Analysis of the Mechanical Characteristics of the Basic WALK Step in Rumba from a Kinematic Perspective

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Abstract
Objective: This study aims to explore the mechanical differences in executing the basic WALK step of the rumba from a kinematic perspective between professional dancers and amateur students, thereby guiding the teaching and training of the WALK step.
Methods: Five professional dancers and five amateur students participated in video recordings using two JVC cameras. Kinematic data were processed using APAS software to analyze the center of gravity changes and lower limb joint data in both groups.
Results: The movement time of the center of gravity showed no significant difference between the professional dancers and amateur students at different stages of the complete WALK step ($p > 0.05$). Center of gravity displacements were similar on the X-axis, but significant differences were observed on the Y and Z axes ($p < 0.05$). In lower limb kinematics, the amateur group exhibited notable variations in hip and knee flexion and extension in the sagittal plane compared to the professional group. Peak hip flexion and extension angles were 51.26 ± 4.45° and -11.33 ± 0.91°, respectively, in the amateur group, both smaller than those in the professional group ($p < 0.05$). Additionally, the peak knee adduction angle in the frontal plane was -4.64 ± 5.65°, significantly smaller than that of the professional group ($p < 0.05$). The amateur group also demonstrated significant differences from the professional group in hip internal and external rotation, knee internal rotation, and ankle external rotation in the horizontal plane.
Conclusion: The amateur group exhibits insufficient hip twisting and weak joint control during the execution of WALK steps, making them more susceptible to sports injuries. Strengthening lower limb muscle groups and improving overall body stability are recommended for this group.

Keywords: *Kinematics, Rumba, WALK step, Mechanical characteristic.*

Introduction

Sports dance is a form of athletic activity that combines elements of sports, dance, and competition. With its development in sports competitions [4], major universities are increasingly emphasizing the study of sports dance and enhancing the training and development of dance athletes. The practice of dance plays a pivotal role in enhancing physical function and cognitive abilities [12]. Rumba, a fundamental dance in Latin dance, is known for its passionate and unrestrained style and dynamic postures. While popular, it involves intricate and challenging movements, demanding higher physical fitness from athletes. The WALK step, a foundational move in rumba, is widely used and forms the basis of rumba dance education. Understanding the WALK step's inherent rules and characteristics is essential to effectively grasp the technical nuances of the WALK step and prevent movement distortion during learning and training. Advancements in high-speed camera technology [5], sensors [7], surface electromyography [2], and other technologies have expanded the methods for analyzing technical movements in sports. Molnár et al. [8] conducted a study on the balance ability and lower limb kinematics of Hungarian folk dancers, and found that during dance performance, the average range of motion for knee joint flexion-extension angle and hip joint flexion significantly increased. van Seters et al. [15] analyzed the risk factors for lower limb injuries in modern dance students, and through a study of 45 dancers, found that the one-year incidence rate of lower limb injuries reached 82.2%, with ankle joint dorsiflexion during single-leg squats being a serious risk factor for lower limb injury. Swain et al. [14] conducted a study on the relationship between dance and low back pain using data collected from a nine-camera motion analysis system operating at 100 Hz. They discovered that compared to non-dancers, dancers showed a smaller upper lumbar angle while standing, as well as greater range of motion in the sagittal plane of both their upper lumbar vertebrae and inferior thoracic segment. In another study by Rajic et al. [11], they examined 22 female dancers to analyze the influence of a nine-week training program focusing on hip joints. The results revealed a significant interaction between hip joint peak torque and countermovement jump performance. Li et al. [3] investigated the biomechanical differences in female Latin dancers when performing the bounce and side chasse step, revealing notable disparities in lower limb biomechanics for these two movements. Therefore, they emphasized the significance of increasing heel height. In another study by Seki et al. [13], they examined the relationship between degree of hallux valgus and kinematics in classical ballet, discovering a substantial correlation between hallux valgus angle and pelvic tilt based on their analysis of 17 dancers. Currently, in the research on rumba, most of the focus is on performance style, historical origins, and artistic expression, and there is relatively little research in the field of kinematics. The primary purpose of this article is to analyze the mechanical characteristics of the basic WALK step in rumba from a kinematic perspective. It compared the differences between professional dancers and amateur students in executing the WALK step, aiming to provide targeted guidance for teaching and training sports dance at universities. This will help students gain a comprehensive understanding of the key movements involved in the WALK step and achieve better competition results.

