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Article

# Detection method of arm force point in shot put based on ant colony algorithm

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**Abstract:** In order to better improve the ability of shot put, an ant colony algorithm-based detection of arm force point in shot put is proposed. Firstly, integrate the ant colony algorithm theory to obtain the values of the two influencing factors of the arm force point, the special absolute strength of the upper limb and the special speed strength training of the upper limb in shot put, calculate the correlation coefficient between the absolute strength training of the upper limb and the arm force point in shot put, and obtain the correlation degree between the influencing factors of the absolute strength training of the upper limb and the arm force point in shot put, Obtain the interaction relationship between the upper limb muscle tissue and the support system, calculate the influence of the work degree of the upper limb muscle under the special speed and strength training of the upper limb on the arm force point in push and throw, give the force of the muscle group in the process of "pulling" and "pushing" shot put in the process of gradually increasing the training load of upper limb throw, and obtain the synergy effect index of the shoulder muscle group in the process of "pushing" shot put. The test model of arm force point in shot put is established. The simulation results show that the proposed detection method of arm force point in shot put based on ant colony algorithm can accurately track and monitor the throwing situation of shot putters, obtain accurate data of arm force point in shot put and optimize the technology.

**Keywords:** ant colony algorithm; shot put; arm force point; force point detection

## 1. Introduction

With the further development of sports training science in China, the methods and means of strength training for athletes in different sports are becoming more and more specialized, which makes more and more coaches pay attention to strength training and gradually realize the importance of strength skills. Shot put is one of the events requiring high intensity in track and field sports. How to effectively improve shot putter's shooting skills has become a hot issue concerned by relevant experts and scholars in this field [1]. At this stage, the application of strong shot putter arm strength point detection methods include: Zhang et al. [2] proposed modeling and analysis of impact force diffusion mechanism based on digital arms. Based on the image data of the shoulder to fingertips in Chinese digital humans, the geometric entities of the tissue structure are obtained through tissue segmentation, 3D modeling, and reverse transcription. A model of the human forearm injury mechanism is established in finite element simulation software. This method can analyze in detail the damage effects inside the human arm during explosive impact and lateral instantaneous tilting, providing scientific basis for sports training and rehabilitation. However, the model building process is complex, requiring a large amount of image data and computational resources, and its direct application for specific arm force point detection is limited. Wang and Xia [3] proposed a method for measuring arm motion posture based on Mahony EKF algorithm. This method combines the advantages of Mahony filter and EKF algorithm, improves the accuracy and stability of attitude calculation, and can monitor the motion status of the arm in real time. However, the system has high requirements for the accuracy and stability of sensors, and the algorithm implementation is relatively complex, requiring a certain technical foundation and computing power. Li and Zhao [4] proposed a path planning method for obstacle avoidance in robotic arms based on quantum ant colony algorithm. By simulating the foraging behavior of ants and combining the advantages of quantum computing, a safe and efficient obstacle avoidance path is planned for the robotic arm in three-dimensional space. Improved the efficiency and accuracy of path planning, suitable for obstacle avoidance path planning of robotic arms in complex environments. However, quantum computing is still in the development stage, with relatively complex algorithm implementation and high requirements for hardware resources.

In addition, combining machine learning with sports biomechanics provides a new perspective for a deeper understanding of the movement mechanism of shot-put athletes. By analyzing biomechanical parameters such as electromyographic data, joint angles, and movement speed of athletes, and combining them with machine learning algorithms, more accurate motion models can be established. These models can not only help coaches and athletes identify technical deficiencies, but also provide personalized training recommendations to more effectively improve athletes' shooting skills.

However, although these methods have made some progress in the analysis of shot-put athletes' movements, there are still some challenges and problems. For example, deep learning algorithms require a large amount of annotated data for training, and high-quality annotated data is often difficult to obtain; Meanwhile, the interpretability of machine learning models is relatively weak, making it difficult to visually display analysis results and decision-making basis. To address these issues, we propose a method based on ant colony algorithm to detect the arm force points of athletes pushing, in order to achieve better results in strength training and technical improvement for shot put athletes.

## 2. Detection of arm force point in shot put

### 2.1. Influencing factors of arm force in shot put

Shot put technology is a whole technology composed of five parts: holding the ball, preparation stage, sliding step, final force and maintaining body balance. That is to say, the key to creating excellent results lies in the stable connection and play of the whole technology. From the perspective of biomechanics, the performance of shot put depends on three basic factors: shot speed, shot angle and shot height [5,6]. Shoulder joint angle refers to the angle formed by the connecting line between shoulder joint and elbow joint and the connecting line between shoulder joint and hip joint [7]. The angle of the right shoulder joint reveals the lifting height of the elbow joint and the tightness of the shot put against the clavicular fossa. Taking the most common right hand holding the ball as an example [8], as the throwing arm, the right hand should be kept behind the body as far as possible to keep the shoulder joint Angle in a relatively stable range, which is conducive to creating good throwing conditions for the final force stage [9,10]. To illustrate the influence of shoulder joint angle on shot put, a group of shot-put athletes were selected and their throwing results were recorded at different shoulder joint angles. When the angle of the athlete's right shoulder joint is maintained within a certain range (such as 70° to 110°), the throwing performance is generally good, as shown in **Table 1**:

