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A Study on the Lower Limb Biomechanical Characteristics of Elite Weightlifter Li Fabin during the Snatch Phase—Based on Anybody Simulation

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Abstract

Objectives: This study uses the Anybody simulation software to analyze the dynamic data of elite weightlifter Li Fabin during competition, focusing on the biomechanical characteristics during the critical snatch phase. The research aims to provide theoretical support for training, evaluating, and diagnosing technical movements during this phase of weightlifting. **Methods:** High-speed cameras were placed on both sides of the weightlifting platform to capture video footage of Li Fabin performing a 143 kg snatch at the 2020 National Weightlifting Championship. The SIMI Motion 10.0 motion analysis system was used to mark 42 skeletal features manually. The data was imported into the Anybody simulation, and various parameters such as height, weight, and barbell weight were defined. **Results:** During the snatch phase, the vertical ground reaction force (VGRF) increased continuously in the sagittal axis direction. The peak VGRF reached approximately 3332.0N, equivalent to 5.5 times the body weight, at 63% of the force generation phase. The athlete's lower limbs reached their peak forces simultaneously, with the hip, knee, and ankle forces being notable. Muscle strength imbalances between the two legs were observed, with the left leg having lower strength in specific muscle groups. **Conclusions:** 1) Elite athletes can generate significant ground reaction forces, emphasizing the importance of lower limb extensor training while considering biomechanical principles. 2) Approaching the barbell during the knee extension and lifting phase increases the vertical ground reaction force, highlighting the need for knee extensor training and knee joint stability. 3) The timing of peak muscle forces in certain muscle groups can contribute to improved hip extension power. Training for high-weight hip extensor strength should focus on activating specific muscle groups. Muscle strength imbalances between the left and right lower limbs may impact snatch success and should be addressed by coaches and athletes to maintain proper barbell balance.

Subject Areas

Sports Science

Keywords

Anybody, Li Fabin, Biomechanics

1. Introduction

Since the 1970s, men's weightlifting has been a traditional champion sport in China. However, with the transition of generations of athletes, China's dominance in the kilogram category has entered the non-Olympic events. In recent years, this dominance has been narrowing further. Therefore, it is necessary for us to gain a deeper understanding of the internal mechanisms of weightlifting and develop more efficient training methods to ensure China's dominant position in weightlifting. In the snatch process, the knee lifting and bell raising serve as a transitional phase for both the first and second forces, playing a significant role in the smoothness of force generation during the snatch. The second force generation phase, as part of the second force, requires high force power and a long distance of work, making it the phase with the highest demands on athletes' absolute strength and technical proficiency during the snatch process. These two phases play crucial roles and are key stages throughout the entire snatch process [1].

Previous research in the field of weightlifting has mainly focused on kinematic data analysis, electromyographic data analysis, and force platform kinetics data analysis. Kinematic analysis is advantageous in capturing the kinematic data of competitive athletes. However, electromyographic data analysis and force platform kinetics analysis have limitations in practical use, as they can affect the athletes' performance during experiments [2] [3] [4].

In this study, we used motion simulation software Anybody to collect the kinematic data of weightlifters during competitions and obtained dynamic simulation data of the moment when the excellent weightlifter Li Fabin was competing. This research aims to reveal the mechanical characteristics of Li Fabin during the knee lifting and bell raising phase and the force generation phase in the snatch. This information provides a reference for the training, evaluation, and diagnosis of athletes' technical movements during the snatch phase.

2. Methods

2.1. Research Object

The research focuses on the technical movements of Li Fabin, a Chinese athlete competing in the 61 kg category, during the snatch phase of the 2020 National Weightlifting Championship. He successfully lifted 143 kg, and this performance serves as the research object.

2.2. Research Methods

2.2.1. Three-Dimensional Fixed-Focus Photography Measurement Method

Two high-speed cameras (SONY DCR-HC52E) with a frame rate of 25 frames per second were used. They were fixed on both sides of the weightlifting platform at approximately 90 degrees. Prior to the competition, a Peak three-dimensional calibration was performed to ensure that the cameras did not experience any distance or angle deviations [5].