Subjects and methods

Research subjects

The participants were from the Wuhan Sports University. The cohort consisted of five professional Latin dancers (three males and two females), boasting over a decade of training experience with the varsity sports dance team, and five amateur students (three males and two females) majoring in sports dance, each having undergone more than three years of training. All participants fully understood the experiment's objectives and procedures and provided informed consent by signing the respective form. All subjects had no history of lower limb surgery, gait abnormalities, or cardiovascular or cerebrovascular diseases within the preceding six months. The basic information for the individuals in both groups is detailed in Table 1.

Table 1. Basic information of the subjects

Basic information	Professional group (n = 5)	Amateur group (n = 5)
Age, years	23.45 ± 0.77	24.21 ± 0.68
Height, cm	177.84 ± 1.62	178.33 ± 1.08
Weight, kg	55.87 ± 1.56	56.79 ± 1.73

Research methods

Experimental procedures

The study subjects were examined and informed about the relevant matters. The basic information was collected. They uniformly wore training clothes and Latin dance shoes.

The experimental site was arranged by deploying two JVC cameras. A stereo frame's lowest point was positioned at a distance of 70 cm from the ground, and two cameras were spaced 9 m apart. Each subject kept a distance of 10 m with both cameras. The main optical axes formed a 120° angle. The experimental setup is shown in Fig. 1.

Fig. 1 Experimental setup

Marker balls were affixed to different joints of the subjects to facilitate subsequent video analysis. A pre-experimentation phase was carried out to ensure the proper functioning of the apparatus. The placement of the marker balls is given in detail in Table 2.

Table 2. Marker ball position (L. – left, R. – right)

Marker point	Position	Marker point	Position
L. Foot	Tip of the first toe of the left foot	R. Foot	Tip of the first toe of the right foot
L. Ankle	Left lateral ankle point	R. Ankle	Right lateral ankle point
L. Knee	The patellar point of the left knee joint	R. Knee	The patellar point of the right knee joint
L. Hip	Left anterior superior iliac spine point	R. Hip	Right anterior superior iliac spine point
L. Shoulder	Left shoulder crest edge	R. Shoulder	Right shoulder crest edge
L. Elbow	Lateral epicondyle of the left humerus	R. Elbow	Lateral epicondyle of the right humerus
L. Wrist	Left ulnar styloid process	R. Wrist	Right ulnar styloid process

After sufficient warm-up, each subject completed three standard full WALK steps at a one-minute interval. The WALK step was divided into five stages based on their movement essentials:

- Stage 1: Place the sole of the left foot flat on the ground, point the toetip of the right foot to touch the ground, place the sole of the right foot flat on the ground, and point the toetip of the left foot to touch the ground.
- Stage 2: Place the sole of the right foot flat on the ground. The left leg touches the ground with the toes until both feet meet.
- Stage 3: Transfer the center of gravity with the right leg.
- Stage 4: The two feet meet again.
- Stage 5: Place the sole of the right foot flat on the ground and point the toetip of the left foot to touch the ground.

The highest quality video of each subject was captured and subjected to analysis. The footage was processed using APAS software [6], involving cutting and saving through the Trimmer module. Marker balls in the video were digitally marked. The filter module was used for filtering and smoothing: "filter" was double-clicked, and then "autosmooth" was selected for smoothing treatment. In the Display module, specific kinematic indicators for analysis were selected, and the outcomes were exported to Excel.

Mathematical statistics and analysis

The recorded data were organized in Excel and underwent processing in SPSS 22.0 software. An independent samples t-test was employed, with a significance level set at 0.05.

Results

First, the movement time of the center of gravity of the two groups at different stages of the complete WALK step was compared (Fig. 2).

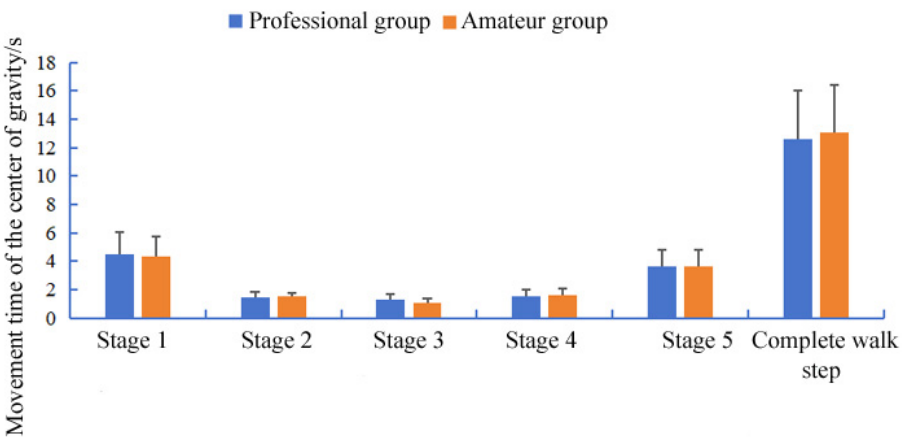

Fig. 2 Comparison of the movement time of the center of gravity in the complete WALK step (from the beginning to the end of the movement)

