

Biomechanics of the back handspring from the round off in youth artistic gymnastics

بايوميكانيك قفزة اليدين الخلفية من الراوند اوف في الجمباز الفني للشباب

¹ Qasim Mohammed Sayah, The Department of Students' Activities, the University of Basra, Iraq

qasim.sayah@uobasrah.edu.iq

² Kanel Abed Farhan, The Department of Students' Activities, the University of Basra, Iraq

Kamellkamell08@gmail.com

³ Wafaa Hassan Kadhum, The Department of Students' Activities, the University of Basra, Iraq

wafaa.kadhum@uobasrah.edu.iq

Received: 28/12/2025

Accepted: 03/03/2026

Published: 30/03/2026

Abstract: The purpose of this study was to examine the biomechanical characteristics of the back handspring. Biomechanical variables were calculated for 15 young gymnasts. They were filmed using a camera at 120 frames per second, and the videos were processed using Sport2D software to obtain the data required for this study. The results showed that during the landing phase of the first round off, the horizontal velocity of the center of mass decreases slightly. This is likely due to the angle of inclination of the body upon landing. The vertical velocity is negative during this phase, probably due to the cushioning effect during foot contact and preparation for the subsequent takeoff, as evidenced by the decrease in the knee joint angle at this point. From the point of foot contact, the horizontal velocity of the center of mass increases, and the vertical angle becomes positive, indicating that the takeoff is upward and backward. Both the shoulder joint angle and the hip joint angle increase significantly throughout the landing phase. During this period.

Keywords: tilt angle, center of mass.

المخلص : الغرض من هذه الدراسة هو فحص الخصائص البيوميكانيكية لحركة قفزة اليدين الخلفية. تم حساب متغيرات بايوميكانيكة لدى 15 لاعب جمباز ناشئة. من خلال تصويرهم بواسطة كاميرا سرعتها 120 صورة بالثانية وعولجت الفيديوها من خلال برنامج sport2d للحصول على البيانات المطلوبة في هذه الدراسة. اشارت نتائج الدراسة خلال مرحلة الهبوط على القدمين في المرحلة الأولى بعد الروند اووف، تنخفض السرعة الأفقية لمركز الكتلة انخفاضاً طفيفاً. يُعزى ذلك على الأرجح إلى أن زاوية ميل الجسم عند هبوط القدمين. تكون السرعة العمودية سالبة في هذه المرحلة. ويرجع ذلك على الأرجح إلى تأثير التوسيد أثناء ملاسة القدمين للأرض والاستعداد للانطلاق التالي، كما يتضح من انخفاض زاوية مفصل الركبة عند هذه النقطة. من مرحلة ملاسة القدمين للأرض، تزداد السرعة الأفقية لمركز الكتلة، وتصبح الزاوية العمودية موجبة، مما يشير إلى أن الانطلاق يكون مائلاً للأعلى وللخلف. تزداد كل من زاوية

مفصل الكتف وزاوية مفصل الورك بشكل ملحوظ طوال مرحلة ملاسة القدمين للأرض. خلال هذه الفترة، ينخفض الزخم الزاوي حول مركز ثقل الجسم في البداية، ثم يزداد. خلال المرحلة الهوائية الأولى بعد الانطلاق، تظل السرعة الأفقية لمركز كتلة الجسم ثابتة تقريبًا.
الكلمات المفتاحية : زاوية الميل، مركز الكتلة.

1- Introduction:

Floor exercises, a type of artistic gymnastics, rely heavily on the quality of acrobatic movements to determine the final score for both men and women. These movements consist primarily of forward and backward flips, typically performed after a round-off or back handspring. Flips, especially those requiring multiple twists or turns, usually begin with a backflip, which serves as a prelude to the subsequent flips.

When performing a back handspring from a round off, the sequence of steps is as follows: landing on the first foot, the first flight, landing on the hands, the second flight, and finally landing on the second foot. The final landing on the second foot coincides with the take-off phase of the back handspring. The height of the body in the air during a back handspring is determined by the vertical and horizontal velocities immediately after the take-off, while the position and number of turns of the back handspring are determined by the angular momentum. Therefore, the backhand jump is essential for generating the velocity and angular momentum required to successfully execute subsequent back handspring aerobic flips, at various positions and with varying numbers of rotations.