**Table 1.** Throwing results at different shoulder joint angles.

| Shoulder joint angle | Average throwing score (m) |
|---|---|
| 60°–70° | 17.0 |
| 70°–80° | 18.2 |
| 80°–90° | 18.8 |
| 90°–100° | 19.2 |
| 100°–110° | 19.0 |
| 110°–120° | 18.5 |

From **Table 1**, it can be seen that when the shoulder joint angle is between 80° and 100°, the athlete's throwing performance reaches its best, verifying the importance of shoulder joint angle in shot put throwing. In addition, detailed records were made on the stress angles of the left shoulder joint during specific support stages and the right shoulder joint during dual support stages, as shown in **Tables 2** and **3**. These data show the range of changes in shoulder joint angle and the angle values at the maximum and minimum stress moments under different throwing scores. By comparing these data, we can further understand the influence of shoulder joint angle on shot put throwing.

**Table 2.** List of left shoulder joint force in double support stage.

| | Time | | | |
|---|---|---|---|---|
| **achievement** | **Start time** | **End time** | **Maximum moment** | **Minimum time** |
| 18.65 m | 107.15º | 92.21º | 109.01º | 90.06º |
| 18.63 m | 113.41º | 85.46º | 113.52º | 85.46º |
| 18.25 m | 103.48º | 83.58º | 103.48º | 82.88º |
| 17.82 m | 109.02º | 92.51º | 109.02º | 92.51º |

**Table 3.** List of right shoulder joint force in double support stage.

| | Time | | | |
|---|---|---|---|---|
| **Achievement** | **Start time** | **End time** | **Maximum moment** | **Minimum time** |
| 18.65 m | 70.51º | 55.78º | 111.75º | 55.71º |
| 18.63 m | 73.33º | 60.35º | 120.78º | 59.63º |
| 18.25 m | 99.17º | 76.95º | 99.18º | 75.65º |
| 17.82 m | 107.69º | 92.35º | 108.31º | 92.62º |

Combined with the development history of shot put technology, it can be concluded that the release speed in the final force stage of shot put is mainly related to the distance of shot put work and the length of time used, that is, the longer the distance of shot put work is, the shorter the time of shot put work is, the greater the explosive force of the final release moment is, and the faster the release speed [11]. Under different constraints, the manifestation of the force point is different. The general manifestations are maximum strength, rapid strength, strength endurance and reaction strength. The strength point of athletes mainly depends on morphological factors (muscle volume, muscle fiber structure, etc.), neurophysiological factors (intramuscular coordination and intermuscular coordination) and motivational psychological factors [12,13]. Based on this, the influencing factors of arm force in shot put are divided, as shown in the following **Figure 1**.

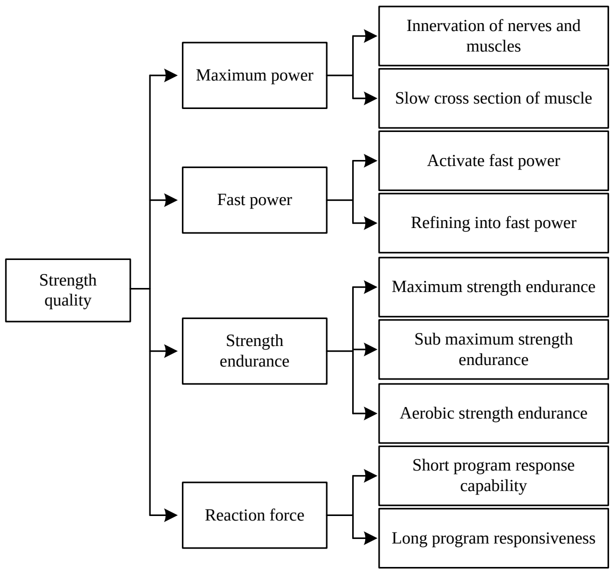


**Figure 1.** Influencing factors of arm force in shot put.

When optimizing the throwing target technology, we should focus on the athlete's upper limb throwing training, calculate the impact of the upper limb special training on the throwing target training, and obtain the synergy effect index of the athlete's shoulder muscle group in the process of "putting" shot put [14]. However, the traditional method carries out technical optimization by analyzing the relationship between the upper limb throwing training and the arm force point in shot put [15,16]. However, it cannot obtain a clear synergy effect index of athletes' shoulder muscle group in the process of coordinated "push" shot put, which reduces the effect of technical optimization.