2.2.2. Three-Dimensional Video Marker Point Collection Method

The German software SIMI Motion 10.0 was utilized for motion analysis. The imported analysis videos had a sampling frequency of 50 Hz, and original video data was smoothed using a 6 Hz low-pass filter. Manual recognition was employed to mark 42 bony landmarks on the athlete's body, including the center above the right eyebrow, the center above the left eyebrow, and the right side of the occiput (**Table 1**). These kinematic markers' parameters were then converted into C3D files recognizable by the Anybody biomechanical software.

2.2.3. Anybody Simulation

The three-dimensional markers were imported into the Anybody standing model in C3D format, adjusting the model's height and weight to match those of the experimental subject (**Table 2**). Additionally, a barbell rigid body (Mass = 143) was added to the model and connected to the hands through joint hinges. In the Full Body-GRF prediction module, inverse dynamics analysis was performed (**Figure 1**). The following is the calculation function for muscle maximum force, which minimizes muscle activity, muscle recruitment, and the objective function G required for the motion. Its formula is as follows [6]:

Objective Function

$$G\left(f_i^M\right)$$

Constraints

$$Cf = d$$

$$f_i^M \geq 0, i \in \left\{1, 2, \cdots, n^M\right\}$$

Muscle Recruitment

$$\min G\left(f^M\right) = \max\left(A_i^M\right) = \max\left(\frac{f_i^M}{N_i}\right)^P$$

Table 1. 42 bone markers.

Bony landmarks	Bony landmarks
RFHD	LFIN
LFHD	RFRA
RBHD	LFRA
LBHD	RASI
C7	LASI
RBAK	RPSI
LBAK	LPSI
CLAV	RTHI
T10	LTHI
RUPA	RKNE
LUPA	LKNE
STRN	RTIB
RSHO	LTIB
LSHO	RHEE
RELB	LHEE
LELB	RTOE
RWRA	LTOE
LWRA	RANK
RWRB	LANK
LWRB	RMT5
RFIN	LMT5

Table 2. Athlete's basic information.

Name	height (cm)	weight (kg)	Lifting weights (kg)
LiFabin	160	50.6	143

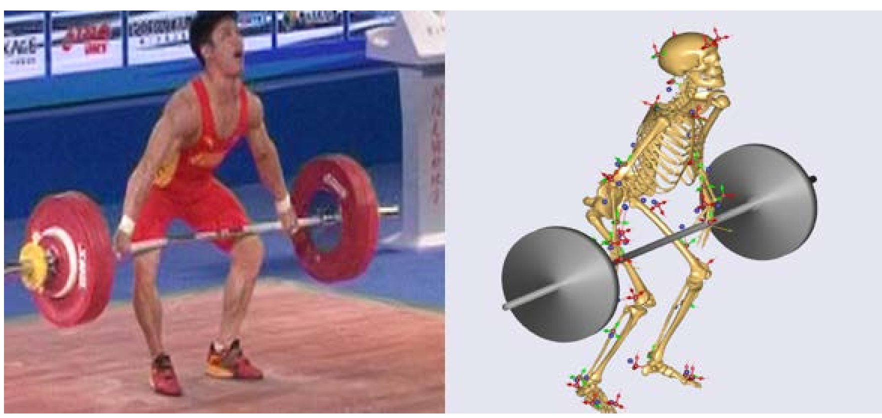

Figure 1. Snatch exercise simulation images.

P is between 1 and 5.

$$Cf^M = R, 0 \le f_i^M \le N_i, i \in \{1, 2, \cdots, n^M\}$$

Muscle Activity: a_i

$$a_i = \left(\frac{f_i^M}{N_i}\right), i \in \{1, 2, \cdots, n^M\}$$

C: This represents the system matrix, which likely describes the relationships and interactions between various components of the biomechanical model.

d: This represents external forces acting on the human body's system. These forces can include things like gravitational forces, contact forces with external objects, or other applied forces.

f_i : These are the individual muscle forces for muscle i during a specific time period while performing a movement. Each muscle contributes to the overall force and movement of the system.

f_i^M : This represents the maximum force that muscle i can generate. It's the maximum strength or force capacity of that muscle.