During the second landing phase, the final phase of the back handspring, and the subsequent recovery phase, it is crucial to convert the body's horizontal velocity into vertical velocity or to alter the angular momentum as needed. This recovery technique has been analyzed and studied biomechanically by Qasim Sayah (2025), Qasim Sayah and Zdzisław (2015), Penitente et al. (1990), Chenfu Huang and Gin-Shu Hsu (2009), and Lovecchio et al. (2013). However, despite the extensive coverage of the back handspring in instructional materials and research, studies elucidating the biomechanical characteristics of the entire movement, after the take-off phase, are very few.

Recently, while the overall movement process has remained unchanged, reports indicate that the back handspring has become more common, largely influenced by the development of back handspring aerobatics and changes in floor gymnastics equipment standards. It is characterized by features such as no initial elbow flexion and a greater shoulder flexion angle compared to the traditional back handspring. It is easy to imagine that this new form of back handspring has emerged due to the advantages it offers when performing back handspring aerobatics. However, a detailed study of these advantages is necessary, and to do so, the individual characteristics of the back handspring must be clarified.

2- The method:

2-1 Participants:

The study included 14 male gymnasts who participated in the 2025 Iraqi Junior Artistic Gymnastics Championship. The average age of the participants was

16.6±3.11 years, with an average mass of 55.64±9.33 kg and an average height of 1.58±0.077 meters.

2-2 Imaging and Analysis:

The back handspring movements of each participant during the floor exercises were filmed at a rate of 120 frames per second using an iPhone 11 Pro video camera positioned perpendicular to the floor's diameter. All filmed backhand jump movements began from a round-off position and then transitioned to a back handspring.

After recording, the videos were transferred to an MSI PC for data analysis using Sport2D software (Pagnon et al., (2024)). A C3D file was then generated, and the data was processed using PLAViMoP software (Decatoire et al., 2018). Eighteen measurement points were numbered on the body for each image, and the two-dimensional coordinates for each measurement point were obtained, as shown in Figure 1.

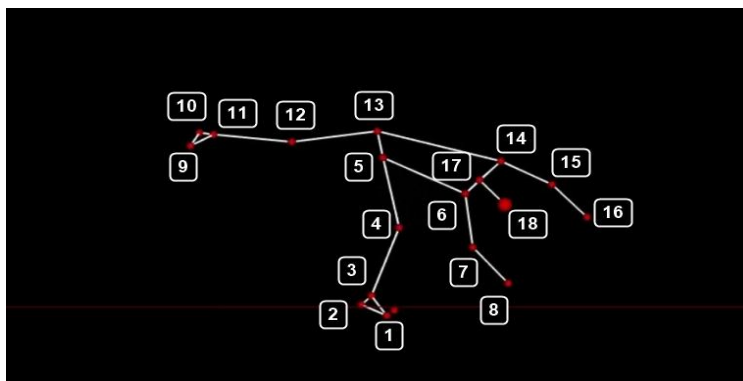


Figure 1. Position of points on the body

2-3 The measured variables, Figure 2.

- 1 .Horizontal and vertical velocity of the center of mass.
- 2 .Angles of the shoulder, hip, and knee joints.
- 3 .Angular momentum about the center of mass.
4. Body tilt angle.

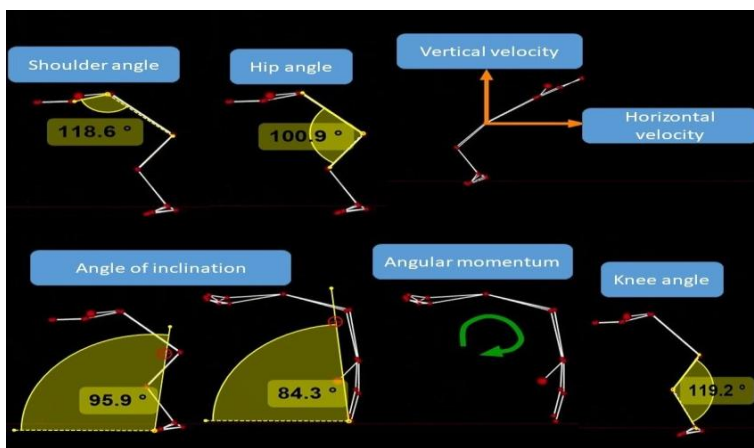


Figure 2. Measured variables

2-4 Phases:

Table (1) and Figure (3) show the phases of performing the back handspring from the round off.