Based on the data and experimental results of morphological, neurophysiological, and motivational psychological factors mentioned above, it is concluded that the arm strength points of shot-put athletes are influenced by various factors, including muscle volume, muscle fiber structure, intra - and inter muscle coordination, nerve conduction velocity, self-confidence, and stress resistance. These factors interact with each other and together determine the throwing performance of athletes. Therefore, when optimizing throwing techniques, these factors should be comprehensively considered to develop targeted training plans and technical optimization strategies.

## 2.2. Algorithm of force variation of throwing arm of shot putter

In the process of establishing the principle model for the detection of the force point of the throwing arm of shot putters, first describe the upper limb training methods of historical shot putters, calculate the muscle strength of the upper limb, chest and shoulder of the athletes under different training methods, obtain the proportion of the training load of the athletes' muscle strength under different training methods, and calculate the relevant influence coefficient of the release speed of the athletes when putting the shot at the last effort on the force point of the arm in the push and throw [17,18]. The effect of upper limb throwing force on arm force point in push and throw is obtained. Based on this, the principle model of shot putter's throwing arm force point detection is established $\varphi(x)$ represents the upper limb throwing training means of previous shot putters, $e(o)$ represents the contraction direction of upper limb muscles of athletes under different training means, $\phi(t)$ represents the nature of shot putting force of athletes, $w(r)$ represents the action range of shot putting and the speed of shot putting, then use Equation (1) to calculate the maximum muscle strength f(k) of upper limbs of athletes under different training means:

$$F(k) = \frac{\varphi(x) \times w(r)}{\gamma \cdot v} \times e(o) \times \phi(t) \tag{1}$$

Among them, $\frac{\varphi(x)\times w(r)}{\gamma\cdot v}$ represents the training cycle of upper limb throwing [19]. Assuming that $\delta(\lambda)$ represents the upper limb extensor strength of athletes under different training methods, and $\vartheta(p)$ represents the pectoralis major strength of athletes, Equation (2) is used to give the ultimate strength $y(\alpha)$ of shoulder muscles and lumbar and abdominal muscles under the maximum upper limb strength training of shot putters:

$$Z(\kappa) = \frac{\delta(\lambda) \times g(p)}{F(k) + \phi(t)} \times y(\alpha)\varepsilon(s) \tag{2}$$

Among them, $\varepsilon(s)$ Represents the maximum strength of shot put by athletes in upper limb throwing training, $g(f)$ represents fast strength and $o[\tau(\zeta)]$ represents the upper limb strength endurance of shot put athletes $\xi_v(h)$ . Then, the proportion of upper limb throwing training load under different training methods is calculated by using the Equation (3):

$$r(h) = \frac{[Z(\kappa) \times g(f)]}{\xi_v(h)} \times o[\tau(\zeta)] \tag{3}$$

Assuming that $U(n)$ represents the upper limb throwing speed and strength of shot putters, $U(n)$ represents the release height of shot put under different training methods, and $r(h)$ represents the effect of upper limb throwing training on the arm force point $k, r$ in push and throw, the principle model of detecting the arm force point of shot putters is established by using Equation (4):

$$F(o)=\frac{Z(\kappa)/U(n)}{\omega(z)\psi(\hbar)}\cdot\varepsilon(s)\frac{r(\hbar)-kr}{(\theta(\beta)+\vartheta(u))^2} \quad (4)$$

Among them, $\theta(\beta)$ represents the horizontal coefficient of upper limb throwing. The higher $\vartheta(u)$, the more significant the influence on the arm force point in push throwing [20]. When optimizing the throwing target technology, we should focus on the athlete's upper limb throwing training, calculate the influence degree of the upper limb special training on the throwing target training, and obtain the synergy effect index of the athlete's shoulder muscle group in the process of "putting" shot put [21]. However, the traditional method optimizes the technology by analyzing the relationship between the upper limb throwing training and the arm force point in shot put, However, it can not obtain a clear synergy effect index of athletes' shoulder muscle group in the process of coordinated "push" shot put, which reduces the effect of technical optimization [22]. As the third factor affecting shot put performance, shot put height is mainly affected by three factors: shot putter's height, arm length and the height of hand from the ground at the moment of shot put.