N_i : This variable represents the tensile strength of a single muscle. It indicates the maximum force that a muscle can provide when it is at its optimal length condition.

A_i^M : This is the muscle activity level or activation level for muscle i. It represents the ratio of muscle force to muscle strength.

R: This variable represents the ground reaction force, which is the force exerted by the ground on the body during contact.

n^M : This likely represents the number of muscles involved in the biomechanical model.

2.3. Division of the Snatch Phase

In the analysis of a rapid and continuous movement, dividing it into stages is an efficient method in the field of motion analysis. In previous analyses of snatch techniques, it has typically been divided into 5 or 6 stages. This study divides it into 6 stages with 7 key time points and focuses on the knee lifting and bell-raising stages for research (**Figure 2**). Here are the stages: Knee Extension Stage (a)-(b): From the moment the barbell leaves the ground to the point of maximum knee extension for the first time. Knee Lifting and Bell Raising Stage (b)-(c): From the maximum knee joint angle to the minimum knee joint angle. Force Generation Stage (c)-(d): From the end of knee lifting to the moment when the barbell velocity reaches its maximum. Inertial Ascent Stage (d)-(e): From the moment of maximum barbell velocity to when the barbell reaches its highest point. Squatting and Support Stage (e)-(f): From the point where the barbell reaches its highest point to the moment when the barbell descent velocity reaches its maximum. Bell Reception Completion Stage (f)-(g): From the moment when the barbell descent velocity reaches its maximum to the moment when the barbell velocity reaches zero. This study specifically focuses on the knee lifting and

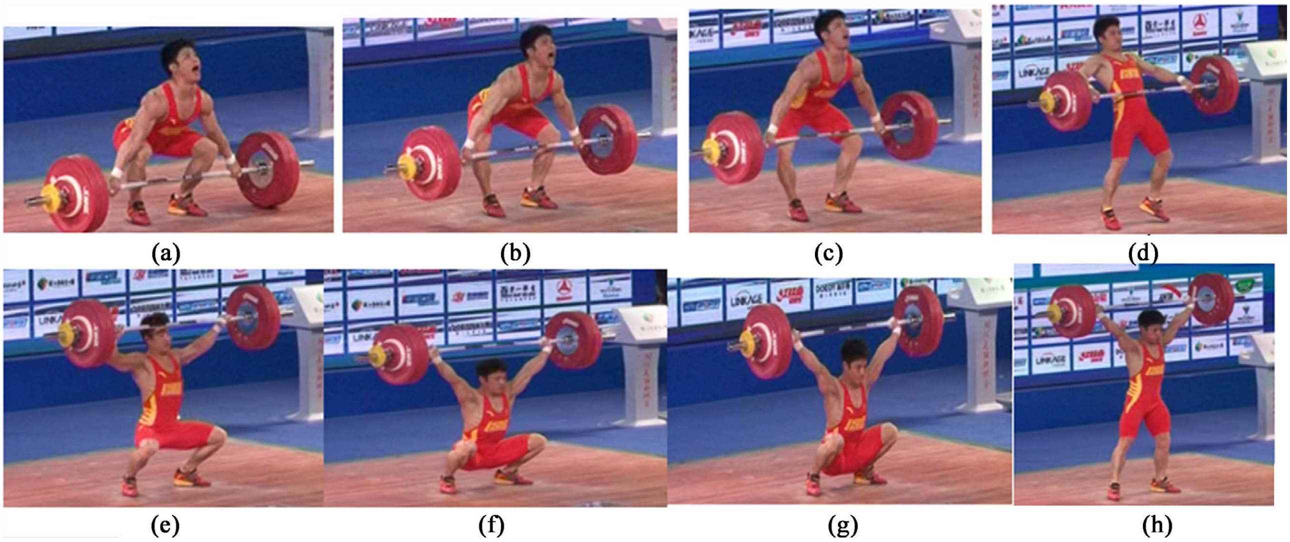

Figure 2. Division of the snatch phase.

bell-raising stage and the force generation stage of the snatch movement. These stages are crucial in understanding the mechanics of the snatch and are key to analyzing athlete performance [5] [7] [8] [9].