Phase (1)	Phase (2)	Phase (3)	Phase (4)	Phase (5)
Landing on the feet	First flight	Landing on hands	Second flight	Take off

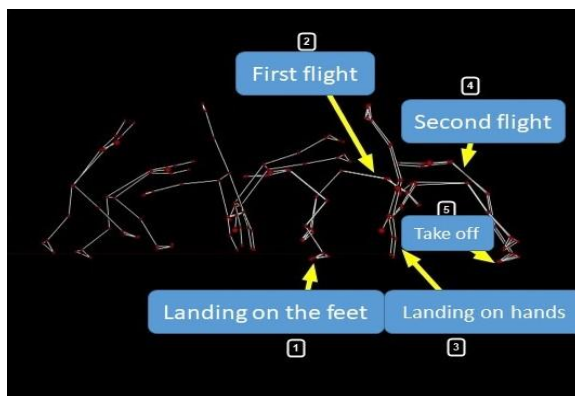


Figure 3. Phases

2-5 Statistical processing:

Calculating the arithmetic mean and standard deviation using the Minitab 19 statistical software.

3- Results and discussions:

3-1 Results

1) Horizontal and vertical velocity of the center of mass:

Table 2: Horizontal and vertical velocity values of the center of mass (m/s).

	Phase (1)	Phase (2)	Phase (3)	Phase (4)	Phase (5)
Variables	Landing on the feet	First flight	Landing on hands	Second flight	Take off
Horizontal velocity	4.22 ± 0.113	4.13 ± 0.135	4.21 ± 0.187	3.72 ± 0.218	3.53 ± 0.256
Vertical velocity	-1.23 ± 0.054	0.78 ± 0.112	-0.47 ± 0.066	-0.69 ± 0.112	-0.95 ± 0.082

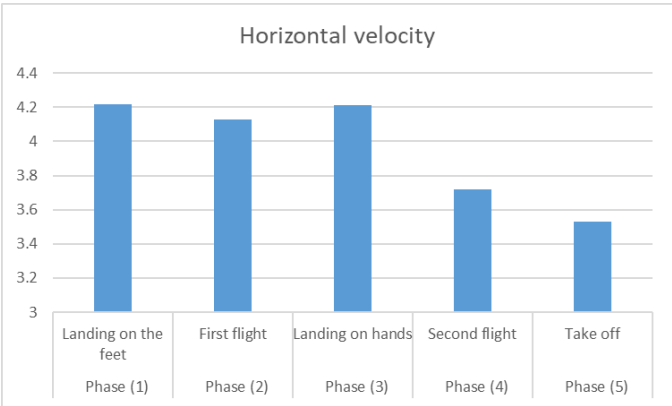


Figure (4) Horizontal velocity plot

- Horizontal Velocity

Figure (4) and Table (2) illustrate the change in the horizontal velocity of the center of mass at each phase. From the first to the second phase, the horizontal velocity decreased, then increased during the third phase. From the third to the fourth phase, the horizontal velocity tended to decrease. After that, the horizontal velocity remained almost constant from the fourth to the fifth phase.

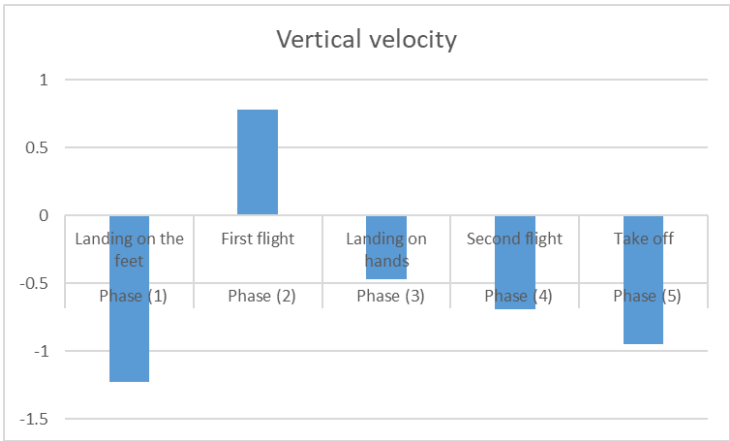


Figure (5) Vertical velocity plot

- Vertical Velocity

Figure (5) and Table (2) illustrate the change in the vertical velocity of the center of mass. Table 1 shows the values for each phase. The vertical velocity of the center of mass was negative in the first phase, then increased to a positive value

during the second phase. From the second to the third phase, the vertical velocity decreased, becoming negative again. From the third to the fourth phase, the vertical velocity decreased again and became negative. Consequently, from the fourth to the fifth phase, the vertical velocity continued to decrease.

