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Mathematical analysis of the relationship between snatch performance and athlete's weight based on mechanics

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ABSTRACT

Snatch process is the acting process that the human body consumes internal energy and can drive the devices off the ground and over the head; in its acting process, the body needs to receive force at reasonable posture. This article through biomechanics theory and function transform theorem, conducts detailed analysis on the four stages of the snatch technology process prophase of squat, anaphase of squat, force and inertial rising, in order to obtain the mechanical features and data characteristic of function transform aspect of snatch technique; for body weight and snatch performance it builds regression equation, conducts data simulation study, and elaborates on the necessity of weightlifters' reasonable lose weight from the simulation image. By the studying results we conduct the biomechanical description and argumentation on the overall process of weightlifting snatch, confirm previous findings and the advantages and disadvantages of existing technologies and make reasonable suggestions for the development of movement technology.

KEYWORDS

Biomechanics;
Function theorems;
Snatch;
Mathematic simulation.

INTRODUCTION

With the rapid development of science and technology, sports also witnessed the vitality scene; as the theoretical discipline to study sport the sports biomechanics has also constantly evolved. From the development trend of sports biomechanics, its findings directly affect the medical, industrial and sports. According to Nigger's perspective, the development of sports biomechanics in the 20th century, is mainly reflected in three aspects: it becomes a professional course of university, research results is gradually used for practice, and study the effect of human animal and movement on muscle-skeletal system. Sports Biomechanics is a theoretical tool discipline. Historical experience tells us: every improvement of research tools will bring a broader development space for the development of various undertakings, and the relationship between weightlifting sport as a snatch way and sports biomechanics is very close.

Snatch technology is divided into four stages, for the research of above four stages many people have made the efforts, and with the findings of these researchers the movement technology has been in sustained development, but studies on the combination of application mechanics and mathematics are few and far. This article through biomechanics theory and function theorem, conducts detailed analysis on the four stages of the snatch technology process, analyzes the differences of the athletes' characteristics data using the research results, confirms snatch technique's rationality and provides rationalization proposals for the technology.

BIOMECHANICAL ANALYSIS OF THE VARIOUS STAGES OF SNATCH

Squat motion process includes four phases: prophase of squat, anaphase of squat, force and inertial rising. The movement process is that the body consumes internal energy and acts it on the barbell, making the barbell quickly and successively reach two arms from the weightlifting table, and then lift the barbell to the head and unbend; the following is the analysis of four stages in the snatch process.

Squat preliminary stage analysis

The prophase of squat is to prepare the barbell lifting posture; excellent preparation posture plays a vital role on the final snatch performance. For the whole snatch process, one needs master the balance of the body meanwhile selects appropriate barbell crawl area at this stage. Here we conduct theoretical analysis on the body's stability and the barbell crawl area.

The factors affecting the body stability have steady angle, which is the angle of the centroid line and the connection line of the supporting surface edge. Establish a three-dimensional Cartesian coordinate system, suppose the projection of gravity center of human body in *xoy* surface locates in point *O* with coordinates (0,0,0); two landing points of the barbell are respectively N_1, N_2 with coordinates $(x_1, y_1, 0)$ and $(x_2, y_2, 0)$; athletes' feet centroid when landing are respectively N_3, N_4 with coordinates $(x_3, y_3, 0)$ and $(x_4, y_4, 0)$; and the body's center of gravity is point C_0 of the coordinates $(0, 0, z_0)$; then the stability angle of the body posture is divided into around center of gravity, i.e., the angle of vector $\bar{a} = (0,0,z_0)$ with plane $C_0N_1N_2$ is a α_{foward}, the angle with plane $C_0N_3N_4$ is α_{back}, the angle with plane $C_0N_1N_4$ is α_{left}, and the angle with plane $C_0N_2N_3$ is α_{right}. Human stability is determined by the smallest angle between the center of gravity line and support surface edge connection, expression of the angle α* that determines the body's preparation operation stability degree is shown in formula (1):

$$\alpha^* = \min\{\alpha_{foward}, \alpha_{back}, \alpha_{left}, \alpha_{right}\} \quad (1)$$

By the formula (1) it shows that the minimum stability angle determines the stability degree of the body preparatory actions, which requires reasonable arrangements of athletes' legs open distances, the position that both hands takes the barbell, the position of the body center and centroid line.

For the smooth going of the subsequent three stages, it is necessary to determine the barbell grab location, the gravity of the barbell needs to be all throughout the arm and can not deviate from the node of the shoulder, or it would generate the role of rotational torque on the arm, so two hands' crawling distance should be the same as shoulder width as shown in Figure 1.

