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Article

# Kinematic analysis of aerobics using biomechanics: Comparisons between different complex movements in ten athletes

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**Abstract:** Accurately executing high-difficulty aerobics movements is essential for improving competitive scores. This paper carried out a kinematic analysis of two complex movements, A104 and A136, ten aerobics athletes from three universities in Beijing. The results indicated minimal difference between the two movements during the plio push-up phase. However, in the airborne phase, A136 demonstrated a higher elevation and a larger angle of the elbow joints to facilitate subsequent landing. In the touchdown cushioning phase, A136 and A104 exhibited significant differences in the right hip joint angle and left shoulder joint angle. Amateur athletes had a higher degree of joint variation during airborne and touchdown buffer phases compared to professional athletes, making them more prone to joint injuries.

**Keywords:** biomechanics; aerobics; kinematics; complex movement

## 1. Introduction

During aerobics competitions, athletes must continuously perform sets of combination movements while showcasing their strength and flexibility [1,2]. Aerobics encompasses many complex movements, from simple jumps and turns to intricate balance and flexibility movements, each with unique biomechanical characteristics [3]. The difficulty level of these movements and the quality of execution directly impact an athlete's score [4]. Therefore, conducting a scientific kinematic analysis of complex aerobics movements can enhance athletes' training and competition performance by understanding the fundamental techniques involved [5].

Several relevant studies have been conducted in this field. Vijaya et al. [6] examined the impact of own body calisthenics with asana practices on female college students' high-density lipoprotein and low-density lipoprotein levels and found a significant positive change in both lipoprotein levels following own body calisthenics with asana practices. Yu et al. [7] analyzed constructing and optimizing a complex system model for teaching aerobics in colleges and universities. The data analysis revealed that aerobics trainees experienced less teaching pressure and displayed outstanding performance within the experimental environment. Ayzyatullova et al. [8] investigated the balance of forces in various types of competitive aerobics competitions to develop a training way for highly skilled athletes for the Russian national aerobics team. The aforementioned studies all analyzed aerobics. Some focused on its physiological effects on the human body, some examined teaching methods for aerobics, and some researched techniques related to aerobics. This article utilized biomechanics to analyze the movements of aerobics in order to guide training. Following the introduction of competitive aerobics, this paper proceeds to conduct a kinematic analysis of two complex movements, A104 and A136, using ten male aerobics athletes from the Aerobics Department at the Beijing Institute of Fashion Technology and ten male aerobics amateurs.

## 2. Case study

### 2.1. Analysis subjects

This study compared the complex movements by selecting ten male aerobics athletes from the Aerobics Department at the Beijing Institute of Fashion Technology and ten male aerobics amateurs as subjects. These athletes had a training experience of three years in aerobics. The participants had an average age of 20 ± 0.2 years, with an average height of 175 ± 1.2 cm, and an average body weight of 70 ± 0.3 kg. Moreover, they had no family history of illnesses and had not sustained any injuries in the last three months. They were classified into the professional group. The only difference between the aerobics amateurs and athletes was their experience in aerobics training. The amateurs had only half a year of training experience, and they were classified into the amateur group.

### 2.2. Complex aerobics movements

As a competitive sport, aerobics has established scoring standards to assess athletes' skill levels. During competitions, athletes demonstrate their technical proficiency and physical capabilities by performing sets of movements and moreover showcase the artistic elements of their routines [9]. Complex movements are integral to aerobics routines and play a crucial role in scoring. Athletes strive to incorporate complex movements with higher scoring potential into their routines. However, it is essential to note that higher scores correspond to more significant difficulty. Any mistakes in executing complex movements can result in point deductions, which can significantly impact the overall flow and continuity of the routine [10]. Therefore, athletes must practice and refine their execution of complex movements to enhance accuracy and skill level [11].