### 2.3. Realization of detecting the force point of throwing arm of shot putter

The various points of upper limb exertion do not exist independently, but are interrelated and mutually restricted. The development of impurities directly affects the development of other qualities [23]. Therefore, in terms of explosive force quality, we should not only consider the phase restriction relationship of power cord questioning, but also pay attention to the influence of emotion factors on other qualities. Based on this, an ant colony algorithm is proposed to detect the arm force point of shot putters. Suppose, by $y_{ik}$. It represents the sample data characteristic sequence of the influence of historical upper limb throwing training on the arm force point in shot put [24]. There are m related factor sequences, $Y_i$ and $Y_0$ represents the ith related factor sequence. Combined with the initial value operator $y_{0N}$. And $y_{iN}$ are initialized, and the Equation (5) is used to represent the initial value image of the arm force point and its influencing factors in shot put:

$$\begin{cases}Y_0=(y_{01},y_{02},\cdots,y_{0k},\cdots,y_{0N})\\ Y_i=(y_{i1},y_{i2},\cdots,y_{ik},\cdots,y_{iN})\end{cases} \quad (5)$$

In the process of establishing the influence model of upper limb throwing training on the arm force point in shot put, first integrate the ant colony algorithm theory to analyze the correlation of the arm force point in shot put under the upper limb special absolute strength training, obtain the initial value image of the arm force point in shot put and its influencing factors, calculate the correlation coefficient between the upper limb throwing training and the arm force point in shot put, and obtain the upper limb special strength index of shot putters [25]. The correlation degree between the influencing factors of upper limb absolute strength training and the arm force point in push and throw is obtained [26]. The specific process is as follows: assuming that $\xi$ represents the muscle ability under upper limb throw training, $y_{0k}$ represents the ability of muscle groups to overcome resistance and work under upper limb throw training, and $y_{ik}$ represents the definition coefficient of upper limb special strength of shot putters, the correlation coefficient between $X(q)$ and $X(r)$ is calculated by Equation (6):

$$\gamma_{0i}(k) = Y_0 \frac{\min_k \left\{ \left| y_{0k} - y_{ik} \right| \right\} + X(q)\xi \max_i \left\{ \left| y_{0k} - y_{ik} \right| \right\}}{Y \left| y_{0k} - y_{ik} \right| + X(r)\xi \max_k \left\{ \left| y_{0k} - y_{ik} \right| \right\}} \quad (6)$$

In the Equation, $\xi \in (0,1)$ represents the coefficient of separation, usually taken $G_r$ = 0.5. Assuming that $G_r$ represents the thrust of the upper limb, $n_i$ represents the bowl bending force of the upper limb, $e_k$ represents the contraction direction of the triceps $f_r$ during the throwing process under the special absolute strength training of the upper limb, and G represents the maximum work done by the triceps $a(w)$ at the moment of pushing, the throwing force of the batsman's upper limbs can be expressed by the following Equation (7):

$$F_r = \gamma_{0i}(k) - \beta \frac{G_r[n_i(e_k \times f_r)]}{a(w) \times w(k) \times \sigma} \quad (7)$$

where, $w(k)$ represents the special absolute strength of the upper limb, which reflects the ability of the shot putter to rely on the upper limb to make himself able to bear the maximum weight, e represents the speed strength of the upper limb, which reflects the ability of the shot putter to rely on the upper limb to make the weight work fastest, and $\sigma$ represents the forearm muscle group [27]. When selecting training means, it is better if the two methods can develop the ability of multiple force points at the same time. Based on this, the mechanism of force point conversion of shot putter's throwing arm is further optimized, as shown in the **Figure 2**:

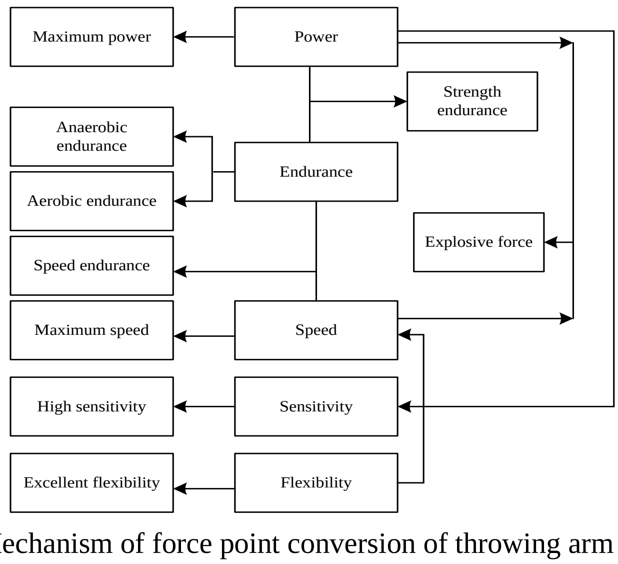


**Figure 2.** Mechanism of force point conversion of throwing arm of shot putter.

The coordination ability of multiple force points refers to the ability of athletes to coordinate different systems, different parts and different organs to complete actions or technical and tactical activities [28]. It is the basis for the formation of sports technology. When the body is moving, each motion force point constitutes an internal steady-state system, and all force points are interrelated in the form of network structure. Coordination is mainly reflected in the timely contraction and relaxation of muscles that need to cooperate at the same time [29]. German scholar güsser pointed out that coordination is the comprehensive expression of various functions of the human body, including flexibility, learning ability, spatial orientation ability, response ability, rhythm, balance, accuracy and so on.