2.4. Anybody Model Validation

The biomechanical simulation software Anybody is one of the few software packages in the market that can simultaneously handle kinematic, inverse dynamic data, and musculoskeletal biomechanics [10]. It utilizes three-dimensional dynamics to convert human skeletal muscles into material models related to density and strength, forming a human body simulation model [11]. In this study, kinematic data of human motion was captured using high-speed cameras, and the kinematic data of markers were obtained through SIMI Motion 10.0. The XMP format files were then converted into C3D format files. C3D files are internationally recognized binary storage files for motion capture data. These C3D files, along with external constraints on the human body, were imported into the Anybody software for kinematic and inverse dynamic analysis to derive biomechanical indicators [12]. Previous research in this area has found that high-speed camera-captured kinematic parameters in simple movements are more accurate in simulation than those captured using infrared motion capture [13]. Infrared motion capture with Mark points can affect the performance of the subjects, and the Mark points pasted on the body surface can easily come off. Manual recognition of marker points is precise. The predicted muscle activation curves of the lower limbs after Anybody's inverse dynamic analysis closely match synchronized physiological electromyography curves [14]. Through validation studies conducted by previous researchers on the Anybody model, it is evident that the biomechanical simulation software Anybody provides a high level of realism and accuracy in its simulations.

3. Results

During the athlete's knee lifting and bell-raising stage, the duration was approximately 40 milliseconds, while the force generation stage lasted around 140 milliseconds. Here are the key findings of the study: Vertical Ground Reaction Force (VGRF) in Knee Lifting and Bell-Raising Stage: The VGRF showed a stable and gradual increase during this stage. The average VGRF was measured at 197.6 N/ms. In the sagittal plane, the ground reaction force continued to rise, providing acceleration that moved the athlete's center of gravity forward. Vertical Ground Reaction Force (VGRF) in Force Generation Stage: In the force generation stage, VGRF exhibited a single-peak pattern, with a peak value of approximately 3332.0 N, which is equivalent to 5.5 times the athlete's body weight (BW). This peak occurred at approximately 63% of the force generation phase. The average loading rate during this stage was 158.0 N/ms (**Figure 3**).

During the late phase of the force generation stage, the athlete's lower limbs were in a triple-extension position, with the hip, knee, and ankle joints all reaching their peak forces almost simultaneously (within a time frame of >20 ms). Taking the left foot as an example, here are the peak vertical joint forces and the corresponding values in terms of body weight (BW): Hip: 12376.87 N (equivalent to 20.4 times the athlete's body weight) Knee: −2170.93 N (equivalent to −3.58 times the athlete's body weight) Ankle: 282.81 N (equivalent to 0.47 times the athlete's body weight). The difference in muscle forces between the athlete's two legs was 81.3%. For the left leg, the peak force values for specific muscle groups during this phase were as follows:

Hip Extensor Muscle Group: The peak force occurred at 100% of this phase and had a value of −2630.0 N. Hip Adductor Muscle Group: The peak force occurred at 0%, with a value of −1418.0 N. Hip Abductor Muscle Group: The peak force occurred at 100% of this phase and had a value of −3784.9 N (**Table 3**).