Due to space constraints, this paper focuses on the kinematic analysis of two complex ground movements from Group A to examine their technical characteristics [12]. The chosen movements are A104, which is explosive A-frame with a score of 0.4, and A136, which involves explosive A-frame to free support Wenson and has a score of 0.6 [13]. The schematic diagrams of the two complex movements are shown in **Figure 1**. For the A104 movement, its key movements include: 1) front support; 2) perform a plio push-up and lift the hips while airborne; 3) the bending posture requires legs to be perpendicular to the ground with chest close to knees; 4) land into a push-up position. For the A136 movement, its key movements include: 1) front support; 2) perform a plio push-up and lift the hips while airborne; 3) the bending posture requires legs to be perpendicular to the ground with chest close to knees; 4) both hands and feet touch the ground simultaneously to form a posture of free support Wenson push-up.

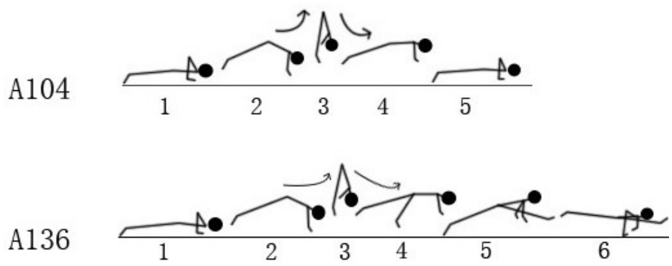


**Figure 1.** The schematic diagram of the two complex movements.

Both A104 and A136 are a series of movements of explosive A-frame in the dynamic strength category of Group A. Both movements start with explosive A-frame, and the only difference lies in the subsequent movements when hands and feet touch the ground during landing. It is worth noting that A136 carries a higher point value, indicating its higher difficulty level than A104. The scoring evaluation of the movements is based on the Scoring Rules for Group A Difficulty of Competitive Aerobics in the 2022–2024 Cycle.

### 2.3. Analysis methods

Relevant equipment included infrared high-speed camera, medical alcohol, degreasing cotton balls, and medical tape [14].

This paper utilized infrared high-speed cameras to capture the kinematic parameters, specifically the changes in joint angles, during the execution of complex movements by the athletes. The setup of the infrared high-speed cameras is illustrated in **Figure 2**. A total of eight infrared high-speed cameras calibrated according to the instruction manual were employed for data collection. The aerobics venue had dimensions of 7 m × 7 m.

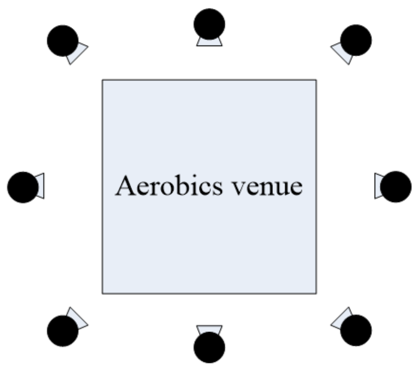


**Figure 2.** Schematic diagram of the arrangement of the infrared high-speed camera.

The key steps of the two complex movements, A104 and A136, have been described in the previous text. On the day before the formal testing, athletes had sufficient rest and maintained a consistent diet. In order to prevent athletes from getting injured during the testing process, a thorough warm-up activity was conducted before testing the two complex movements. Following the warm-up, each athlete performed A104 and A136 three times at the center of the field [15]. A rest period of 2 min was provided between the execution of the two movements.

The overall movements of A104 and A136 were categorized into three distinct phases: the plio push-up phase, the airborne phase, and the touchdown buffer phase, as illustrated in **Figure 3**. The plio push-up phase consisted of a buffer phase and a push-up phase, while the airborne phase encompassed ascending and descending phases [16]. The touchdown buffer phase only included one buffer phase. **Figure 3** presents the division features between these phases. Taking the buffer phase in the plio push-up phase as an example, it begins from the picture of "hand touching the ground" and concludes at the picture of "minimum elbow angle".