## 3. Analysis of experimental results

The experimental parameters of ant colony algorithm are as follows (**Table 4**):

**Table 4.** Experimental parameters of ant colony algorithm.

| Parameter | Describe | Selection and Adjustment Fundamentals | Convergence performance impact |
|---|---|---|---|
| Pheromone importance factor α | The importance of determining pheromones in path selection | Larger alpha values accelerate convergence, but may lead to local optima; Need to adjust to a suitable range based on specific issues | *α* value that is too high may lead to premature convergence, while a value that is too low may result in slower convergence speed |
| Heuristic factors β | The Importance of Heuristic Information in Path Selection | A larger beta value increases exploration ability, but may slow down convergence speed; Need to coordinate and adjust with the alpha value | A high beta value may increase the randomness of the search and reduce convergence, while a low beta value may lead to unclear search direction |
| Pheromone volatility coefficient ρ | Determine the rate at which pheromones evaporate over time | A smaller value of ρ increases memory capacity, but may get stuck in local optima or slow down convergence speed; Need to adjust according to the number of iterations and path length | A high value of ρ may cause pheromones to disappear too quickly and the algorithm to lose its memory ability, while a low value may lead to excessive accumulation of pheromones and the algorithm falling into local optima |
| Ant number m | Affects the exploration ability and robustness of algorithms | More ants increase exploration ability and robustness, but also increase computational complexity; Choose based on the scale and complexity of the problem | A high value of m may increase computational burden and may not necessarily improve performance, while a low value may lead to insufficient search |

Two Sony 300 cameras (120 frames/s) are used to record the shot-put competition in which the athletes participate. Machine 1 is placed in the left front of the shot-put circle, machine 2 is placed in the right front of the shot-put circle, and the included angle of the main optical axis of the two machines is 45°. APAs video analysis software is mainly used to analyze the athlete’s technical action videoAPAs, and the low-pass digital filtering method is used to smooth the original data first, with the truncation frequency of 8 Hz. As an auxiliary analysis software, dartifish has a three-dimensional video recording site diagram as shown in **Figure 3**:

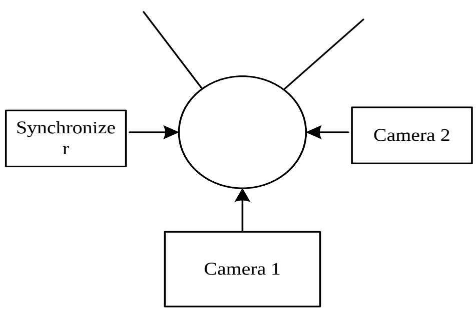


**Figure 3.** Schematic diagram of 3D video recording site.

The athlete's shot-put technique movements and changes in force points are shown in **Figure 4**.

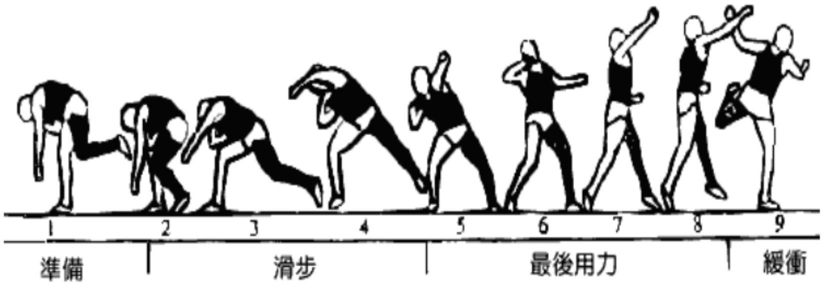


**Figure 4.** Diagram of athletes' shot-put techniques and force point changes.

This paper analyzes the exertion characteristics of male shot putters in the final exertion stage by using surface electromyography technology, analyzes the technical rationality of the final exertion stage of rotary shot putter Technology (the moment before the shot is ready to release) through effective data mining, and finds out the time sequence (start time, end time and duration), muscle EMG discharge and contribution rate of the main exertion muscles in the preparation part of the final exertion stage in the shot putter process, It provides a theoretical reference for the future daily special strength training and the improvement of throwing techniques in the final force stage. The basic information of shot putters is shown in **Table 5**:

**Table 5.** Basic information of shot putters.

| Age | Height | Weight | Training years | Best results | Sport level |
|---|---|---|---|---|---|
| 35 | 183 | 117 | 17 | 19.16 | Master Sportsman |

A Nissan Sony dcrvx2100e digital video recorder is used to shoot the athletes at a fixed point on the competition site. The camera is about 12 m away from the center of the throwing circle, the included angle between the main optical axis of the camera and the fan-shaped central line of the throwing area is about 90°, the machine is 1.2 m high and the shooting frequency is 50 Hz. After the competition, the scale with two-mark points is photographed at the same time in the throwing circle. The American Ariel motion video analysis system is used to analyze the collected motion video point by point and frame by frame. The American Dempster model brought by the system is selected to obtain the kinematic parameters such as the position, displacement, velocity, acceleration, angle and angular velocity of the force point of each arm joint in the process of shot put through digital calculation, and automatically generate the action stick diagram, as shown in **Figures 5** and **6**, The low-pass digital filtering method is used to smooth the original data, and the truncation frequency is 8 Hz.