During the knee lifting and bell-raising stage, the forces of specific muscle

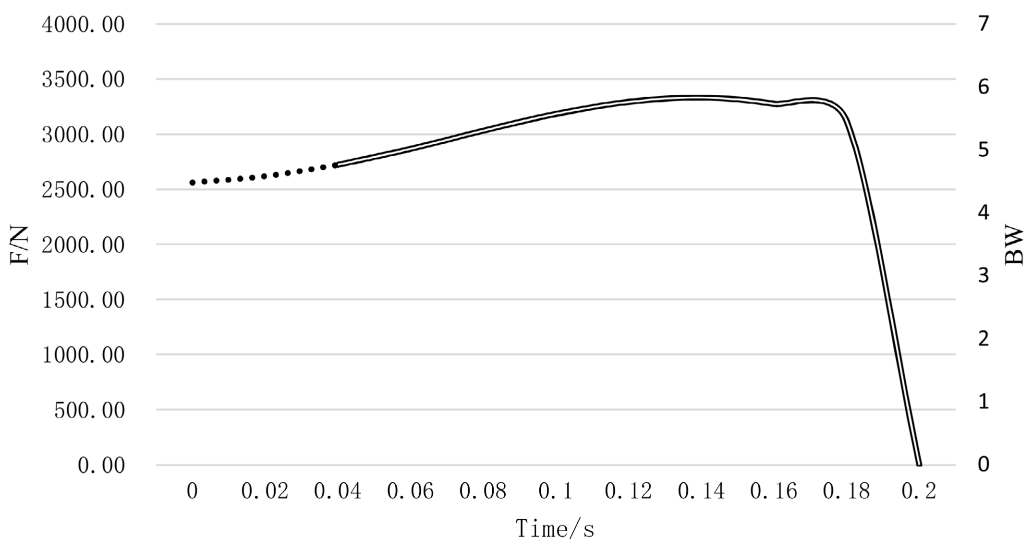

Figure 3. The vertical ground reaction force.

groups exhibited the following trends: Semitendinosus Muscle and Semimembranosus Muscle: These muscles showed an upward trend in force during this stage. Knee Flexor Muscle Group and Quadriceps Muscle: The knee flexor muscle group and quadriceps muscle reached their peak forces at 0% of this stage. After reaching their peak, the knee flexor muscle group exhibited a gradual decrease in force, while the quadriceps muscle decreased rapidly. Hip Flexor Muscle Group: The hip flexor muscle group showed a decreasing trend in force during this stage (**Table 4**).

During the force generation stage, the forces and contributions of specific muscle groups were as follows: Gluteus Maximus Muscle: The gluteus maximus muscle had the highest contribution to hip extension force during the force generation stage, accounting for 45.8% of the hip extensor muscle group's force. The force trends of the gluteus maximus and hip extensor muscle group were highly similar (**Figure 4**), with the peak force of the gluteus maximus muscle accounting for 58.7% of the total. Gluteus Maximus, Fascia Latae Muscle, Rectus Femoris Muscle, Long Head of Biceps Femoris Muscle, Short Head of Biceps Femoris Muscle: These muscles reached their peak forces at 100% of the force generation phase, with force values of −1544.96 N, −297.06 N, −1135.25 N, −536.80 N, and −1050.69 N, respectively. Semitendinosus Muscle and Semimembranosus Muscle: The semitendinosus and semimembranosus muscles reached their peak

Table 3. The vertical joint force and the hip muscle group force.

time (s)	Hip (N)	Knee (N)	Ankle (N)	Hip flexor (N)	Hip adductor (N)	Hip extensor (N)
0	1677.66	−363.42	−12.22	−129.69	−1418.08*	−228.35
0.02	1715.72	−413.09	−6.57	−53.88	−1340.13	−335.17
0.04	1803.34	−569.47	−0.44	−0.01	−1144.46	−503.15
0.06	2122.47	−716.36	3.04	−0.01	−1019.21	−715.80
0.08	2469.30	−854.51	1.41	0.00	−893.83	−888.22
0.1	2976.19	−1019.49	0.61	−18.08	−758.08	−1082.19
0.12	4418.16	−1341.76	−1.41	−177.76	−641.26	−1514.02
0.14	12376.87*	−2170.93*	282.81*	−3784.88*	0.00	−2629.98*

Note: *Represents muscle strength peak.

