ($p < 0.05$). Similarly, the right knee joint angle in group A was 172.36° ± 1.45°, significantly larger than group B (170.48° ± 1.36°) ($p < 0.05$). These findings indicated significant differences in hip and knee joint angles between the two groups during the preparation phase.

Table 4 compares hip and knee joint angles during the 180° rotation between the two groups.

Table 4. Comparison of hip and knee joint angles during 180° rotation.

		Group A (*n* = 10)	Group B (*n* = 10)
Hip joint angle	Left	177.21 ± 1.56*	173.84 ± 1.62
	Right	176.67 ± 1.12*	174.21 ±1.68
Knee joint angle	Left	177.84 ± 0.65*	175.21 ± 1.12
	Right	174.02 ± 1.65*	171.24 ± 2.01

Note: unit: °; *: $p < 0.05$ compared to group B.

According to **Table 4**, during the 180° rotation, group A exhibited left and right hip joint angles of 177.21° ± 1.56° and 176.67° ± 1.12°, respectively. In contrast, group B showed angles of 173.84° ± 1.62° and 174.21° ± 1.68° for the left and right hip joints, respectively. Group A's hip joint angles were significantly larger than those of group B ($p < 0.05$). Additionally, group A displayed left and right knee joint angles of 177.84° ± 0.65° and 174.02° ± 1.65°, respectively, which were also significantly larger than group B ($p < 0.05$). These findings indicated that during the 180° rotation, group A demonstrated better control of the knee and hip joint angles and exhibited greater stability compared to group B.

A comparison of the hip and knee joint angles during the 360° rotation between the two groups is displayed in **Table 5**.

Table 5. Comparison of hip and knee joint angles during the 360° rotation.

		Group A (n = 10)	Group B (n = 10)
Hip joint angle	Left	177.42 ± 1.36*	173.45 ± 1.14
	Right	176.46 ± 2.33*	173.22 ± 1.68
Knee joint angle	Left	178.64 ± 0.26*	176.36 ± 0.71
	Right	175.21 ± 1.64*	170.35 ± 2.55

Note: unit: °; *: $p < 0.05$ compared to group B.

As shown in **Table 5**, during the 360° rotation, group A exhibited left and right hip joint angles of 177.42° ± 1.36° and 176.46° ± 2.33°, respectively. These angles were significantly greater than those of group B, which were 173.45° ± 1.14° (left) and 173.223° ± 1.68° (right) ($p < 0.05$). Similarly, group A displayed larger knee joint angles, specifically 178.64° ± 0.26° (left) and 175.21° ± 1.64° (right), which were significantly greater than group B ($p < 0.05$). These findings indicated a significant difference in hip and knee joint angles between the two groups during the 360° rotation.

Figure 5 compares the elapsed time during the 1080° continuous rotation between the two groups.

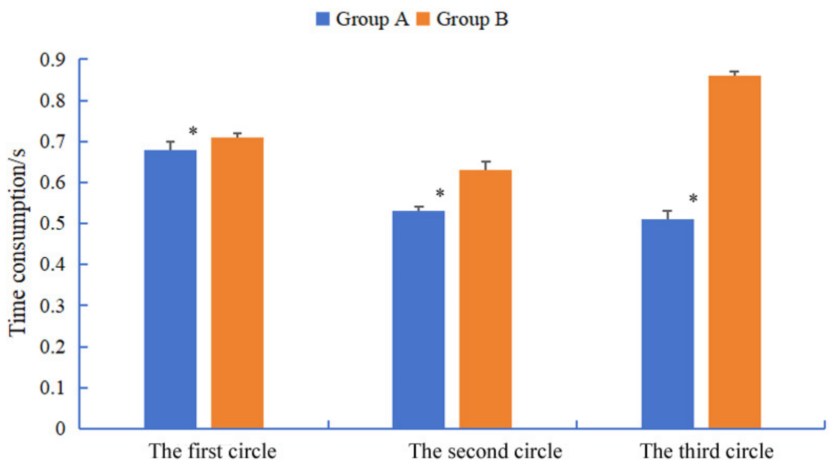

Figure 5. Comparison of time taken for continuous rotation of 1080° between the two groups (*: $p < 0.05$ compared to group B).

