MAIN TECHNICAL ANALYSES OF THE MOTION TRAJECTORY INFLUENCING THE HORSE-VAULTING MOVEMENT

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INTRODUCTION: The key to improving horse vaulting movement is to obtain an ideal motion trajectory of the center of mass, to increase the height and distance, and to prolong the time in the second flight phase, so as to increase the degrees where the body rotates around vertical axis, abscissa axis and compound axis in the air. This makes gymnasts give rein to their technical movement efficiency of run-up, jumping and push off, in order to increase the quality of the second flight phase. With the means of computer, video recording and high-speed photography, this paper has provided data on every technical phase accomplished by gymnasts to help them master the key techniques and improve the effects of training.

METHODS:
1 According to the principles of kinesiology and biomechanics, the rule of every technical phase in the horse vault has been analyzed, the mathematical model of the motion trajectory for the center of mass has been established and the model has been simplified with the calculation of BASIC program.
2 Pictures of horse vaulting movements by 5 elite gymnasts from Shandong Province, China obtained by high-speed photography were analyzed and compared to test and verify the correctness and scientific rigor of the program design.
3 According to the requirement as planned, 6 different variables and 500 item-by-item values were inputted into the computer. The 6 variables are the instantaneous takeoff velocity on the vaulting block (Vo) is 6-7m/s; the spring-up angle of takeoff (Q), 35-45 degree; the height of the center of mass for gymnasts (h), 1-1.1m; the horizontal distance (L) from the starting point of takeoff to vault supporting point, 1.5-2m; the first flight phase (T1), 0.18-0.25s and the push-off time (Td), 0.16-0.24s. 17920 data in all have been obtained for statistical treatment to make a further quantitative analysis of every phase in the horse vault.

RESULTS AND DISCUSSION:
1 Takeoff Velocity: Takeoff velocity refers to the instantaneous velocity stepping on the vaulting block and is an important technical key to improving horse vaulting movement. Only in combination with a correct spring-up angle of takeoff can it form a good trajectory for the first flight phase. The close coordination of variables of takeoff and push-off can increase the efficiency of takeoff velocity. If not, it cannot improve the quality of the second flight phase. When the takeoff velocity increases, the incident angle of vault supporting, the instantaneous tangential velocity of that and the rotational speed of the forehead-shape axis around the body increase correspondingly. When the takeoff velocity increases 0.1m/s, push-off angle increases 3.717 degree, but the time and height of the second flight phase decrease. In order to guarantee the quality of the second flight phase and to make full use of the efficiency of the takeoff velocity, the push-off time must shorten

0.01s, at least when the takeoff velocity increases 0.1m/s based on the calculated data of the computer.
2 Spring-Up Angle of Takeoff: The spring-up angle of takeoff means the forerake angle of the upper part of the body when step-jumping forward at the moment of stepping off the vaulting block. The best takeoff angle depends on the concrete conditions of gymnasts (physical fitness and body height) and technical requirement of various type movements. It varies with the individual to solve the concrete problem of takeoff technique. According to the results of calculations, the determination of the best spring-up angle of takeoff has a close relation with seven factors, as follows: various type movements and vault-supporting instantaneous incident angle having a specific requirement of takeoff variables; the relation of velocities of stepping on the board and stepping up the board; the relation of the height of body mass; the relation of the height of the vault horse; the first flight time; the horizontal distance from the takeoff point to the vault supporting point; the distance from body mass to the supporting point when vault supporting. A comprehensive analysis as follows:
2.1 The influence of spring-up takeoff angle on the distance from vault supporting incident angle and instantaneous body mass to the supporting point.
The determination of the distance (R) from vault supporting instantaneous body mass to supporting point depends on the sizes of the length of the arm (L_1), the length of the trunk (L_2) and the angle of the shoulder (α). Suppose the vault supporting instantaneous shoulder angle is 130-150 degrees, then $R^2=(L_1)^2+(L_2)^2-2L_1L_2\cos\alpha$. The distance from the body mass to the supporting point can be calculated from it.
When the four variables, which are takeoff velocity (Vo), horizontal distance (L) from takeoff point to supporting point, the first flight time (T_1) and the height of body mass (h), are given, the item-by-item value of the spring-up angle of takeoff is inputted. The vault supporting instantaneous incident angle increases with the increase of the spring-up angle of takeoff. When the takeoff angle increases 1 degree, the vertical initial velocity increases 0.888m/s, the horizontal initial velocity decreases 0.071m/s, the vault supporting incident angle increases 0.441 degree and the tangential velocity increases 0.47m/s evenly.
When the spring-up angle of takeoff decreases 35-33 degree, the distance from the total body mass to the vault supporting point shortens. It is a must to adjust the distance between body mass and vault supporting point to a reasonable distance scope by decreasing the first flight time (T1) from 0.20s to 0.18s and enlarging the horizontal level (L) between the takeoff point and the vault supporting point up to 15cm. If not, it can result in a narrow shoulder angle and the mistake of vault supporting with a bent arm. This method can resolve the contradiction of the supporting distance, but the vault supporting incident angle decreases 5 degree. At this moment, the increasing of the instantaneously entering-the-horse velocity makes the arm increase its load and the horizontal velocity of the second flight decreases owing to the decrease of tangential velocity.
After the spring-up angle of takeoff increases 42 degree, the distance between the total body mass and the vault supporting point is too long, and the vault supporting incident angle increases correspondingly. It is a must to prolong the first flight time to adjust vault supporting variables. If the spring-up angle of takeoff increases up to 45 degree, the first flight time can increase to 0.24 second. If the vault supporting incident angle surpasses 49 degree, it can only be pushed off the vault horse when

