ANALYSIS OF THE ARTICULAR LOAD ON THE LOWER LIMBS DURING BACKFLIP

ANÁLISE DA CARGA ARTICULAR NOS MEMBROS INFERIORES DURANTE O BACKFLIP

ANÁLISIS DE LA CARGA ARTICULAR EN LOS MIEMBROS INFERIORES DURANTE EL BACKFLIP

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ABSTRACT

Introduction: Sports injuries restrict the acquisition of optimal results and represent a great threat to the athlete's physical health, lower limb injuries being the most prominent, mainly those caused by landing. Objective: Use biomechanics to analyze the joint load of the lower limbs during the landing process in the gymnastics backflip, establishing movement control and reducing the risk of lower limb injury. Methods: The male athletes of the National Gymnastics Team were selected as the research objects, and the three-dimensional backflip (BS) motion trajectory was completed after the landing process was completed, the vertical ground reaction force (VGRF) after landing and the lower limb muscle electromyography (EMG) after landing was collected, and the human multi-body system model and the landing platform model of the landing action were completed with the help of the system simulation software. Results: Statistics show that gymnasts train more intensively during competition or daily training, performing more than 200 landings per week, a factor that increases the risk of injuries during the backflip in athletes. Conclusion: The lower limb joint load of the landing action in gymnastics backflip is high, which will cause a certain risk of injury, and specific measures can be taken to control it. ***Level of evidence II; Therapeutic studies - investigation of treatment outcomes.***

Keywords: Biomechanical Phenomena; Cumulative Trauma Disorders; Athletic Injuries.

RESUMO

Introdução: Lesões esportivas restringem a aquisição dos resultados ótimos e representam uma grande ameaça à saúde física do esportista, sendo as lesões nos membros inferiores as mais proeminentes, majoritariamente as causadas pela aterrissagem. Métodos: Os atletas masculinos da Equipe Nacional de Ginástica foram selecionados como objetos de pesquisa, e a trajetória de movimento tridimensional do backflip (BS) foi completada após a conclusão do processo de aterrissagem, a força vertical de reação ao solo (VGRF) após a aterrissagem e a eletromiografia do músculo do membro inferior (EMG) após a coleta do pouso, e o modelo do sistema humano de multicorpos e o modelo da plataforma de aterrissagem da ação de aterrissagem foram completados com a ajuda do software de simulação do sistema. Resultados: As estatísticas mostram que os ginastas treinam mais intensamente durante a competição ou no treinamento diário, efetuando mais de 200 aterrissagens semanais, fator que aumenta o risco de lesões durante o backflip nos atletas. Conclusão: A carga articular dos membros inferiores da ação de aterrissagem no backflip da ginástica é alta, o que causará um certo risco de ferimentos, e medidas específicas podem ser tomadas para controlá-lo. **Nível de evidência II; Estudos terapêuticos - investigação dos resultados do tratamento.**

Descritores: *Fenômenos Biomecânicos; Transtornos Traumáticos Cumulativos; Traumatismos em Atletas.*

RESUMEN

Introducción: Las lesiones deportivas limitan la obtención de resultados óptimos y representan una gran amenaza para la salud física del deportista, siendo las lesiones en los miembros inferiores las más destacadas, principalmente las causadas por el aterrizaje. Objetivo: Utilizar la biomecánica para analizar la carga articular de los miembros inferiores durante el proceso de aterrizaje en el backflip gimnástico, estableciendo el control del movimiento y reduciendo el riesgo de lesiones en los miembros inferiores. Métodos: Se seleccionaron como objetos de investigación los atletas masculinos del Equipo Nacional de Gimnasia, y se completó la trayectoria de movimiento tridimensional del backflip (BS) tras el proceso de aterrizaje, se recogió la fuerza de reacción vertical del suelo (VGRF) tras el aterrizaje y la electromiografía (EMG) de los músculos de las extremidades inferiores tras el aterrizaje, y se completó el modelo del sistema multicuerpo humano y el modelo de la plataforma de aterrizaje de la acción de aterrizaje con la ayuda del software de simulación de sistemas. Resultados: Las estadísticas muestran que los gimnastas entrenan más intensamente durante la competición o el entrenamiento diario, realizando más de 200 aterrizajes a la semana, un factor que aumenta el riesgo de lesión durante el backflip en los atletas. Conclusión: La carga de la articulación del miembro inferior en la acción de aterrizaje en el backflip de gimnasia es elevada, lo que provocará un cierto riesgo de lesión, y se pueden tomar medidas específicas para controlarla. **Nivel de evidencia II; Estudios terapéuticos - investigación de los resultados del tratamiento.**