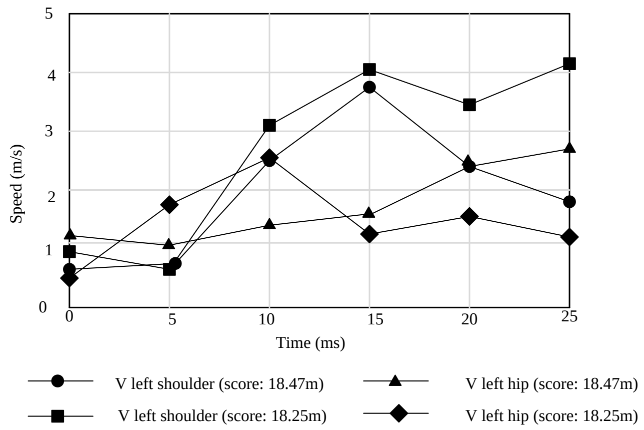


**Figure 5.** Force variation curve of right arm in the final force stage of shot put.

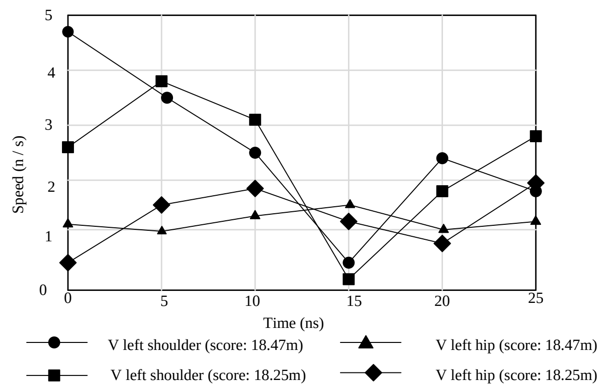


**Figure 6.** Force variation curve of left arm in the final force stage of shot put.

Based on the formation process of basic movements and the theories of anatomy, physiology and neurology, FMS detection was carried out for the force point of the arm, including three exclusion tests (shoulder pain excitation test, trunk stability push down extension test and rotation stability backward upper body exclusion test). It was used to sort the normal basic movement patterns of the human body and find the movement patterns of asymmetry and poor function. The function of functional action screening is shown in the **Table 6**.

**Table 6.** Functional action screening sub test function.

| FMS self test | function |
|---|---|
| Squat | Evaluate the bilateral and symmetrical flexibility and stability of bilateral hip, knee and ankle joints. Evaluate the bilateral and contralateral flexibility and stability of bilateral shoulders, shoulder blades and thoracic spine. |
| Hurdle step | Evaluate bilateral, symmetrical flexibility and stability of bilateral hips, knees and ankles. To evaluate the stability and control ability of bone salt basin and core parts of the body. |
| Straight lunge | Evaluate the stability of spine, pelvis and core parts of the body. Evaluate the flexibility and stability of hip, knee, ankle and foot. Evaluate the flexibility of multi joint muscles. |
| Active straight knee lift | Evaluate the flexibility of one hip joint and the extension of the other hip joint. Evaluate the active flexibility of hamstring, gastrocnemius and Biri fish machine. Evaluate the stability of the pelvis and core of the body. |
| Trunk stability push down support | Evaluate the stability of the core of the body. Evaluate the stability of shoulder blades, the strength of shoulder joints and the balance of left and right shoulders |
| Rotational stability | Evaluate the stability of pelvis, body core and shoulder strap. To evaluate neuromuscular coordination and trunk energy transmission |

Correlation characteristics in the muscle strength characteristics of the three joints of the throwing arm, the flexion and extension torque and power of the three joints of the international elite athletes in shot put are greater than those of the elite athletes, especially the international elite group has a strong basic muscle strength level of the elbow, which proves that the strong muscle strength of the three joints of the throwing arm is the fundamental guarantee for the excellent results of shot put. The test and statistics of basic muscle strength are shown in **Table 7**.