2) Body Joint Angles

Table 3: Values of body joint angles (°)

Variables	Phase (1)	Phase (2)	Phase (3)	Phase (4)	Phase (5)
	Landing on the feet	First flight	Landing on hands	Second flight	Take off
Shoulder	187 ± 3	181 ± 3	158 ± 4	214 ± 7	274 ± 5
Hip	167 ± 1	162 ± 3	147 ± 1	234 ± 4	247 ± 1
Knee	182 ± 2	147 ± 3	115 ± 4	177 ± 1	154 ± 3

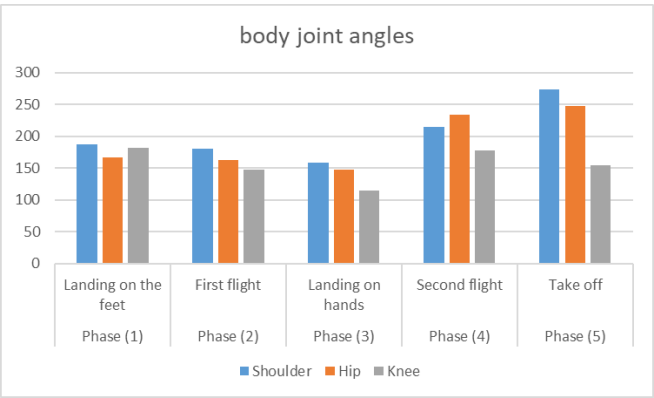


Figure (6) body joint angles plot

Figure (6) and Table (3) illustrate the change in shoulder joint angle at each phase. The shoulder angle increased in the first phase after the round off, then

decreased in the second phase, then decreased in the third phase, and increased in the fourth and fifth phases.

Similarly, Figure (6) and Table (3) illustrate the change in hip joint angle. It increased in the first phase, then decreased in the second phase, then decreased in the third phase, and increased in the fourth and fifth phases.

3) Angular momentum about the center of mass.

Table 4: Initial and final angular momentum values for the landing phase on the feet and hands ($\text{kg}\cdot\text{m}^2/\text{s}$).

Variables	Phase (1)	Phase (3)
	Landing on the feet	Landing on hands
Initial angular momentum	-0.72 ± 0.006	-0.76 ± 0.008
Final angular momentum	-0.81 ± 0.006	-88 ± 0.009

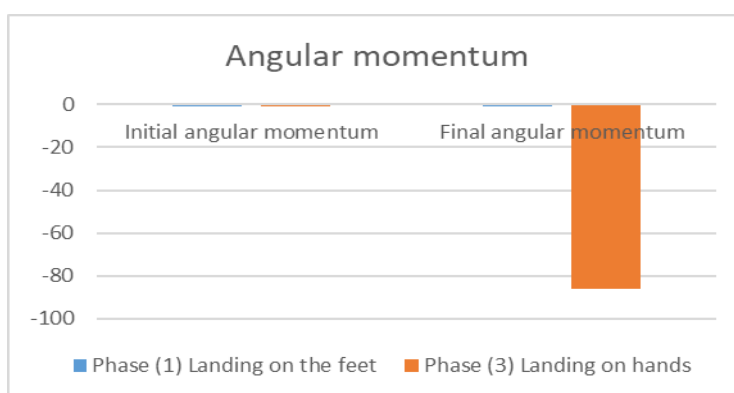


Figure (7) Angular momentum plot

Figure (7) and Table (4) illustrate the change in angular momentum from landing on the feet to just before rising when representing each phase. In the first phase, the landing of the feet, the initial angular momentum increased, then decreased in the pre-rising phase. In the final angular momentum, the initial angular momentum increased in the first phase, the landing of the hands, and then decreased in the pre-rising phase.

4) Body tilt angle

Table 5: Angle of Body tilt angle during the landing phase on the feet and hands.

