ISSN 2618-1576 Vol. 7, Issue 1: 30-39, DOI: 10.25236/FSR.2025.070105

Exploration of the Triple Extension Pattern of Hip, Knee, and Ankle in the Squat Snatch: Analysis of Hip Joint Motion Trajectories in Elite Chinese Weightlifters

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Abstract: *This study employs video analysis technology in an exploratory approach to further investigate the tracking of hip joint motion trajectories, building upon existing research on joint angles and barbell trajectories. By analyzing the hip joint motion trajectories of three Olympic champion-level Chinese athletes during the squat snatch, it was observed that the hip joint follows a mirrored "S" shaped movement pattern in the first three phases of the squat snatch. Specifically, during the second pull phase, the hip joint exhibits a characteristic motion pattern of first descending and then ascending. By tracing the dynamic changes in hip, knee, and ankle joint angles, this paper delves into the mechanisms of hip descent. Furthermore, combined with barbell trajectory analysis, it investigates the variation in hip vertical displacement amplitude among athletes with different technical profiles under varying loads. The findings indicate that a moderate hip vertical displacement significantly enhances technical efficiency and athletic performance in the squat snatch. However, the relationship between vertical displacement amplitude and load is influenced by the athlete's technical style, exhibiting distinct characteristics.*

Keywords: *Squat snatch, Video analysis, Kinematics*

1. Introduction

The squat snatch is a complex weightlifting movement requiring precise coordination of the joints and musculoskeletal system. It involves full-body coordination, engaging nearly all muscle groups to stabilize and execute the lift. The squat snatch relies heavily on the explosive power of the legs to rapidly lift the barbell from the ground to an overhead position. The triple extension movement in the squat snatch effectively reflects the characteristics of vertical jumps, which cannot be fully replicated by other exercises. Therefore, the squat snatch is not only crucial for weightlifters but also highly beneficial for athletes in sports such as sprinting and volleyball, as it aids in improving overall coordination and explosive power.

In the squat snatch, the trajectory of the hip joint provides an intuitive representation of lower limb joint movement patterns and serves as a key kinematic variable. The hip joint is not only the central point for generating and transferring force, but also reveals the details of force production and movement control. Its trajectory determines the path of the barbell and affects the efficiency of force transmission, thereby influencing the success of the lift. An optimized hip trajectory represents the athlete's ability to coordinate the angles of the hip, knee, and ankle joints, enabling more efficient force transmission to the barbell while minimizing horizontal displacement and energy loss. This allows the athlete to utilize the elastic energy generated by the lengthening-shortening cycle to enhance performance [1]. Conversely, a poorly executed hip trajectory can reduce movement efficiency, cause the barbell to deviate from its intended path, and increase the risk of injury.

By conducting an in-depth analysis of the hip trajectory and its variations, this study aims to uncover the details of force generation and movement control in the squat snatch, providing a scientific foundation for technical optimization. This analysis not only enhances athletic performance but also reduces injury risks caused by technical errors. The focus will be on optimizing the hip trajectory and exploring its

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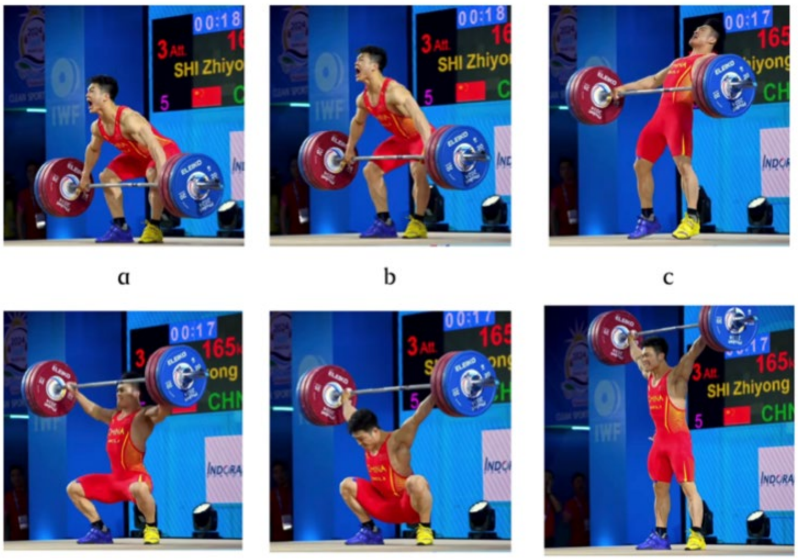
relationship with variations in squat snatch techniques and load, offering empirical evidence for improving squat snatch performance.