**Table 7.** Legal principle and average characteristics of elbow joint of Shot Putters.

| group | Number of tests | PT/Nm | | PT/BW/(Nm/kg) | | F/E | P/W | |
|---|---|---|---|---|---|---|---|---|
| | | F | E | F | E | | F | E |
| International elite group | 60°/s | 65 ± 25.5 | 50.5 ± 10.6 | 0.57 ± 0.3 | 0.45 ± 0.2 | 1.25 ± 0.2 | 41.6 ± 10.7 | 35.6 ± 6.38 |
| | 240°/s | 45 ± 7.08 | 65 ± 7.08 | 0.38 ± 0.1 | 0.57 ± 0.1 | 0.68 ± 0.2 | 66.6 ± 12.03 | 115.6 ± 28 |
| Master group | 60°/s | 73 ± 24.5 | 50 ± 7.08 | 0.65 ± 0.3 | 0.47 ± 0.1 | 1.51 ± 0.7 | 34.6 ± 2.13 | 32.5 ± 6.4 |
| | 240°/s | 37 ± 16.3 | 48.1 ± 4.96 | 0.35 ± 0.2 | 0.45 ± 0.1 | 0.75 ± 0.3 | 55.3 ± 23.1 | 80 ± 11.32 |

The average power of elbow flexion and extensor muscles of the subjects in the table increased with the acceleration of the test speed. There was no significant difference in the average power of elbow flexion, and the average power was significantly higher than that of the master group ($P < 0.05$). Shot put is a group of explosive events dominated by technology. In the selection of shot put, the explosive force of the throwing arm needs to be taken as the key index for reference and evaluation. The original EMG data obtained through the experimental test is mainly processed synchronously by combining megawin6000 EMG software made in Finland and the corresponding image data taken by the camera. The measured muscle activity intensity is analyzed, and the original data is sorted out. Then, excel 2010 software and spss19 statistical software are used for processing and analysis (**Table 8**).

**Table 8.** List of starting time sequence of each muscle discharge in the last use case stage unit: S.

| Muscle type | First shot | Second shot | Third shot | Fourth shot | Fifth shot | X ± SD |
|---|---|---|---|---|---|---|
| Posterior segment of right the biceps brachii | 0.001 | 0.0169** | 0.001 | 0.001 | 0.001 | 0.0039 ± 0.0065 |
| Right biceps femoris | 0.001 | 0.048** | 0.001 | 0.002 | 0.018** | 0.0105 ± 0.0206 |
| Right quadriceps femoris | 0.001 | 0.001 | 0.001 | 0.003 | 0.008* | 0.0049 ± 0.0068 |
| Right arm major muscle | 0.001 | 0.001 | 0.003 | 0.002 | 0.001 | 0.0027 ± 0.0027 |
| Right erector spinalis muscle | 0.001 | 0.001 | 0.002 | 0.001 | 0.008* | 0.0013 ± 0.0006 |
| Right external oblique abdominal muscle | 0.001 | 0.001 | 0.001 | 0.004 | 0.001 | 0.0027 ± 0.0032 |
| Left biceps femoris | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.0011 ± 0.0000 |
| Left quadriceps femoris | 0.001 | 0.001 | 0.003 | 0.001 | 0.001 | 0.0013 ± 0.0006 |

Note: ** $p < 0.05$, * $p < 0.1$.

According to the table, the discharge time of the right biceps and the posterior segment of the right biceps in the first shot is significantly later than that of the corresponding muscles in other shots. The discharge of the right triceps brachii in the fifth shot started later, which was significantly different from the corresponding muscles in other shots. In addition, the discharge start time of right external oblique abdominal muscle and right tendon was also slightly later, which was significantly different from the first four shots. Other muscles began to discharge in each shot, and the starting time was basically the same. From the situation of each muscle starting to discharge during each throw, the starting time of each muscle in the first throw is consistent, while the starting time of muscle discharge in other throws is inconsistent. In the final exertion stage, the preparation part is mainly to maintain the existing speed of the shot put and make full preparations for accelerating the rapid exertion of the throwing arm. Therefore, in this process, the right arm and right hip should actively rotate and exert force, while the left muscle group of the body should form a pre-elongated state. Therefore, in theory, the right muscle group of the preparation part of the final exertion stage of rotary shot put begins to discharge first. In the five throwing tests, the right lower limb muscle group of the third throw began to discharge actively at the same time, indicating that the positive pedaling effect of the right lower limb muscle group is obvious and the upper body is fully tightened. In addition, the discharge start time of the left muscle group of the three shots was relatively earlier than that of the right muscle group, but there was no significant difference (except the second shot). In terms of performance, the first shot is better than the other four shots, indicating that all muscles are actively activated in the preparation part of this stage. In the final exertion stage of the throwing process, the time sequence of preparing the discharge of some muscles is as follows: the left side (biceps brachii and triceps brachii), the right side (erector spinalis, external oblique abdominal muscle, tendon, posterior segment of biceps brachii, triceps brachii and biceps brachii). The power generation sequence of the above muscles is in line with the principle of the first activity of the large joint. The left biceps brachii, the right triceps brachii and the erector spinalis belong to the large muscle groups around the hip and knee joints. Therefore, in the future, we should focus on strengthening the rapid strength explosive power and endurance training of the large joint muscle groups. At the same time, it is also necessary to strengthen the stability and durability training of the rapid discharge of the right lower limb muscles (right biceps, right triceps and right biceps). The duration of discharge of each muscle is an important manifestation of the continuous discharge ability (i.e. force) of the muscle during work and operation. See the **Table 9** for details.