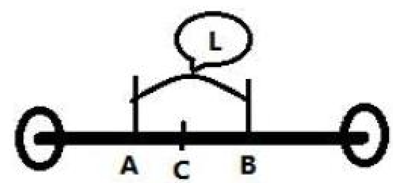

Figure 1 : Schematic of barbell capture location

In Figure 1, A point is the left hand's capture location, B point is the right hand's capture location, C point is the midpoint of left and right hand's capture position, L is the distance between the two hands. According to above state, the value of L should be almost the same with the shoulder width.

Due to human behavior, generally the power of the right hand is stronger than the power of the left hand. In order to keep the bar is translational in risen process, we should make the point C move in a direction toward a small force; that is to say when the power of the right hand is stronger than the power of the left hand, we should let the midpoint C of his hands fall on the left of barbell midpoint. The specific location should be determined according to the athlete's individual circumstances.

Squat late stage analysis

The purpose of squat anaphase stages is to prepare the distance of barbell off the ground and best choice of the cited knee efforts. When the barbell lifts from the ground, the body completes the action by the snatch of the arm and reasonable support of the leg; in this process we should also pay attention to the body's stability. Leg contraction distance in the vertical direction is the distance that leg support acts, which overcomes the gravitational force of the bar at the same time also allows the bar have a kinetic energy. Through inter-coordination of various aspects of the body, the stretching movement of the support legs is that the upper torso and upper limb provide vertical speed and distance, so the squat anaphase has a very important role in the whole barbell snatch process. The human action of this stage is shown in Figure 2.

Figure 2 : Human action schematic of squat anaphase stage

In Figure 2, the athlete's arm is in stretched state, torso forward, hips back, and both legs contraction. When the arm is in stretched state, it is easy to make the barbell's gravity acting on the arm; the purpose of torso forward is to make the projection point of body's center of gravity falls in the supporting surface, which helps the body to maintain stable; hips backward actions can help the smooth going on of the body's other actions; legs contraction, the angle between the line where the thigh locates and the line where the leg locates should be 90o, since the body rising process is mainly the thigh straight course, if we can maintain the largest force arm of the thigh we will be able to save labor in motion process; the horizontal distance between the calf and barbell should be reduced to help reduce rotational torque of the arm.

Particle's mass is *m*, the distance between the particle and the shaft is *r*, then the product of the mass and the distance means the rotational moment of inertia; for various aspects of the human body, the rotational moment of inertia has the additivity as shown in formula (2).

$$\mathbf{I = m_1r_1^2 + m_2r_2^2 + m_3r_3^2 + \cdots m_nr_n^2 = \sum m_ir_i^2} \quad \textbf{(2)}$$

Wherein: *I* represents the body's total moment of inertia, $\mathbf{m_ir_i^2(i = 1,2,3,\cdots,n)}$ means the certain aspects' rotational inertia of the human various aspects. The parameters that affect human rotational inertia are quality and distance, so the body can change the rotational inertia by changing body position or transform rotation axis.

According to angular momentum we have the expression of formula (3):

$$\mathbf{\sum M\Delta t = I\omega_2 - I\omega_1 \Rightarrow \sum M = I \cdot \beta} \quad \textbf{(3)}$$

Wherein: β means the change rate of angular speed that is the angular acceleration vector.

When the body is in translation motion, somewhere in the body suffers the brake, the body will produce rotation around the constraint points; part of the linear momentum before rotation turns into rotation angular momentum. Since the expression of the angular velocity is the ratio of the line speed and the rotation radius, the greater the line speed is, the greater the angular momentum is; the greater the smaller the rotation radius is, the greater the angular momentum is.

Therefore, the size of the torque is associated with the rotation radius and forces. When the force is constant, the greater the rotation radius is, the greater the torque becomes. So when the thigh and calf is of 90o, and the torque is constant, the force that consumes is smaller. The smaller the distance from calf to the barbell is, the smaller the rotation moment of inertia of the arm in the lifting process is, and the smaller the torque is, thus it will improve the mechanical efficiency of the body on the barbell.

Force stage analysis

Force stage is the phase that body acts on the barbell, which includes extend knee and raise barbell, the cited knee process; the movement of the barbell is that lifting the barbell off the ground to the knee, then to the thigh and finally the body stretches fully to lift the barbell from the cited knee end to the skeleton. Force stage plays a decisive role on snatch performance, and the action process of this stage is shown in Figure 3.