Note: *: p < 0.05 compared to group B.

As shown in **Figure 5**, the elapsed time during the first-circle rotation in group A was 0.68 ± 0.02 s, significantly smaller than 0.71 ± 0.01 s in group B ($p < 0.05$). Similarly, during the second-circle rotation, group A took 0.53 ± 0.01 s, significantly smaller than 0.63 ± 0.02 s in group B ($p < 0.05$). In the third-circle rotation, group A took 0.51 ± 0.02 s, significantly shorter than 0.86 ± 0.01 s in group B ($p < 0.05$). These findings indicated that group A consumed less time during the continuous rotation of 1080° and was in an accelerated rotational state.

The center of gravity displacements and velocities during the continuous rotation of 1080° were compared between the two groups as follows.

Table 6. Comparison of the center of gravity displacement and velocity.

		Group A (n = 10)	Group B (n = 10)
Center of gravity displacement/m	The first circle	0.71 ± 0.02*	0.61 ± 0.02
	The second circle	0.53 ± 0.03*	0.64 ± 0.02
	The third circle	0.48 ± 0.02*	0.63 ± 0.03
Center of gravity velocity/(m/s)	The first circle	1.09 ± 0.08	0.89 ± 0.11
	The second circle	1.04 ± 0.06	1.04 ± 0.12
	The third circle	1.01 ± 0.02	1.01 ± 0.08

Note: *: p < 0.05 compared to group B.

According to **Table 6**, there was a significant difference in the center of gravity displacement between the two groups from the first circle to the third circle during the continuous rotation of 1080°. Specifically, group A displayed a decreasing pattern in the center of gravity displacement from the first circle to the third circle, while group B's displacement was not stable. In terms of center of gravity velocity, although there were no significant differences between the two groups in each circle of rotation, group A exhibited a decrease in the center of gravity velocity, while group B's change in velocity was relatively unstable. Based on the changes in the center of gravity, it can be concluded that group A demonstrated better stability during the continuous rotation of 1080° compared to group B.

Based on the above results, the following findings were summarized:

1) the time taken by group A during a 180° rotation and a 360° rotation was significantly shorter than that of group B ($p < 0.05$);
2) the trunk angles of group A were significantly greater than those of group B during the preparation phase, 180° rotation, and 360° rotation ($p < 0.05$);
3) there were significant differences in the angles of hip and knee joints between the two groups in the preparation phase, 180° rotation, and 360° rotation ($p < 0.05$);
4) group A consumed a significantly shorter time than group B during the 1080° continuous rotation ($p < 0.05$);
5) the displacement of the center of gravity of group A showed a decreasing trend when rotating continuously by 1080°, indicating better stability.

4. Discussion

Kinematic mechanics is applied to analyze technical movements, injury prevention, and other aspects [29]. However, there is relatively limited research on rotational movements in Chinese dance. In both teaching and training, rotational movements have a high technical difficulty. The quality of rotational movements is related to factors such as the quantity, speed, and angle of rotation. As a type of rotation with a pivot but no physical axis, rotation requires high levels of strength, coordination, and stability in the body. Therefore, gaining a better understanding of the technical characteristics exhibited by high-level dancers while performing rotational movements is of great significance for training and teaching purposes.

The rotational movements were compared between dancers of varying proficiency levels. Group A took a shorter time to complete a 360° single-circle rotation, indicating a higher rotational speed. Regarding torso angle, group A maintained perpendicular alignment with the ground during the preparation stage, providing a solid foundation for subsequent rotations. Moreover, group A showed a more stable axis during rotation, closer to the vertical orientation compared to group B. Group B had a relatively smaller torso angle and a slightly unstable center of gravity. It is inferred that the core muscles of group A dancers are stronger, enabling better control over joints and the spine. The twisting power of the waist and abdomen, the adduction strength of the thigh muscles, as well as the strength of deep and superficial muscle groups provide reinforcement for the spine and support for the ankles. By coordinating both internal and external muscles, a more stable rotational effect can be achieved. Therefore, in the practice of rotational movements, it is crucial to focus on strengthening core muscles to enhance stable control of the body.