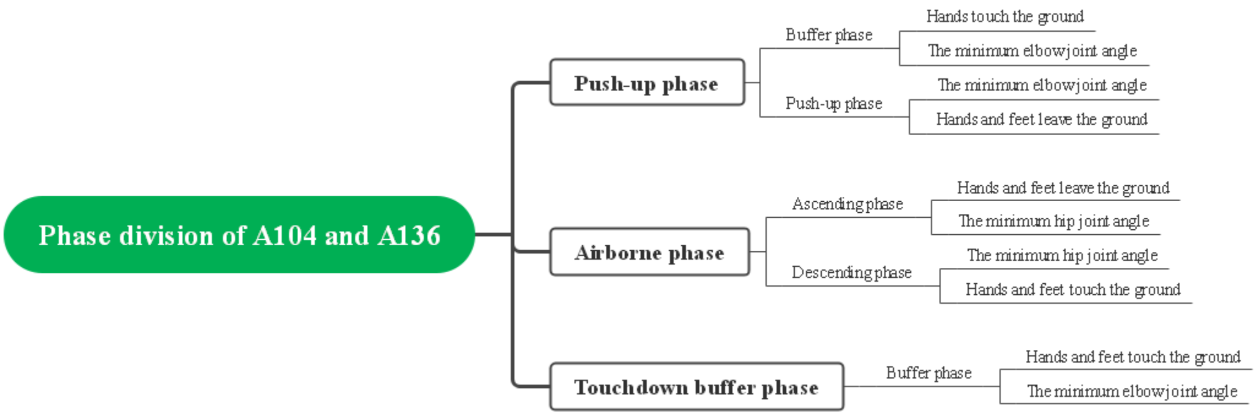


**Figure 3.** Phase divisions of two complex movements.

## 2.4. Statistical analysis

The movement data of the athletes performing complex movements was collected using infrared high-speed cameras. The Kwon3D XP motion capture and analysis software was used to convert captured motion images into movement data. SPSS software was used for statistical analysis. For the differences in kinematic parameters between the professional group and the amateur group, as well as the differences in kinematic parameters between different difficulty levels of movements, an independent sample t-test was conducted. A $p$ value less than 0.05 during the test indicates a significant difference at a 5% significance level.

## 2.5. Test results

### 2.5.1. Test results of the plio push-up phase

The test results for the plio push-up phase are presented in **Tables 1** and **2**. According to **Table 1**, at the end of the buffer phase, there were no significant differences in the angles of the elbow and shoulder joints between the two movements. However, **Table 2** reveals that at the end of the plio push-up phase, the A136 movement exhibited a significantly higher center of gravity and more pronounced shoulder joint displacement and elbow joint angle. However, no significant differences were observed in the hip joint between the two movements. For the same movement, it can be observed that there was no significant difference in kinematic parameters between the professional and amateur groups at this phase.

**Table 1.** Mean values of kinematic parameters for two complex movements of the two groups when the elbow angle is the smallest in the buffer phase.

| **Complex movement** | **A104** | | **A136** | | ***P* value of the professional group** | ***P* value of the amateur group** |
|---|---|---|---|---|---|---|
| **Group** | **Professional group** | **Amateur group** | **Professional group** | **Amateur group** | | |
| Left elbow joint angle/° | 70.32 | 72.36 | 70.29 | 72.12 | 0.987 | 0.974 |
| Right elbow joint angle/° | 69.98 | 71.11 | 70.15 | 71.87 | 0.896 | 0.965 |
| The vertical plane angle of the left shoulder joint/° | 67.84 | 68.97 | 67.59 | 68.54 | 0.998 | 0.947 |
| The vertical plane angle of the right shoulder joint/° | 67.75 | 68.78 | 67.44 | 68.34 | 0.978 | 0.941 |
| The horizontal plane angle of the left shoulder joint/° | 142.57 | 145.23 | 141.99 | 146.25 | 0.879 | 0.852 |
| The horizontal plane angle of the right shoulder joint/° | 141.89 | 144.22 | 141.88 | 145.87 | 0.869 | 0.897 |

Note: * indicates a significant difference between the professional and amateur groups.