Variables	Landing	Before take off
Landing on the feet	86.4 ±6.2	126.2 ±4.1
Landing on hands	77.6 ±8.4	119.3 ±7.3

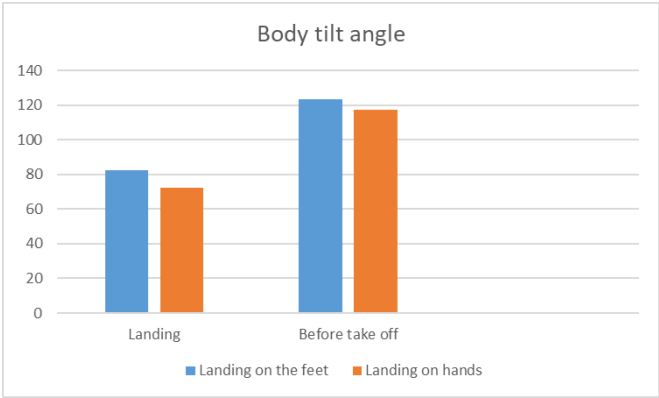


Figure (8) Body tilt angle plot

Figure (8) and Table (4) illustrate the change in the body's angle of inclination. During the landing on the feet, the body's angle of inclination decreased and then increased during the pre-start phase. Similarly, during the landing on the hands, the body's angle of inclination decreased and then increased during the pre-start phase.

3-2 Discussions

During the landing phase of the first run-off, the horizontal velocity of the center of mass decreases slightly. This is likely due to the body tilt angle at landing being a full 90 degrees, resulting in a forward tilt position where the feet land behind the center of mass. As the feet tilt forward, a force is applied to the ground in the same direction as the backstroke of the backflip, and this reaction force is thought to reduce the horizontal velocity. The vertical velocity is negative at this phase, likely due to the cushioning effect during foot contact and preparation for the subsequent take-off, as evidenced by the decrease in the knee joint angle at this point. From the foot contact phase, the horizontal velocity of the center of mass increases, and the vertical angle becomes positive, indicating that the take-off is upward and backward. The decrease in the knee joint angle during this take-off suggests that knee extension plays a key role. Both the shoulder joint angle and the hip joint angle increase significantly throughout the foot contact phase. Just before takeoff, the shoulder joint is near its maximum flexion, and the hip joint is also near its maximum extension. During this period, the angular

momentum around the body's center of gravity initially decreases, then increases. The decrease in angular momentum coincides with the point where the body's angle of inclination is less than 90 degrees. This clearly demonstrates that if a body rotating backwards collides with the feet in a forward-leaning position, the rotation is halted. These results indicate that the decrease in horizontal velocity and angular momentum in the first half of this phase negatively impacts the dual function of the backflip: increasing the body's horizontal velocity and angular momentum. To address this issue, it is beneficial to incline the body at an angle of 9 degrees or more when landing from the round-off position, thus avoiding a decrease in horizontal velocity or inhibiting the backflip. In other words, it is advantageous to position the feet in front of the center of gravity and assume a backward-leaning position. In this case, it is crucial to minimize the impact of the foot-sucking effect, which involves knee flexion, so that the forward thrust can be applied simultaneously with the foot landing.

During the initial aerobic phase following takeoff, the horizontal velocity of the body's center of mass remains nearly constant, while the vertical velocity decreases and becomes negative. This is thought to indicate that the body's center of gravity is moving parabolically in the air. During this period, the body rotates backward, and the shoulder and hip angles increase in preparation for takeoff. However, prior to takeoff, the shoulder and hip angles reach their maximum values and begin to decrease.

During the subsequent approach phase, the vertical deflection of the center of mass changes from negative to positive in the first half of the phase and from

positive to negative in the second half. This is thought to be due to the body's downward movement immediately following the approach, which then reverses to an upward direction upon separation. The direction of the body's rotation around the wrist also changes downward in the second half.

The second half of the phase. This release is largely due to shoulder flexion, and the change in the shoulder angle indicates that it occurs in the middle to the latter half of the approach phase, when the rate of decrease in the shoulder angle ceases and then begins to increase. The horizontal velocity of the center of mass decreases during this phase. However, in the middle of this phase, which is thought to be the beginning of the push phase based on changes in the shoulder joint angle, there is no decrease, but rather a slight increase. This indicates that the decrease in horizontal velocity of the center of mass occurs just before the start of the push phase and in its latter half. Because the body's angle of inclination immediately after the push phase exceeds 90 degrees, it is likely that a force with a component in the same direction as the body's forward motion is acting on the ground at this time. The decrease in horizontal velocity immediately after the push phase is most likely due to a reaction force to this force. The final value of angular momentum around the center of mass during this phase was significantly negative compared to the initial value, indicating that an increase in angular momentum, a key feature of the backflip, occurs during this phase. However, the angular momentum decreased immediately after the start of this phase and then increased from the point where the push phase is thought to have begun. This decrease in angular momentum is thought to be due to the body's angle of inclination being less than 90 degrees immediately after ground contact, similar to ground contact when throwing a round dart. This