In Figure 3 the body consumes internal energy, overcomes the barbell and self-gravity acting, makes the body part and barbell have kinetic energy and gravitational potential energy. Assuming that the rise height of the body center of gravity in the force stage is h_0, the height of the barbell from the ground is H_0, the body mass is *m*, the barbell mass is *M*, the speed of the bar moves to the skeleton is V_1, then the kinetic energy of

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the human body is e_k, according to the law of energy conservation we have formula (4):

$$E = mgh_0 + MgH_0 + \frac{1}{2}MV_1^2 + e_k \quad (4)$$

In Formula (4) E represents the internal energy consumption of the human body. From the above equation, in the force stage the internal energy consumption of the human body can be divided into two parts, one is acting on the body itself, the second is acting on the barbell; if we can reduce the acting on the body, then we can increase the kinetic energy that barbell has; acting on the human body is mainly reflected in overcoming the increase of the body's gravitational potential energy, and the gravitational potential energy of the human body is mainly reflected in the rise height of the center of gravity. So to control the rise height of body center of gravity helps to improve the kinetic and gravitational potential energy of the barbell, it is necessary to maintain the stable minor changes of the body's center of gravity.

Figure 3 : Human action schematic of force stage

In the force stage, the projection position of the whole human body and barbell system's center of gravity should fall in the supporting surface that two feet constitute, which helps increase the stability of the system, so the horizontal distance between the barbell and the human body must narrow reasonably.

Force stage is the main acting stage of the body on the barbell, so athletes' limb should play a traction role on the barbell, that is, beyond the equipment movement; the uplift procedure of arms and stretch procedure of legs and the movement of other aspects of the body should all be in force state. When the force stage ends, the human and barbell should reach their maximum kinetic energy.

Inertia rising phase analysis

The inertia rising phase can be understood as the rising phase that the force between the bar and the human body are greatly reduced relatively, i.e., the process that the bar goes up to the head by the speed at the end of force phase, the movement is in Figure 4.

Figure 4 : The rising phase schematic of barbell inertia

Excluding the air resistance the motion state of barbell can be denoted by formula (5).

$$\Delta H = \frac{V_1^2}{2g} \quad (5)$$

In Formula (5), V_1 means the speed of the bar when the force phase ends, ΔH means the height that the bar can increase with the initial velocity V_1.

Human arms have kinetic energy along with free-rise process of the barbell; if the body centroid at the end phase of force can maintain unchanged, then the momentum of the body is shown in the formula (6):

$$\left.\begin{aligned} p &= mv \\ e_k &= \frac{1}{2}mv^2 \end{aligned}\right\} \Rightarrow p = \sqrt{2me_k} \quad (6)$$

Figure 4 shows that, after the free rising end the bar will have a falling trend, so athlete's center of gravity will fall again to support the weight of the bar. In the body centroid decreasing process, the barbell already has a small momentum P_ε, but this time the human body's kinetic energy increases because the decrease of the gravitational potential energy. Assuming the body centroid decreases by Δh, the momentum of the human body (7)is shown in equation (7):

$$p_\Sigma = p + m\sqrt{2\Delta h} = \sqrt{2me_k} + m\sqrt{2\Delta h} \quad (7)$$

In Formula (7), p_Σ means the human body's momentum after the centroid has fallen.

In the stable phase of human body and barbell it maintains a very short time, we see no vertical displacements and internal force is far greater than the external force (gravity) and system consisting of the human body and barbell instantly satisfies conservation of momentum. When the state of the human body and the barbell is as the right figure in Figure 4, the bar and the body's momentum is both zero, we can draw the numerical relationship in formula (8).

$$P_{\varepsilon} = p_{\Sigma} \tag{8}$$

SNATCH CHARACTERISTIC DATA ANALYSIS

In the weightlifting process by snatch way, in addition to mechanical factors of technical operation, it also suffers some data characteristics. By analyzing the results data of this technique, we can draw the notable features of weight, snatch success rate and the acting assignment problem, which can provide some experience for snatch technique.

According to the competition rules of modern weightlifting, athletes must be weighed before the game. When the weightlifting performance results are the same, judge the ranking based on the weight size before the game; the one with a smaller weight wins, so that there is a certain relationship between the athlete's body weight and total score. The data is shown in TABLE 1.