**Table 2.** Mean values of kinematic parameters of the two complex movements of the two groups during the plio push-up phase when the hands and feet are off the ground.

| **Complex movement** | **A104** | | **A136** | | ***P* value of the professional group** | ***P* value of the amateur group** |
|---|---|---|---|---|---|---|
| **Group** | **Professional group** | **Amateur group** | **Professional group** | **Amateur group** | | |
| The *Z*-axis displacement of the left shoulder joint/cm | 26.43 | 27.41 | 28.31 | 28.64 | 0.012 | 0.897 |
| The *Z*-axis displacement of the right shoulder joint/cm | 26.39 | 27.15 | 28.36 | 28.12 | 0.011 | 0.896 |
| The *Z*-axis velocity of the left shoulder joint cm/s | 145.09 | 146.32 | 175.68 | 175.55 | 0.010 | 0.975 |
| The *Z*-axis velocity of the right shoulder joint cm/s | 146.01 | 147.11 | 174.89 | 174.78 | 0.011 | 0.868 |
| Left elbow joint angle/° | 23.66 | 24.11 | 30.21 | 29.98 | 0.010 | 0.875 |
| Right elbow joint angle/° | 22.98 | 23.21 | 30.14 | 29.89 | 0.010 | 0.846 |
| Left hip joint angle/° | 120.37 | 121.11 | 121.36 | 121.14 | 0.697 | 0.736 |
| Right hip joint angle/° | 120.41 | 121.13 | 120.89 | 120.78 | 0.748 | 0.885 |
| Height of center of gravity/cm | 55.47 | 55.63 | 57.36 | 57.13 | 0.010 | 0.784 |

Note: * indicates a significant difference between the professional and amateur groups.

### 2.5.2. Test results in the airborne phase

The test results for the airborne phase are displayed in **Tables 3** and **4**. It is evident from **Table 3** that there was a significant difference in the elbow joint angle at the end of the ascending phase between the two movements. However, no significant differences were observed in the hip and knee joint angles. **Table 4** indicates that at the end of the descending phase, the change in the left elbow joint angle was significantly smaller, whereas the change in the right hip joint angle and the change in the left shoulder joint angle were both significantly larger. For the same movement, it can be observed that there were significant differences in kinematic parameters between the professional and amateur groups at this phase.

**Table 3.** Mean values of kinematic parameters of the two complex movements of the two groups when the hip joint angle was the smallest in the ascending phase.

| Complex movement | A104 | | A136 | | *P* value of the professional group | *P* value of the amateur group |
|---|---|---|---|---|---|---|
| Group | Professional group | Amateur group | Professional group | Amateur group | | |
| The left elbow joint angle/° | 130.99* | 133.25 | 137.36* | 139.32 | 0.014 | 0.012 |
| The right elbow joint angle/° | 130.31* | 133.26 | 137.28* | 139.74 | 0.013 | 0.016 |
| The left hip joint angle/° | 56.78* | 58.97 | 58.13* | 60.24 | 0.758 | 0.789 |
| The right hip joint angle/° | 56.75* | 58.89 | 58.02* | 60.21 | 0.745 | 0.785 |
| The left knee joint angle/° | 169.74* | 171.58 | 171.41* | 173.25 | 0.658 | 0.741 |
| The right knee joint angle/° | 168.97* | 170.32 | 170.25* | 172.36 | 0.684 | 0.732 |
| Height of center of gravity/cm | 73.24 | 73.56 | 85.36 | 85.65 | 0.011 | 0.017 |

Note: * indicates a significant difference between the professional and amateur groups.

**Table 4.** Mean values of kinematic parameters of the two complex movements of the two groups when the hands and feet touch the ground in the descending phase.

| Complex movement | A104 | | A136 | | *P* value of the professional group | *P* value of the amateur group |
|---|---|---|---|---|---|---|
| Group | Professional group | Amateur group | Professional group | Amateur group | | |
| The angle of the left elbow joint/° | 14.42* | 16.54 | 10.65* | 12.10 | 0.011 | 0.010 |
| The angle of the right elbow joint/° | 13.98* | 15.23 | 14.32* | 16.23 | 0.674 | 0.741 |
| The angle of the left hip joint/° | 12.29* | 14.25 | 13.24* | 15.14 | 0.010 | 0.011 |
| The angle of the right hip joint/° | 12.36* | 14.32 | 33.65* | 35.21 | 0.647 | 0.654 |
| The angle of the left shoulder joint/° | 9.01* | 11.21 | 16.39* | 18.43 | 0.011 | 0.012 |
| The angle of the right shoulder joint/° | 9.12* | 11.14 | 10.11* | 12.03 | 0.687 | 0.689 |

Note: * indicates a significant difference between the professional and amateur groups.