Descriptores: *Fenómenos Biomecánicos; Trastornos de Traumas Acumulados; Traumatismos en Atletas.*

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INTRODUCTION

Biomechanics is based on human physiological anatomy and theoretical physics, with the effectiveness of body coordination during the transformation of sports posture as the research goal, the functional structure of motor organs and the law of movement are analyzed, and the application of general mechanical principles is used to study the maintenance and mastery of body balance, in order to expect to fundamentally make scientific guidance for human protection and health care, and to avoid sports injuries to the greatest extent.[1] Sports injuries restrict the acquisition of excellent results and pose a great threat to physical health, of which lower limb injuries are the most prominent, and most lower limb injuries are caused by landing or descending. Statistics show that gymnasts train more intensely, in the process of competition or daily training, there must be more than 200 landings or downs per week, which undoubtedly increases the risk of injury to athletes.[2,3] Through scientific means to analyze the lower limb joint load of gymnastics backflip type landing action, and put forward targeted guidance, it can not only provide a reasonable theoretical basis of the prevention of sports injuries, maximize the health escort of athletes, but also help athletes improve the difficulty of movements, improve the stability of landing, and obtain more excellent results.

Experimental objectives and methods

The study is Purely observational studies which no need to registry ID of ICMJE, and all the participants were reviewed and approved by Ethics Committee of Pingdingshan University, China (NO. 2022073)

Experimental objectives

In accordance with the regulations of the Ethics and Ethics Committee of the Institute of Sports Science of the General Administration of Sport of the People's Republic of China, the study selected an active athlete of the Chinese National Gymnastics Men's Team as the research object, the athlete is 20 years old, 172cm tall, weighs 58kg, has a gymnastics training career of 13 years, participated in the Gymnastics World Championships, and has no bone and muscle injuries in the lower limbs for nearly a year. Truthfully inform the research process before the study is carried out, and complete the signing of the informed consent form. The study completes three movements as backflips, straight backflips 720° and straight backflushs 1080°.

Instrument selection

Gymnastics backflip rotation landing speed is faster, the completion time is shorter, so for the athlete to rotate the landing action of the clear acquisition, through the Qualisys Oqus motion capture system to complete the recording.[4] The system is native to Sweden with a sampling frequency of 250Hz and contains an HD camera and 8 infrared cameras; Equipped with 16 mm diameter standard infrared reflective markers to complete the acquisition of three-dimensional motion trajectories; Equipped with a Model 9260A Kistler 3D side force table to complete the acquisition of vertical ground reaction force VGRF; Equipped with the American Delsys wireless 16-channel surface EMG acquisition system to complete the MYO signal acquisition. The position of the infrared reflective markers and EMG sensors on the athletes is shown in Figure 1.

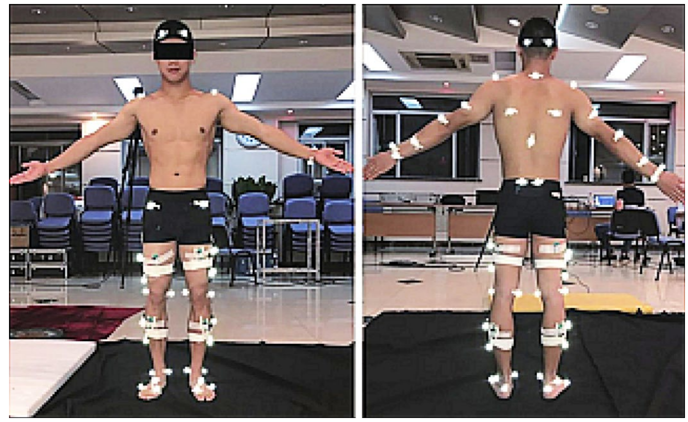

Figure 1. The placement of infrared reflective markers and EMG sensors on athletes.