The hip and knee joint angles at each stage were compared. During the preparation stage, group A showed a smaller left knee joint angle, which allows for larger rotational inertia. In contrast, group B had a larger left knee joint angle, which is less conducive to generating the twisting force necessary for rotation. Moreover, group B had larger right knee and hip joint angles, providing stronger support for rotational movement. Group A decreased the angle of the left knee and increased the angles of the right knee and hip joint. Therefore, in the practice of rotational movements, it is important to focus on the twisting and confrontation of the key components of the body. The large joints drive the small joints, the thighs drive the knees, and the knees drive the ankles, thus enhancing the rotary power.

When performing a 180° rotation, group B's hip and knee joint angles were significantly smaller than those of group A, indicating that dancers in group B slightly leaned forward, resulting in poor stability and inadequate support for the subsequent movements. In contrast, group A maintained greater hip and knee joint angles, allowing them to remain upright and providing additional power for the following rotation. In the process of rapid rotation, dancers may lack good support for the spine and joints due to poor neuromuscular coordination ability and weak muscle strength. Therefore, when practicing rotational movements, enhancing control over hip and knee joint stability is crucial. During the 360° rotation, group B's center of gravity still slightly leaned forward, indicating that the instability during the 180° rotation affected the subsequent rotation. Group A's larger hip and knee joint angles ensured the verticality and stability of their lower limbs, indicating a good vertical position and providing favorable conditions for continuous rotation. During a single-circle 360° rotation, the body's stability in the previous stage impacts the subsequent stages. Maintaining good core and trunk stability in each phase is essential for achieving high-quality rotations. In general, when practicing rotational movements, dancers should focus on maintaining stable control of their center of gravity and joints, as well as strengthening the relevant muscle groups. However, excessive hip joint movement may increase the risk of hip joint instability [30], leading to the occurrence of injuries such as hip pain. This should be taken into consideration during dance practice.

During the continuous rotation of 1080°, it was observed that group A consumed the longest rotation time in the first circle, followed by the second and third circles. This result indicated that group A was in a state of accelerated rotation as they performed this movement. Group A demonstrated good body control when performing a 360° single-circle rotation, which translated into excellent stability during the continuous rotation of 1080°. As a result, the quality of their rotations improved gradually over the weeks. Group B's rotational elapsed time was longer in the first circle than in the second circle and longer in the second circle than in the third circle. This result indicated that group B had poor stability, i.e., poor body control, during the continuous rotation of 1080°. Similarly, the comparison of the displacement and speed of the center of gravity in the three circles showed that group A exhibited better stability than group B, thereby confirming the good coordinated control ability of group A.

Based on the analysis of the above results; in order to achieve better rotation quality and enhance technical level, coaches can refer to these results when designing training programs for dancers. They should focus on strengthening the core muscle group and enhancing core strength to improve control over the body. Additionally, attention should be paid to mobilizing the muscles of the lower limbs to participate more effectively in rotations, ensuring that the body axis remains perpendicular to the ground, and strengthening control over various joints.

However, there are also some limitations in this study. For example, the sample size of dancers is small and it did not take into account other factors such as age and gender that may influence the performance of rotational movements. In future research, a more in-depth analysis will be conducted on the kinematic models of dancers at different skill levels to further understand the differences in rotational movements among dancers with varying levels. Additionally, comparative experiments will be conducted using a larger sample size.

5. Conclusion

This paper compared the characteristics of dancers at different skill levels in performing rotational movements in Chinese dance from a kinematic mechanics perspective. The study found that high-level dancers demonstrated better control over their body joints and muscles during rotational movements, resulting in higher quality rotations. The underlying mechanisms causing these differences were also analyzed. This article provides some feasible suggestions for the development of practical training programs in Chinese dance, offering theoretical support for enriching research on the biomechanics of Chinese dance.

Ethical approval: Informed consent was obtained from all subjects involved in the study.

Conflict of interest: The author declares no conflict of interest.

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