TABLE 1 : The comparison table of snatch performance and personal weight

Scale	Max Weight	Result
1	54	132.5
2	59	137.5
3	64	147.5
4	70	162.5
5	76	167.5
6	83	180.0
7	91	187.5
8	99	185.0
9	108	195.0
10	Exceed 108	197.5

According to the data in TABLE 1, use the Excel to draw the weight performance trend figure shown in Figure 5:

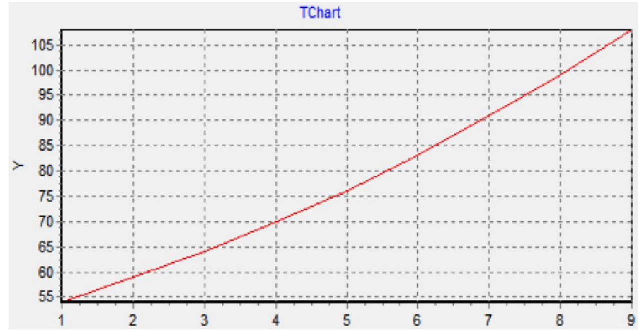

Figure 5 : The maximum weight change trend with the level

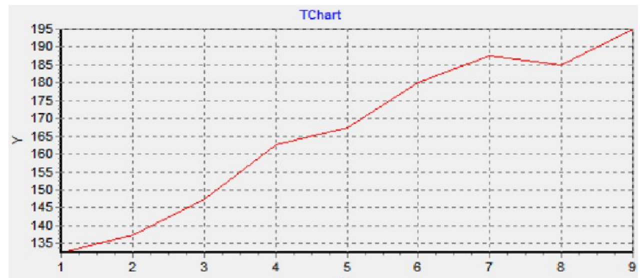

Figure 6 : Snatch performance change trend with level

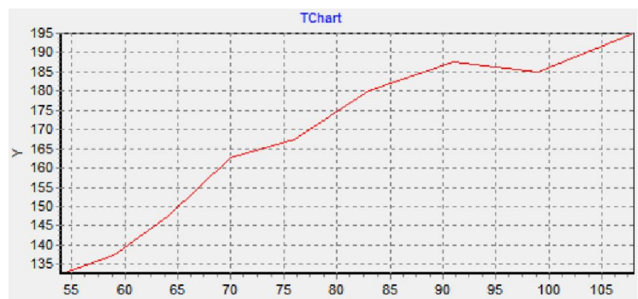

Figure 7 : Snatch performance change trend with weight

The left in Figure 5 shows the trend change figure of the snatch level and the maximum weight of this level, the horizontal axis is the snatch level and the vertical axis is the maximum weight; using the logarithmic regression can obtain the trend line equation as shown in the formula (9) below:

$$\mathbf{Y_1 = 49.4676 * e^{(0.0867 X_1)}} \tag{9}$$

In Formula (9) Y_1 indicates that the maximum weight of the corresponding level with unit in kilograms X_1 means that the level has no unit.

The statistical parameters of Formula (9) trend line equation are as follows:

Residual sum of squares = 4.6141*10-5

Sum of deviation squares = 0.4506

Multiple correlation coefficient = 0.9999

Variance = 4.6141*10-5

The simulation curve of regression equation (9) is

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shown in Figure 8:

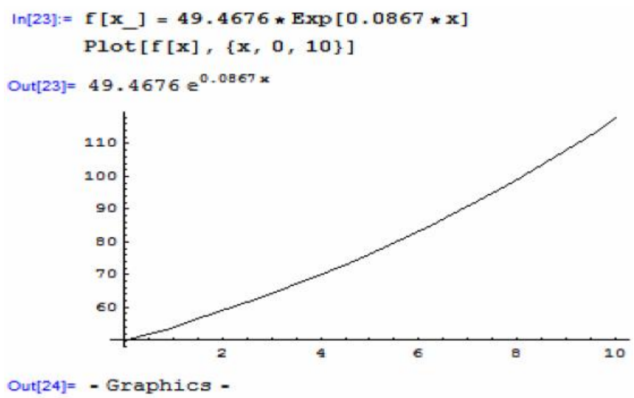

Figure 8 : The simulation curve of maximum weight changing with the level

By the formula (9) and simulated curves and statistical parameters, we know that snatch level and snatch performance has a high correlation. The higher the weight is, the higher the level is, the weight varies logarithmically with the index.

Figure 6 shows the trend change figure of the snatch level and the final grade, the horizontal axis is the snatch level and the vertical axis is snatch performance; using the logarithmic regression can obtain the trend line equation as shown in the formula (10) below:

$$Y_2 = 122.7337 + 30.4954*\ln(X_1) \qquad (10)$$

In Formula (10) Y_2 indicates the snatch performance of the corresponding level with unit in kilograms.