Data Acquisition and Processing

First of all, the basic procedures, methods and risks of the experiment are informed to the athletes. During the experiment, athletes are required to wear tank top shorts on their bare feet, and complete the BS landing action after 15 minutes of warm-up, in order to ensure that the experimental data collection is more representative, the athletes are required to complete 3 landings. During the experiment, two international-level referees scored according to the FIG2013 rules, and selected the actions with the most standard landing quality of digital analysis.[5,6] In order to ensure the comprehensiveness of the study, the BS landing process is decomposed into a pre-activation stage, indicated by T0, which refers to the first 100ms of ground touch; The initial stage of the landing impact, denoted by T1, refers to the PvGRF from ground touch to peak; The late stage of the landing impact, denoted by T2, refers to the return of PvGRF to 1BW. The data processing is done using qualities Track Manager software.

Data indicator selection

The dynamic stability evaluation index VSI is calculated as follows:

where: $$VSI = \sqrt{\frac{\sum\left(\frac{bodyweight - vGRF}{bodyweight}\right)^2}{numberofdatapo\,\mathrm{int}\,s}}$$

body weigh - the body mass of the athlete

Number of data of data points- The number of data, in this study, the data in 3S is taken, and the data sampled at 1000 Hz is 3 000.

Joint stiffness building stiffness calculation formula:

where: $$Joint\ stiffness = \frac{\Delta M}{\Delta\theta}$$

ΔM -- The amount of change generated by the torque of a joint during the landing process;

$\Delta\theta$ -- The amount of change generated by the displacement of the corresponding joint flexion angle during the landing process.

Simulation Process and Model Validation

The goal of modeling and simulation is to complete the acquisition of indicators that cannot be measured by experiments such as joint force and torque In this study, LifeMod was selected as computer simulation software, combined with ADAMS/Lifemod's mannequin database Gebod based on 19 links and 50 degrees of freedom multi-rigid body model establishment for personalized modeling, based on FIG standardized tests and national standards for gymnastics equipment, using ADAMS software to establish a simplified model of the floor mat. The definition of each link and joint is programmed in Python language, and the simulation process is shown in Figure 2.

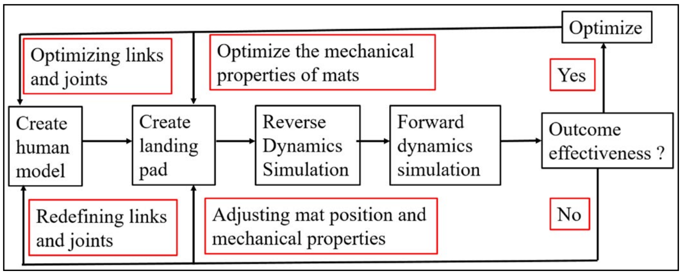

Figure 2. Computer simulation process.

After the establishment of the computer simulation model, a simple optimization algorithm is used to calculate the mechanical characteristic parameters, and the formula is as follows:

$$\Delta\delta = \sqrt{\frac{(x_1 - y_1)^2 + (x_2 - y_2)^2 + \cdots (x_n - y_n)^2}{n}}$$

$$S = \Delta V_{sag} + \Delta V_{tran} + \frac{1}{m}\sum_{i=1}^{1} \Delta Joint\, angles$$

where:

x_i -- Measured kinematic values;

y_i -- Kinematic simulation values;

$\Delta\delta$ -- The rms difference between the measured kinematics value and the simulated kinematic value;

ΔV_{sag} -- Sagittal kinematic velocity;

ΔV_{tran} -- Coronal kinematic velocity,

ΔV_{tran}-- Root mean square difference of the angle of each joint of the lower limb;

n -- The number of data on the curve;

m -- Number of limb kinematic curves;

When S is the minimum value, it represents the standard mechanical parameters of the floor mat.