Table 4. Change in left knee flexor muscle strength.

time (s)	SD (N)	SB (N)	RF (N)	HF (N)	KF (N)
0	0.00	0.00	−409.38*	−1768.83*	−268.62*
0.02	−12.31	0.00	−238.21	−1361.57	−262.64
0.04	−20.29*	−29.83*	−97.81	−889.94	−255.34

Note: *Represents muscle strength peak. SD: Semitendinosus SB: Semimembranosus RF: Rectus Femoris HF: Hip Flexors KF: Knee Flexors.

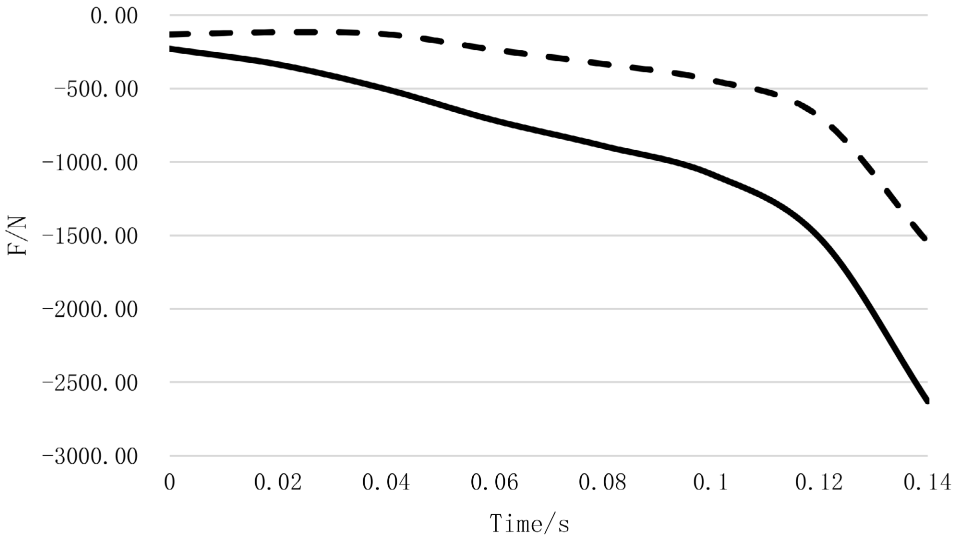

Figure 4. Comparison chart of the left gluteus maximus and hip extensor muscle group on the left side.

forces at approximately 87.5% of this phase, with force values of −216.76 N and 55.43 N, respectively.

4. Discussion

The use of biomechanical simulation software to study the muscle mechanics of weightlifting athletes is not very common in China. Previous research by domestic scholar Bai Xueling [15] used Visual3D to simulate knee joint forces to study the mechanisms related to knee injuries during the snatch. However, previous dynamic studies were limited to the specific requirements of infrared capture instruments and could not analyze the dynamic characteristics of weightlifters during competition moments. This study overcomes the limitations of previous dynamic experiments and research by ensuring the feasibility of high-speed camera capture while performing dynamic analysis on competitive weightlifters. During the knee lifting and bell-raising stage, the key action is the extension of the hip while actively flexing the knee within a short time frame [16]. This knee flexion refers to the rapid bending of the knee joint. In this phase, the Vertical Ground Reaction Force (VGRF) exhibited a stable and gradual increase, and the barbell was in a slow acceleration state. A good measure of a weightlifter's snatch technique is whether the vertical velocity of the barbell's center of gravity can maintain a continuous upward trend during the knee lifting stage [3]. Excellent weightlifters typically show a continuous increase in barbell vertical velocity during this stage [7]. The vertical ground reaction force in the sagittal plane continued to rise, which resulted in a decrease in the distance between the athlete and the barbell. This aligns with the principle of "close" in snatch technique [17]. It also indicates that during the knee lifting and bell-raising phase, the proximity between the barbell and the athlete's center of gravity is achieved not only through active pulling by the upper body but also through simultaneous leg push-off. In the force generation stage, VGRF reached a peak of 3332.0 N (5.5 times the athlete's body weight), which is higher than the typical VGRF peak of 4 - 4.5 BW for weightlifters. Excellent weightlifters can often achieve VGRF peaks exceeding 5 BW. This difference between excellent and average weightlifters lies not only in their technique but also in their strength levels. Excellent weightlifters possess strong explosive power during ground contact [3]. During this phase, the knee flexor muscle group and the rectus femoris muscle reached their peak forces at 0% of this phase, resulting in rapid knee joint flexion, which triggers a stretch reflex in the hip extensor and knee extensor muscle groups [18]. The hip extensor muscle group's force showed a decreasing trend during this phase, effectively inhibiting hip extension force and allowing the subsequent stages to provide sufficient explosive power [19]. This demonstrates that Li Fabin has excellent knee lifting and bell-raising technique.