### 2.5.3. Test results in the touchdown buffer phase

The test results for the touchdown buffer phase are presented in **Table 5**. It is evident that at the end of the buffer phase, no significant differences were observed in the elbow joint angle, the left hip joint angle, and the right shoulder joint angle between the two movements. However, a significant difference was found in the right hip joint angle and the left shoulder joint angle. For the same movement, it can be observed that there were significant differences in kinematic parameters between the professional and amateur groups at this phase.

**Table 5.** Mean values of kinematic parameters for the two complex movements of the two groups when the elbow joint angle was the smallest in the buffer phase.

| Complex movement | A104 | | A136 | | *P* value of the professional group | *P* value of the amateur group |
|---|---|---|---|---|---|---|
| Group | Professional group | Amateur group | Professional group | Amateur group | | |
| The left elbow joint angle/° | 138.54* | 140.21 | 139.74* | 141.25 | 0.639 | 0.784 |
| The right elbow joint angle/° | 139.12* | 141.22 | 139.76* | 141.14 | 0.674 | 0.741 |
| The left hip joint angle/° | 95.34* | 97.85 | 96.34* | 98.57 | 0.015 | 0.013 |
| The right hip joint angle/° | 96.35* | 97.26 | 113.68* | 115.25 | 0.489 | 0.541 |
| The left shoulder joint angle/° | 112.32* | 114.36 | 74.67* | 76.54 | 0.013 | 0.011 |
| The right shoulder joint angle/° | 111.68* | 113.32 | 112.14* | 114.57 | 0.487 | 0.523 |

Note: * indicates a significant difference between the professional and amateur groups.

## 3. Discussion

Competitive aerobics is a sports program that combines elements of gymnastics, music, and dance. During aerobics competitions, athletes must perform continuous movements, show casing their flexibility and strength to the fullest extent possible. The evaluation criteria for aerobics include artistry, movement completion degree, and movement difficulty level. Artistry demands that when choreographing a set of movements, it should highlight the athletes' sense of strength and flexibility without any repetition. Movement completion degree assesses the athlete's ability to accurately execute the choreographed movements, while movement difficulty is rewarded with higher scores for more complex movements. Moreover, the analysis and research of difficult aerobics movements can also contribute to the knowledge system of aerobic exercise analysis.

Conducting kinematics analysis of complex aerobics movements can help to deeply understand the technical aspects and difficulties involved, thereby guiding targeted training and enhancing the degree of movement completion.

This study conducted a kinematic analysis on ten athletes from the Aerobics Department of Beijing Institute of Fashion Technology and ten amateurs to examine two complex movements, A104 and A136. A104 involves an explosive A-frame, while A136 involves explosive A-frame to free support Wenson. Both movements include the explosive A-frame. The only difference lies in the ending movements, where A104 concludes with push-ups while A136 ends with free support Wenson. However, A136 had a higher difficulty score than A104. Both movements consisted of three phases: a plio push-up phase, an airborne phase, and a touchdown buffer phase.

During the plio push-up phase, the moment when the elbow joint angle is at its minimum in the buffering stage is when the push-up movement shifts its center of gravity to its lowest point to accumulate force for the subsequent movement. The tested kinematic parameters indicated no significant difference in the elbow and shoulder joint angles between the two movements at this stage. This is because both movements utilized the push-up movement during this phase. The shoulder joint angle in this phase promoted the dominance of the latissimus dorsi muscle to enhance the stability of shoulder joints. Moreover, the elbow joint angle pulled the chest muscle group to generate force and thus stabilize the body. When the hands and feet left the ground, the body was about to enter the explosive A-frame phase. At this moment, there were more significant vertical displacement of the shoulder joint, changes in elbow joint angle, and variations in center of gravity height during A136 movement. After explosive A-frame, A136 movement required transitioning to the free support Wenson movement by raising the right leg to make contact with triceps brachii. Therefore, sufficient air altitude was needed, resulting in a higher center of gravity height. To achieve sufficient air time, a greater force was applied in the push-up phase, which manifested as larger shoulder joint displacement and more changes in elbow joint angle.