Then, the simulation degree and validity of the model are verified by using the dynamic change similarity of the curve, and the formula is as follows:

$$CMC = \sqrt{1 - \frac{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(x_{ij} - \bar{x}\right)^2 / n(m-1)}{\sum_{i=1}^{m}\sum_{j=1}^{n}\left(x_{ij} - \bar{x}\right)^2 / (mn-1)}}$$

where:

Y_{ij} -- the jth data of the ith curve;

$\overline{Y_{ij}}$-- The average of the jth data of the m-curve;

$\overline{Y}$-- m-curve n overall averages of the data.

Experimental results

Extra-articular load of lower limbs

Based on the joint torque change data, the calculation of the change in the angle of the joint is completed by differential method, and the calculation of the joint stiffness of the lower limb is completed at the same time, and the 100% k benchmark joint stiffness of the lower limb joint in the sagittal, coronal and horizontal planes after the completion of the athlete's BS movement is obtained, and then the internal and external load data of the lower limb joint under different stiffness conditions of 60%K, 100%K and 140%Kare completed. (Table 1).

According to the values of Table 1, it can be seen that during the completion of the gymnastics backflip landing action, there is a large load on the lower limb joint, and the impact force of the sagittal surface of the knee joint to delay the landing has obvious effect, and there will be a large angular velocity before the GRL peak arrives. However, due to the elasticity of the floor mat, the sagittal surface of the ankle joint is smaller. With the change of lower limb joint stiffness, it does not affect the peak of GRF and the peak of the ankle torque, and as the stiffness of the lower limb joint increases, the extensor moment peak of the knee joint will also increase, but the extensor torque peak will show a downward trend. With the decrease in the stiffness of the lower limb joints, although the peak of the extensional and flexion force of the knee joint will also decrease, in the process, it will lead to an increase in the peak torque of the coronary surface of the knee joint.

Angular velocity of lower limb joints

According to the simulation, the numerical values of the angular velocity change of the joints of the lower limbs of BS are shown in Table 2.

According to Table 2, it can be seen that in the T0 stage, the angle of the hip joint and the ankle joint on both sides of the lower limb has a certain degree of change, of which the average extension of the hip joint reaches more than 20°, but the angle of the knee joint does not change significantly during the process; In the T1 stage, the hip and ankle joints on both sides of the lower limbs as well. The joint angle of the knee joint has changed to a large extent, of which the knee joint flexion is the most obvious and basically reaches 20°; In the T2 stage, there is no significant change in the angle of the joints on both sides of the lower limbs, and finally the angle of the hip joint is maintained at 90°, while the knee joint is maintained at 120°, and the ankle joint is maintained around 60°. Throughout the landing phase, the angular velocity of the three joints peaked at the T1 stage, and the angular velocity of the 3 joints in the T2 stage showed a gradual decrease, and finally approached zero at the end of the stage.

Lower extremity joint torque

According to the simulation, the numerical value of the joint torque change of the lower limb of BS is shown in Table 3.

According to Table 2 lower limb joint torque, in the BS landing process, in the T1 stage, the lower limb joint torque is flexor moment; In the T2 stage, the lower extremity joint torque is a directional reversal of the extensor torque.

Table 1. Lower limb joint internal and external load data under different stiffness conditions.

Rigidity (%)	60%K	100%K	140%K
GRFH (BW)	2.45	2.45	2.45
GRF (BW)	11.82	11.82	11.92
Knee Extensor Moment Peak (N/s)	218	276	308
Knee Flexor Moment Peak (N/s)	160	155	147
Peak Coronal Moment Of The Knee Joint (N/s)	283	277	273
Ankle Extensor Moment Peak (N/s)	118	119	120
Ankle Flexor Moment Peak (N/s)	85	85	85
Sagittal Knee Positive Work (%)	87	101	107
Sagittal Ankle Positive Function (%)	90	101	106

Table 2. Values of angular changes in lower extremity joints (degree/s).

Angular velocity of lower extremity joints	T0				T1		T2		
Time (ms)	-100	-75	-50	-25	0	25	50	75	100
Left hip	256	245	240	268	290	-1250	-240	-56	-12
Left knee	11	13	16	22	30	-1500	-236	-52	-15
Left ankle	28	32	35	45	-2500	-625	-265	-46	-16
Right hip	258	246	242	272	300	-1300	-246	-46	-14
Right knee	15	17	16	28	35	-1750	-238	-58	-16
Right ankle	32	33	32	46	-3500	-700	-250	-42	-18

Lower extremity joint reaction force

According to the simulation, the numerical value of the change of the reaction force of the BS landing limb joint is shown in Table 4.