the body mass surpasses the vertical parts to influence the quality of the second flight. The best spring-up angle of takeoff is 40 and 41 degree based on the original variables.

2.2 The requirements of heights of body mass and horse vaulting for the spring-up angle of takeoff: Because of the different heights of body mass for gymnasts, the vault supporting incident angles are different if constant conditions are given. When the height of horse vaulting is 135cm and other original data are constant, the vault supporting incident angle can only reach 24.18 degree. It is a must to increase 6 degrees for the spring-up angle of takeoff to make it reach the original level. Otherwise it will prolong the first flight time and enlarge the distance of the vaulting block.

3 Vault Supporting Incident Angle: The vault supporting incident angle means the horizontal included angle between body mass to pivot point and vault horse. The size of the incident angle depends on the values of 5 variables of Vo, Q, h, L and T_1. A proper incident angle plays an important role in forming a correct push-off angle. There is a better effect if the incident angle is between 35-45 degrees based on the results of calculations.

If the incident angle is too small, the incident velocity increases and the two arms will bear more impulse. The smaller the incident angle, the slower the tangential velocity and the speed around the body forehead shape axis. The enlarged distance between body mass and push-off horse results in prolonged push-off time and lower push-off radial velocity. The smaller the incident angle, the shorter the vertical distance between the body mass and the vault horse. The decrease of the instantaneous radial velocity for the push-off horse results in a decrease in the second flight horizontal velocity based on the calculation of the law of conservation of energy.

The larger the incident angle, the smaller the incident velocity. A smaller incident velocity can result in lacking strength in vault supporting and push-off. The larger incident angle results from the higher motion trajectory of the body mass or longer time of the first flight. It can result in vault supporting when lowering the body mass and increasing the impulse of the two arms. The larger incident angle causes the push off after the body mass surpasses the vertical parts and makes the second flight too low and too short.

4 Push-Off Time and Push-Off Angle: To shorten the push-off time can effectively increase the push-off velocity and the vertical initial velocity of the second flight. The push-off time has a relation with the strength of the shoulder. According to the law of momentum $F=mV_2-mV_1/t$, the shorter the push-off time, the larger the impulse which the arms bear.

Push-off angle means the included angle between body mass and the line of the pivot point and the horizontal line of the vault horse when pushing off the horse. The push-off angle and the incident angle have a close relation with the push-off time. It has been proved after calculation that if the push-off angle is small, the vertical velocity is fast; if the horizontal velocity is low, the vertical velocity becomes low and the horizontal velocity gradually becomes large with the increase of push-off angle. When the push-off angle surpasses 90 degrees, the tangential velocity indicates the lower part and the second flight becomes short and low. Therefore the push-off must be completed before the body mass reaches the vertical part. It has been proved by calculation that the best push-off angle is 85 degrees. If the tangential velocity decreases from 1.5m/s to 1.2m/s, the best push-off angle is 82

degrees. Therefore, the size of the push-off angle should depend on the relationship between the push-off velocity and the tangential velocity. Only the best push-off angle can guarantee the height and long distance of the second flight.
5 The Second Flight and Landing: The motion trajectory of body mass can be determined after pushing off the horse. The action of the second flight is based on the low of slope parabolic movement. The relative movement of every body part can only change the angular velocity with which the body rotates around the body mass, and it cannot change the motion trajectory of the body mass.
The second flight finishes with the landing of the two feet, but at this moment the body mass has a certain height above the floor, that is hn = height of body mass $\times$ $\cos\phi + 0.12$ (ϕ is the descending angle of the body mass, and 0.12 is the height of the mat). The correct position of instantaneous feet landing is in front of the body mass, that is on the projection of the motion trajectory of the body mass.

CONCLUSIONS:

1 It has been shown by arithmetic data on every technical phase of the horse vault that every technical phase of the motion trajectory influencing the horse vaulting movement is interrelated and interacts with the others. It shows the integrity of horse vaulting techniques.
2 The correct coordination of takeoff velocity and other techniques can increase the quality of the second flight phase efficiently.
3 A proper enlarged vault supporting incident angle can increase tangential velocity and the horizontal velocity in second flight.
4 A shortened push-off time can increase radial velocity and the vertical velocity of the second flight effectively.
5 A shortened vaulting block distance and a proper enlarged spring-up angle of takeoff can remedy the poor jumping quality of gymnasts.

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