As depicted in Fig. 2, throughout the complete WALK step, no remarkable difference was observed in the movement time of the center of gravity between the two groups at various stages ($p > 0.05$). Specifically, the time required to execute the entire WALK step was 12.61 ± 3.42 s for the professional group and 13.11 ± 3.34 s for the amateur group, with p value 0.865 (> 0.05). This outcome indicated that the completion time for the movement was essentially equivalent between the two groups.

Taking an experimental subject from the professional group as an example, the three-axis displacement of the center of gravity to accomplish the complete WALK step is shown in Fig. 3.

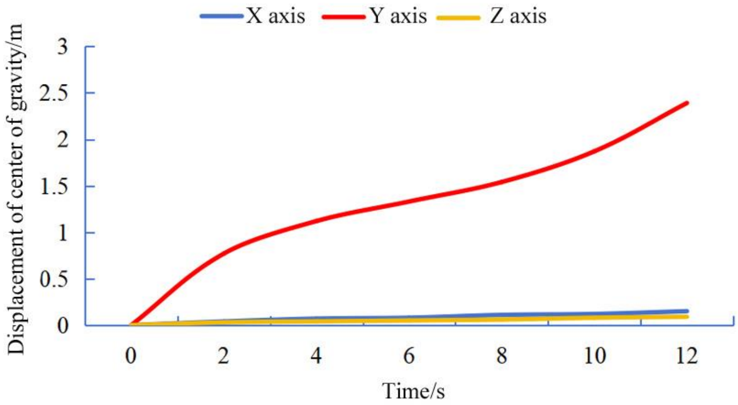

Fig. 3 The three-axes displacement of the center of gravity
to accomplish/fulfill the complete WALK step

From Fig.3, it can be observed that during the process of accomplishing the complete WALK step, the dancer had the greatest displacement in the Y-axis direction, while the displacements in the X-axis and Z-axis directions were relatively small, indicating that this movement was primarily focused on forward and backward motion.

The results of comparing the center of gravity displacements of the two groups at different stages of the complete WALK step are shown in Table 3.

Table 3. Comparison of the center of gravity displacements
(unit: m, bolded indicates $p < 0.05$)

X-axis	Professional group ($n = 5$)	Amateur group ($n = 5$)	p-value
Stage 1	0.04 ± 0.01	0.03 ± 0.01	0.854
Stage 2	0.02 ± 0.01	0.02 ± 0.01	0.758
Stage 3	0.03 ± 0.01	0.03 ± 0.01	0.569
Stage 4	0.03 ± 0.01	0.03 ± 0.01	0.845
Stage 5	0.03 ± 0.01	0.03 ± 0.01	0.658
Complete WALK step	0.14 ± 0.03	0.14 ± 0.03	0.528
Y-axis	Professional group ($n = 5$)	Amateur group ($n = 5$)	p-value
Stage 1	0.78 ± 0.16	0.81 ± 0.14	**0.012**
Stage 2	0.33 ± 0.07	0.37 ± 0.05	**0.022**
Stage 3	0.25 ± 0.03	0.28 ± 0.02	**0.000**
Stage 4	0.51 ± 0.12	0.55 ± 0.08	**0.000**
Stage 5	0.55 ± 0.07	0.57 ± 0.09	**0.000**
Complete WALK step	2.41 ± 0.27	2.56 ± 0.33	**0.000**

Z-axis	Professional group (n = 5)	Amateur group (n = 5)	p-value
Stage 1	0.04 ± 0.01	0.02 ± 0.01	**0.001**
Stage 2	0.01 ± 0.01	0.01 ± 0.01	0.325
Stage 3	0.01 ± 0.01	0.01 ± 0.01	0.215
Stage 4	0.01 ± 0.01	0.01 ± 0.01	0.068
Stage 5	0.03 ± 0.01	0.01 ± 0.01	**0.001**
Complete WALK step	0.11 ± 0.03	0.08 ± 0.02	**0.000**

According to the data in Table 3, during the complete WALK step, the center of gravity displacements in X-axis direction exhibited no remarkable difference between the two groups ($p > 0.05$). However, in Y-axis direction, the displacements for each stage in the amateur group were slightly higher than those in the professional group ($p < 0.05$). Specifically, the center of gravity displacement for the professional group completing the entire WALK step was 2.41 ± 0.27 m, whereas it was 2.56 ± 0.33 m for the amateur group, and this difference was statistically significant ($p < 0.05$). In Z-axis direction, significant differences in center of gravity displacements were observed at stages 1 and 5 ($p < 0.05$). For the professional group completing the entire WALK step, the center of gravity displacement was 0.11 ± 0.03 m, significantly different from 0.08 ± 0.02 m observed in the amateur group ($p < 0.05$). This outcome suggested that the professional group demonstrated superior stability and control in all three direction axes when executing the movement.