The statistical parameters of Formula (10) trend line equation are as follows:

Residual sum of squares = 302.5288

Sum of deviation squares = 4151.3889

Multiple correlation coefficient = 0.9629

Variance = 302.5288

The simulation curve of regression equation (10) is shown in Figure 9:

By the formula (10) and simulated curves and statistical parameters, we know that snatch level and snatch performance has a high correlation. The higher the snatch level is, the higher the snatch score is, the results vary logarithmically with the level.

Figure 7 shows the trend change figure of the maximum weight level and the final grade, the horizontal axis is the maximum weight level and the vertical axis is snatch performance; Using the logarithmic regression can obtain the trend line equation as shown in the formula (11) below:

$$Y_2 = -242.1792 + 94.1929*\ln(Y_1) \qquad (11)$$

The statistical parameters of Formula (11) trend line equation are as follows:

Residual sum of squares = 153.0943

Sum of deviation squares = 4151.3889

Multiple correlation coefficient = 0.9814

Variance = 153.0943

The simulation curve of regression equation (11) is shown in Figure 10:

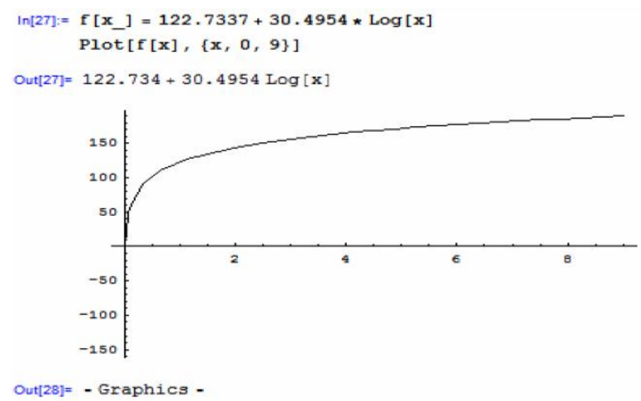

Figure 9 : The simulation curve of snatch performance changing with the level

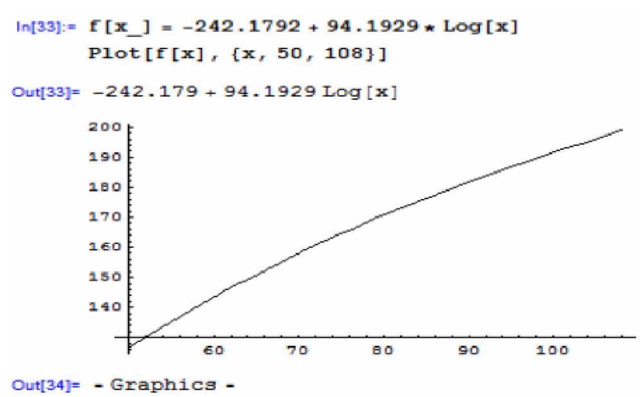

Figure 10 : The simulation curve of snatch performance changing with the body weight

By the formula (11) and simulated curves and statistical parameters, we know that maximum weight level and snatch performance has a high correlation. The higher the weight level is, the higher the snatch score is, the results vary logarithmically with the weight.

To sum up: when the athletes loss weight in strength undiminished circumstances, which helps athletes get a more prominent achievements in a lower level and may break the record achievement of this level.

CONCLUSIONS

1) In the snatch process, we need pay attention to the stability, which requires the projection of the system center of gravity on the ground falls in the support surface;
2) Force stage is a crucial stage during the snatch process; keeping a slight and stable rise of the body center of gravity helps to improve conversion efficiency of the human body internal energy;
3) In the force phase and the inertia rising phase, we need to control the barbell reasonably close to the body center of gravity and arm, which helps reduce rotational torque and has a great impact on the performance results;
4) At the end of the moment of inertia rising phase, the body center of gravity decreases; gravitational potential energy transforms into kinetic energy, in the collision course with the barbell it satisfies conservation of momentum;
5) At the end of the inertia rising phase, the descend range of body center should be reduced, because when the barbell's weight is greater, the impulse of gravity is greater, and when the body's momentum cannot balance the barbell's momentum, the oppression force that body suffers will increase and lead to sports injuries;
6) From the data regression and regression equation simulation images it shows that there exists a logarithmic function relationship between the snatch performance and the athlete's weight;
7) Sports biomechanics and function theorems has been reasonably used in the snatch technique, which well explains the mechanics of the movement, and has been proved by the actual data.

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