**Table 9.** List of discharge duration sequence of each muscle in the preparation part of the final force stage unit: S.

| Muscle type | First shot | Second shot | Third shot | Fourth shot | Fifth shot | X ± SD |
|---|---|---|---|---|---|---|
| Posterior segment of right the biceps brachii | 0.092 | 0.018** | 0.067 | 0.075 | 0.069 | 0.0635 ± 0.0268 |
| Right biceps femoris | 0.1 | 0.072** | 0.075 | 0.075 | 0.068 | 0.0771 ± 0.0132 |
| Right quadriceps femoris | 0.098 | 0.117 | 0.075 | 0.072 | 0.055* | 0.0827 ± 0.0249 |
| Right arm major muscle | 0.098 | 0.098 | 0.068 | 0.073 | 0.065 | 0.0805 ± 0.0166 |
| Right erector spinalis muscle | 0.1 | 0.118 | 0.073 | 0.073 | 0.068 | 0.0865 ± 0.0222 |
| Right external oblique abdominal muscle | 0.1 | 0.118 | 0.075 | 0.074 | 0.063 | 0.0857 ± 0.0226 |
| Left biceps femoris | 0.1 | 0.115 | 0.075 | 0.075 | 0.068 | 0.0861 ± 0.0195 |
| Left quadriceps femoris | 0.096 | 0.106 | 0.070 | 0.074 | 0.068 | 0.0833 ± 0.0158 |

Note: ** $p < 0.05$; * $p < 0.1$.

As shown in the table, the discharge duration of each muscle in the first shot is slightly shorter than that of other muscles, but there is no significant difference in the discharge duration between each muscle. In the second shot, the duration of each muscle discharge is large, especially in the posterior segment of the right biceps brachii. The phenomenon of too late and too early discharge start time and discharge end time leads to the partial activation effect of the posterior segment of the right biceps brachii in the final force stage. Secondly, the discharge of the right biceps brachii also started late, resulting in the inactive rotation of the right shoulder at this stage. The discharge duration of other muscles was longer, the difference was not significant, and was relatively stable. The discharge duration of each muscle in the fourth shot was relatively stable. Only the discharge duration of the right biceps brachii and right tendon in the third shot and the right triceps brachii in the fourth shot were slightly shorter, but there was no significant difference among the muscles. In the fifth shot, the discharge duration of the right triceps brachii was significantly different from that of the other muscles, but the discharge duration of the other muscles was relatively stable. On the whole, except for the fifth shot, there is a phenomenon of short discharge duration in the posterior segment of the right biceps brachii in the other four shots. It shows that the ability of sustained discharge of the posterior segment of the right biceps brachii is insufficient. In the process of special strength training, we should focus on strengthening the sustained strength endurance training of this muscle. The order of the discharge duration of each muscle in the final force stage of the throwing process is as follows: the right erector spinalis muscle, the left biceps brachii muscle, the right lateral oblique abdominal muscle, the left triceps brachii muscle and the right lateral oblique muscle. It can be seen from the results that the discharge duration ability of right erector spinalis muscle, left biceps brachii muscle and right lateral oblique abdominal muscle is better. Therefore, in training, we should strengthen the power output rate of the above three muscles at this stage. At the same time, we should also strengthen the continuous discharge ability of the right tendon and other associated muscles.

## 4. Conclusions

The establishment of a shot-put arm strength point detection method based on ant colony algorithm provides an innovative and efficient training tool for excellent Chinese shot put athletes, significantly improving their competitive ability. This method not only deepens the understanding of the dynamic characteristics of arm strength points in shot put throwing techniques, but also lays a solid scientific foundation for the overall development level of the project. In practical training, this method has broad application prospects. Firstly, by accurately detecting the changes in arm strength points of shot-put athletes during the throwing process, the coaching team can quickly identify the athlete’s technical shortcomings and design targeted training plans, thereby accelerating skill improvement. Secondly, with the development of a specialized strength training device for shot put, athletes can obtain real-time feedback data while simulating a real throwing environment, helping them better adjust their movements and optimize the throwing effect. In addition, this method also helps athletes build confidence on a psychological level, as they can visually see their progress and thus stimulate greater training motivation.

Looking ahead to the future, there are still many research directions worth exploring in depth for the force point detection method of shot-put arm based on ant colony algorithm. With the continuous advancement of technology, algorithms can be further optimized to improve the accuracy and efficiency of detection.

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