During the airborne phase, when the hip joint angle reached its minimum in the ascending phase, the body reached the highest point, and the elbow joint angle of A136 was significantly higher compared to A104. After descending in A136, the transition to free support Wenson followed. The free support Wenson could only be supported by both hands, while A104 used push-ups as the finishing movement, which not only relied on both hands for support but also allowed the use of feet as support. Therefore, A136 necessitated the readiness of the elbow joints during the airborne phase.

During the touchdown buffer phase, when the elbow joint angle reached its minimum value, the entire movement ended. There was a significant difference in the right hip joint angle and the left shoulder joint angle in the A136 movement. This is because the A136 movement ended with the free support Wenson movement. The right leg contacted with triceps brachii so that the body's center of gravity to shift towards the right side.

In addition, this article also compared the professional group and the amateur group. The results showed that there was no significant difference in kinematic parameters between the professional group and the amateur group during the plio push-up phase (the first phase). The reason for this is that there is not much difficulty in the initial stage of movements A104 and A136, and at this time both groups of athletes had relatively sufficient physical strength to complete the initial movements more accurately. However, in the subsequent airborne phase (the second phase) and touchdown cushioning phase (the third phase), there were significant differences in kinematic parameters between professional and amateur groups. One reason is that both movements have a degree of difficulty during the airborne phase, and the subjects expended some physical energy to achieve sufficient height, which increased the difficulty of completing the movement. Professional athletes that received enough training could perform better. From the differences in kinematic parameters between the professional and amateur groups, it can be observed that there were greater joint changes measured in the second and third phases for the amateur group. This is due to their less standardized movements. In order to achieve the same effect, more force was required, which led to greater joint movement. However, this also increased the burden on the joints and raised the risk of joint injuries. This is why the amateur group is more prone to injuries compared to the professional group.

The limitation of this article is that only kinematics was used to analyze the difficult movements in aerobics, without utilizing electromyographic signals to study muscle changes. Therefore, a future research direction is to employ surface electromyographic signals for analyzing the difficult movements in aerobics.

## 4. Conclusion

This paper conducted a kinematic analysis of two complex movements, A104 and A136, on ten athletes from the Aerobics Department of the Beijing Institute of Fashion Technology and ten amateurs. The following are the key findings. (1) In the buffer phase of the push-up phase, there were no significant differences in the elbow and shoulder joint angles between the two movements. However, at the end of the push-up phase, the center of gravity height was significantly higher in the A136 movement. Additionally, there were more significant changes in the shoulder joint displacement and the elbow joint angle in the A136 movement compared to A104. The hip joint angle did not show significant differences between the two movements. (2) At the end of the ascending phase of the airborne phase, there was a significant difference in the elbow angle between the two movements. However, there were no significant differences in the hip and knee joint angles. At the end of the descending phase, there was a significantly smaller change in the left elbow angle, a significantly more significant change in the right hip angle, and a significantly more significant change in the left shoulder angle in the A136 movement compared to A104. (3) At the end of the touchdown buffer phase, there were no significant differences in the elbow joint angles between the two movements. There were also no significant differences in the left hip joint angle and the right shoulder joint angle. However, there was a significant difference in the right hip joint angle and the left shoulder joint angle between the two movements. (4) The amateur group had a higher degree of joint variation during airborne and touchdown cushioning phases compared to the professional group, making them more prone to joint injuries.

The limitation of this article is that only kinematics was used to analyze the difficult movements in aerobics, without utilizing electromyographic signals to study muscle changes. Therefore, a future research direction is to employ surface electromyographic signals for analyzing the difficult movements in aerobics.

**Author contributions:** Conceptualization, WZ and ZH; methodology, WZ; software, WZ; validation, WZ; formal analysis, WZ and ZH; investigation, ZH; resources, WZ; data curation, ZH; writing—original draft preparation, WZ; writing—review and editing, ZH; visualization, WZ; supervision, WZ; project administration, WZ. All authors have read and agreed to the published version of the manuscript.

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**Conflict of interest:** The authors declare no conflict of interest.

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