suggests that the decrease in horizontal velocity and angular momentum in the first half of the landing phase is due to the small angle of inclination of the body at the point of contact with the ground. However, the shoulder joint has already begun to extend at the start of the landing phase. If the maximum shoulder joint angle described in the first aerobic phase is reached simultaneously with landing, the body's angle of inclination is likely closer to 90 degrees. Therefore, to prevent the decrease in horizontal velocity around the body's center of mass at the beginning of the landing phase and to minimize the decrease in angular momentum around the body's center of mass, it is believed to be effective to maximize the shoulder joint angle immediately after landing and to increase the body's angle of inclination to more than 90 degrees. Furthermore, because this initial phase occupies a significant portion of the total backflip time, it is believed that to minimize the decrease in horizontal velocity in the early and late phases of this phase, it would be effective to eliminate the easing motion at the initial movement, perform the push-off immediately after the initial movement, or perform the push-off quickly to reduce the time required for the initial phase.

4- Conclusions

During the landing phase of the first run-off, the horizontal velocity of the center of mass decreases slightly. This is most likely due to the angle of inclination of the body upon landing. The vertical velocity is negative at this phase, probably due to the cushioning effect during foot contact and preparation for the subsequent take-off, as evidenced by the decrease in the knee joint angle at this point. From the foot contact phase, the horizontal velocity of the center of mass increases, and the vertical angle becomes positive, indicating an upward and

backward take-off. Both the shoulder joint angle and the hip joint angle increase significantly throughout the foot contact phase. During this period, the angular momentum around the body's center of gravity initially decreases and then increases. During the first aerodynamic phase after take-off, the horizontal velocity of the body's center of mass remains almost constant, while the vertical velocity decreases and becomes negative. The shoulder joint angle increases to its maximum immediately after foot contact, and the body's angle of inclination increases.

Reference

1. Decatoire, A., Beauprez, S.A., Pylouster, J., Lacouture, P., Blandin, Y., & Bidet-Ildei, C. (2018). PLAViMoP Software: How to standardize and simplify the use of point-light displays, *Behavior Research Methods*, doi: 10.3758/s13428-018-1112-x.
2. Huang, Chenfu & Hsu, Gin-Shu. (2009). BIOMECHANICAL ANALYSIS OF GYMNASTIC BACK HANDSPRING. 10.13140/2.1.2776.9600.
3. Lovecchio, Nicola & Grassi, Gianpiero & Shirai, Yuri & Galante, Domenico & Grandi, Gaia & Ferrario, Virgilio & Sforza, Chiarella. (2013). Kinematics of key technique variables in the backward handsprings of elite gymnasts. *Revista Brasileira de Medicina do Esporte*. 19. 292-296. 10.1590/S1517-86922013000400013.
4. Pagnon et al., (2024). Sports2D: Compute 2D human pose and angles from a video or a webcam. *Journal of Open Source Software*, 9(101), 6849, <https://doi.org/10.21105/joss.06849>

5. Penitente, Gabriella & Merni, Franco & Sands, William. (2011). Kinematic analysis of the centre of mass in the back handspring: A case study. *Gym Coach*. 4. 1-11.
6. Qasim Sayah, Biomechanics of the back handspring between skilled and unskilled in artistic gymnastics, *Sciences of sport performance* Volume 7, Numéro 1, Pages 1-14 2025-11-22
7. Qasim Sayah, Kołaczowski, Zdzisław. (2015).A comparative study between the players the artistic gymnastics and acrobatic in most important of the kinematics to skill back handspring on floor exercise. University of Misan College of Physical Education and Sport Sciences. Vol. 12, Issue 12, pp.9-20.
8. Qasim Sayah, Kołaczowski, Zdzisław. (2015)A comparative study in the values of some variables kinematics between front and back handspring during contact phase hands on floor exercise in the men's artistic gymnastics. *Journal of studies and researches of sport education*, Vol. 12, Issue 38, pp.261-279.