In the force generation stage, the athlete actively extended the hip and knee to resist the resistance of the barbell. Due to the buffering and shock-absorbing function of the musculoskeletal system, the peak forces in the hip, knee, and ankle vertical joints and VGRF peaks were delayed by approximately 40 ms in excellent weightlifters [13].

In the force generation stage, there was an 81.3% difference in muscle force between the right and left legs (right lower limb force/left lower limb force). Muscle force imbalance between the right and left legs can result in differences in the forces applied to the barbell, causing small lateral deviations in the barbell's center of gravity and affecting the quality of the lift [13]. The hip adductor muscle group's force peaked at 0%, increasing the hip adduction angle and reducing the resistance arm. The hip extensor muscle group and hip abductor muscle group showed an upward trend during this phase and reached their peak forces at the end of the phase, with these muscle groups contributing to the maximum barbell velocity [20] [21]. The gluteus maximus muscle, as the "main muscle" in the hip extensor muscle group, exhibited a force change pattern similar to that of the hip extensor muscle group throughout this stage. The gluteus maximus muscle's force accounted for an average of 45.8% of the hip extensor muscle group's force, increasing to 58.7% when the hip extensor muscle group reached its peak force. This indicates that the gluteus maximus muscle is highly activated and has the greatest force potential. The peak force of the semitendinosus muscle and semimembranosus muscle occurred approximately 22.5% earlier than most hip extensor muscle peaks, increasing the work distance and driving hip extension [22]. Therefore, Li Fabin possesses significant explosive power, and his excellent technique allows him to apply a large amount of explosive force to the barbell to achieve rapid peak barbell velocity.

5. Conclusions

1) The Vertical Ground Reaction Force (VGRF) reached its peak at 63% of the force generation phase, with a value of −3332.0 N (5.5 times body weight, BW).

Excellent athletes can generate ground reaction forces of up to 5.5BW during the force generation phase. Lower limb training should emphasize hamstring training while focusing on proper technique to reduce the resistance arm and apply force to the ground effectively.

2) During the knee lifting and bell-raising phase, athletes intentionally approach the barbell, and the vertical ground reaction force in the sagittal plane continues to increase. Knee flexor force significantly increases during this phase. Training processes should not overlook the importance of short-term explosive training for the knee flexor muscle group and stability training for knee joint control.

3) In the force generation stage, the peak forces of the semitendinosus and semimembranosus muscles occur approximately 22.5% earlier than most hip extensor muscle peaks, facilitating increased hip extension power. The gluteus maximus muscle exhibits a similar force trend to the hip extensor muscle group, and as both force values increase, the contribution of the gluteus maximus muscle to the hip extensor muscle group also rises. For heavy weightlifting (1 - 3 RM), emphasis should be placed on activating the gluteus maximus muscle. There is an 81.3% difference in muscle force between the left and right lower limbs. Muscle force imbalance between the left and right sides is closely related to the success rate of the snatch. Coaches and athletes should pay attention to the imbalance in muscle force between the left and right lower limbs, which can lead to lateral deviations in the barbell's center of gravity during training and competition.

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Conflicts of Interest

The authors declare no conflicts of interest.

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