The peak joint angles of the hip-knee-ankle joints in the sagittal plane were compared between the two groups during the complete WALK step (Table 4).

Table 4. Lower limb kinematic data in the sagittal plane
(unit: degrees, bolded indicates $p < 0.05$; + and **-** is the direction of joint motions)

		Professional group (n = 5)	Amateur group (n = 5)	p value
Hip joint	Flexion	66.33 ± 1.86	51.26 ± 4.45	**0.000**
	Extension	-13.36 ± 0.86	-11.33 ± 0.91	**0.001**
Knee joint	Flexion	66.77 ± 1.36	53.54 ± 7.88	**0.000**
	Extension	-8.17 ± 0.36	-11.26 ± 3.12	**0.005**
Ankle joint	Flexion	11.26 ± 1.33	10.21 ± 3.34	0.325
	Extension	-25.78 ± 1.21	-25.36 ± 5.45	0.562

According to Table 4, in the sagittal plane, the peak hip flexion and extension angles for the amateur group were 51.26 ± 4.45° and -11.33 ± 0.91°, respectively. Both angles were significantly smaller than those of the professional group, with p values less than 0.05. Additionally, the peak knee flexion angle for the amateur group was 53.54 ± 7.88°, significantly smaller than that of the professional group, while the peak knee extension angle was-11.26 ± 3.12°, significantly larger than that of the professional group ($p < 0.05$). However, no remarkable difference was observed in the ankle joint. This outcome suggested that during the complete WALK step, the amateur group exhibited a slightly smaller hip twist and consequently, a less effective movement.

The peak joint angles of the hip-knee-ankle joints in the frontal plane were compared between the two groups during the complete WALK step (Table 5).

Table 5. Lower limb kinematic data in the frontal plane
(unit: degrees, bolded indicates $p < 0.05$; + and **-** is the direction of joint motions)

		Professional group (*n* = 5)	Amateur group (*n* = 5)	*p* value
Hip joint	Abduction	5.62 ± 1.11	17.64 ± 4.56	**0.000**
	Adduction	-48.67 ± 2.21	-25.78 ± 8.63	**0.000**
Knee joint	Abduction	34.35 ± 2.34	41.26 ± 13.56	0.121
	Adduction	13.64 ± 0.32	-4.64 ± 5.65	**0.000**
Ankle joint	Abduction	8.84 ± 1.36	12.77 ± 4.56	0.062
	Adduction	-9.87 ± 3.59	-12.07 ± 7.84	0.568

According to the data in Table 5, in the frontal plane, the amateur group exhibited a peak hip abduction angle of 17.64 ± 4.56°, significantly larger than that of the professional group. The peak hip adduction angle was -25.78 ± 8.63, significantly smaller than professional group. The peak knee adduction angle was -4.64 ± 5.65°, also significantly smaller than professional group ($p < 0.05$). No significant differences were observed in the peak knee abduction, ankle abduction, and ankle adduction angles. The results showed that during the complete WALK step, the lower limb hip joints in the amateur group were primarily in an adduction state in the frontal plane, and the knee joints exhibited abduction. The subjects should maintain straight knees to adhere to the movement standard.

The results of comparing the peak joint angles of the hip-knee-ankle joints in the horizontal plane between the two groups during the complete WALK step are presented in Table 6.

Table 6. Lower limb kinematic data in the horizontal plane
(unit: degrees, bolded indicates $p < 0.05$; + and **-** is the direction of joint motions)

		Professional group (*n* = 5)	Amateur group (*n* = 5)	*p*-value
Hip joint	Internal rotation	16.44 ± 1.45	25.58 ± 7.93	**0.000**
	External rotation	-1.89 ± 1.21	5.33 ± 8.97	**0.041**
Knee joint	Internal rotation	-6.84 ± 1.68	-21.26 ± 4.95	**0.000**
	External rotation	-55.74 ± 1.56	-51.26 ± 7.33	0.168
Ankle joint	Internal rotation	11.56 ± 4.37	14.35 ± 11.26	0.612
	External rotation	-8.92 ± 1.68	-18.64 ± 9.35	**0.005**

According to Table 6, in the horizontal plane, the peak hip internal and external rotation angles for the amateur group were 25.58 ± 7.93° and 5.33 ± 8.97°, respectively. Both angles were significantly larger than those of the professional group ($p < 0.05$). Additionally, the peak knee internal rotation angle was -21.26 ± 4.95°, and the peak ankle external rotation angle was -18.64 ± 9.35°, both significantly larger than those of the professional group ($p < 0.05$). However, there was no remarkable difference in the peak knee external rotation and ankle internal rotation angles ($p > 0.05$).