From the perspective of the landing reaction force of the lower limb joint, there is a relationship between the ankle reaction force and the knee reaction force and the hip reaction force, and the PEAK OF JRFs will occur in the T2 stage after PvGRF.

In the T0 stage of BS standardized backflip landing, a total of 8 muscles are activated by the myoelectricity, and 8 muscles are distributed in the left and right limbs, of which RF represents the rectus femoris muscle; BF stands for biceps femoris; TA stands for tibiaterior muscles; LG stands for lateral gastrocnemius muscle. Moreover, the EMG amplitude of these 8 muscles showed a gradual increase trend from the T0 stage to the T1 stage, reaching a peak in PvGRF, and even in the T2 stage, it still had a higher amplitude state, indicating that the MYO mean square root in the T2 stage had a higher activation level.

Table 3. Values of lower limb joint torque changes (N/kg).

Lower extremity joint torque	T0	T1				T2			
Time (ms)	0	10	20	30	40	50	75	100	125
Left hip	-	2.2	2.9	2.5	2.3	1.5	-4.8	-5.6	-4.2
Left knee	-	1.9	2.8	2.4	2.2	1.5	-4.5	-8.1	-7.1
Left ankle	-	0.2	0.1	-0.1	-0.1	0	0.1	1.1	0.9
Right hip	-	4.8	5.1	3.9	3.4	1.5	-4.9	-6.9	-6.3
Right knee	-	3.2	3.4	3.8	3.2	1.6	-5.1	-7.1	-6.2
Right ankle	-	0.3	0.1	-0.1	-0.1	0	0.1	1.2	0.8

Table 4. Values of lower limb joint torque changes (BW).

Lower extremity joint torque	T0	T1				T2			
Time (ms)	0	10	20	30	40	50	75	100	125
Left hip	-	0.5	0.8	1.4	1.3	1.1	1.0	0.6	0.4
Left knee	-	0.7	1.6	2.3	2.2	1.5	1.4	0.8	0.5
Left ankle	-	0.8	2.6	2.8	2.6	2.5	2.3	0.6	0.4
Right hip	-	0.5	0.7	1.3	1.2	0.7	0.6	0.4	0.6
Right knee	-	0.6	1.4	2.0	1.9	1.3	1.1	0.7	0.5
Right ankle	-	0.6	2.2	2.7	2.5	1.9	1.7	0.4	0.4

CONCLUSIONS

BS is the basis of gymnastics, but it is also the action with the highest damage value, and it will bring great loads to the lower limbs during the landing process. In the process of this study, the landing trajectory capture is completed by the motion capture system, the GRF evaluation is completed by the computer simulation method, and the 19 links and 50 degrees of freedom multi-rigid body human body model are established, which has a relatively good practical kinematic performance effect and has high simulation accuracy.

According to the changes in the joint angle and flexion amplitude at different landing stages, it can be known that in order to avoid the increase of the load on the lower limbs at the maximum speed limit and affect the landing stability and safety, the lower limb joints should be actively flexed in advance in the process of landing preparation to achieve the increase of the impact force action time and thus achieve the purpose of slowing the impact; In order to reduce the buffer impact and prevent the "collapse" of the body, it is necessary to actively and quickly complete the flexion of the lower limb joints in the early stage of the landing impact, and at the same time, the lower limb joints need to be fully stretched in the later stage of the landing impact. In addition, as far as the training and competition environment are concerned, it is possible to change the material design of the mat to achieve the improvement of its mechanical properties. Ensure that the stiffness of the floor mat and the surface friction coefficient are reduced to reduce the impact load of the lower limbs during the landing process.

The author declare no potential conflict of interest related to this article

AUTHORS' CONTRIBUTIONS: The author made significant contributions to this manuscript. Cui Zhihao: writing and performing surgeries; data analysis and performing surgeries; article review and intellectual concept of the article.

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