Discussion

The WALK step, a quintessential basic maneuver in rumba, holds prominence due to its frequent occurrence in transitions and movements. Proficiency in executing the WALK step not only enhances the overall execution of dancers' movements but also facilitates a deeper understanding of the articulation between different movements, thereby elevating the proficiency of the entire dance sequence. Using ten dancers as the focus of analysis, this paper compared the mechanical characteristics of professional dancers and amateur students performing WALK steps.

Based on the comparison results, there was no remarkable difference in center of gravity movement time between the two groups. Throughout the experiment, both groups executed the WALK steps synchronously with the same musical cues, resulting in a similar completion time for each stage of the movement. The center of gravity movement time remained consistent. In examining the three-axes center of gravity displacements, notable differences emerged between the two groups on the Y and Z axes, while no significant differences were observed on the X-axis. This discrepancy may be attributed to the large movement of the center of gravity in the Y-axis and Z-axis directions during the complete WALK step and minimal changes in the X-axis. The WALK step involves a swinging movement achieved by transferring the body's center of gravity, which requires appropriate shifts of the center of gravity from left to right or from right to left, thus demanding high body stability. Comparing the two groups, it was evident that the center of gravity in the amateur group exhibited more pronounced vertical fluctuations, indicating poorer stability. In subsequent teaching and training sessions, there is a need to emphasize core strength training to enhance the body's stable control abilities. This approach aims to narrow the gap in the center of gravity displacement between the amateur and professional groups, ultimately improving the stability and fluidity of movement execution.

Sports dance is also a sport that is prone to injuries [10], and this should be fully taken into consideration during daily training. The mechanical characteristics of lower limbs were compared between the two groups, revealing that in WALK steps, the hip joint played a pivotal role and the execution of the movement was closely associated with the flexibility of the hip joint. The amateur group exhibited smaller hip flexion and extension angles in the sagittal plane, larger abduction angles, smaller adduction angles in the frontal plane, and larger internal and external rotation angles in the horizontal plane ($p < 0.05$). These results suggested that the professional group demonstrated a superior hip joint range of motion and flexibility during the execution of a full WALK step, contributing to the overall fluidity of the movement. An inappropriate hip joint range of motion can result in repeated stress on the hip joint [1], potentially compromising ligament protection. Excessive abduction angles may also adversely affect leg aesthetics. Consequently, strengthening gluteal muscle group training is recommended for the amateur group to enhance hip joint control and mitigate the risk of sports injuries. The knee joint is particularly prone to injuries [9], and in the WALK step, maintaining a straight knee is essential for stabilizing the center of gravity. Both groups exhibited flexed knee joints in the sagittal plane and reduced abduction and adduction in the frontal plane. However, the knee joint angle in the amateur group differed to some extent from that of the professional group, leading to reduced accuracy in movement. Finally, concerning the ankle joint, significant differences were observed only in the peak ankle adduction angle in the horizontal plane. The amateur group exhibited a significantly larger external rotation angle, making them more susceptible to sprains.

In summary, significant differences were evident in the mechanical characteristics of amateur and professional groups during the execution of WALK steps. This finding suggests the importance of enhancing the technical proficiency of the amateur group. Therefore, it is crucial to prioritize the strengthening of lower limb muscle groups and improve joint control to enhance the overall execution of WALK steps and mitigate the risk of sports injuries.

Conclusion

In this study, the mechanical characteristics of professional dancers and amateur students completing the basic WALK steps of rumba were analyzed in terms of kinematics. The key findings are summarized as follows:

(1) The time of the center of gravity movement was consistent between both groups, showing no significant differences.

(2) There was no significant distinction in center of gravity displacement in the X-axis direction, but notable differences were observed between the two groups in the Y- and Z-axes directions.

(3) The amateur group exhibited inferior control of lower limb joints and lower stability compared to the professional group.

The research in this article identifies some shortcomings in the execution of movements by the amateur group, which can be effectively applied in practical teaching and training scenarios to offer targeted guidance for enhancing students' technical proficiency.

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