The phases of the squat snatch vary between scholars. Some scholars, such as Linfei Dan et al. [2](2023) and Xun Jin et al. [3](2022), classify the movement based on barbell velocity and lower limb joint angles. However, this study adopts the classification proposed by Korkmaz Sezgin [4](2016), which divides the movement into six phases based on the barbell's relative height to the knees: the First Pull, Transition, Second Pull, Turnover, Catch Phase, and Rising Phase.

This study adopts the latter phase classification method for analysis. Since the hip joint trajectory in the final three phases closely resembles that of a squat, the focus of this study is on exploring the hip joint trajectory during the first three phases of the squat snatch.

For a clearer explanation, the first pull represents the initial phase of the snatch, during which the athlete utilizes leg power to lift the barbell from the ground to just below the knees. The transition phase involves moving the barbell from below to above the knees, establishing optimal conditions for the subsequent explosive phase and serving as a bridge between the first pull and the second pull. The second pull is the most force-demanding and fastest phase of the snatch, commencing when the barbell is just above the knees. During this phase, the athlete achieves triple extension of the hip, knee, and ankle joints to lift the barbell from above the knees to abdominal height, while maintaining fully extended elbows. If the elbows begin to bend, the movement transitions into the turnover phase.

This study analyzes images of Chinese weightlifter Shi Zhiyong performing the squat snatch during the 2024 International Weightlifting Federation (IWF) World Cup, providing visual supplementation to the description of the six stages of the snatch outlined above. (Figure 1).



a b c

d e f

Figure 1: a: First Pull phase, b: Transition phase, c: Second Pull phase, d: Turnover phase, e: Catch phase, f: Rising phase.

2. Methods

This study focused on three elite Chinese weightlifters, all Olympic gold medalists - two males (A, B) and one female (C), analyzing the characteristics of their hip joint trajectories under maximum load (final attempt, 1RM) and sub-maximum load (first attempt) conditions. The videos used in this study were obtained from the website "All Things Gym", a platform offering extensive resources and analyses on weightlifting and strength training [5, 6, 7]. The analysis was limited to the squat snatch movement from the First pull to the Catch Phase to avoid interference from trajectory overlap during the Rising Phase, thus enhancing data accuracy. The First Pull, Transition, and Second Pull phases were distinguished using red, yellow, and blue line segments, respectively.

The study utilized Tracker motion analysis software to process video footage of the athletes' squat snatch technique, tracking hip joint movement and exporting raw coordinate data to plot the hip joint

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trajectory. Given the specific nature of weightlifting movements, the barbell might obscure the surface markers of the hip joint in the frontal-lateral view. Therefore, video footage captured from a 45-degree rear-lateral perspective was used for trajectory analysis, rather than from the 45-degree front-lateral perspective or the frontal-lateral view as shown in the phase division diagram above. However, the angle between the camera and the athlete's body resulted in approximately 70% compression of the coordinate length along the X-axis. To correct this bias, additional reference was made to the hip joint trajectory data from the frontal-lateral view. Missing key points in the frontal-lateral trajectory data, due to the occlusion of surface markers, were reasonably estimated and supplemented based on the overall motion trend. The frontal-lateral trajectory data were primarily used for proportional correction and served as a reference for further analysis.

To explore the mechanism underlying hip joint trajectory formation, the study employed Tracker software to calculate the angle variations of the hip, knee, and ankle joints, generating joint angle-time curve graphs. While the camera angle relative to the lateral view caused acute angles to appear smaller and obtuse angles to appear larger, this had no practical impact on the trends of angle variation analyzed in this study. Additionally, the athletes' barbell trajectories were tracked to determine their squat snatch technique types, providing a more comprehensive basis for analyzing and discussing trajectory characteristics.

3. Results

Using the lateral view video of Athlete A as a reference, the hip joint trajectory was plotted. It was observed that during the first three phases of the squat snatch technique, the overall hip joint motion exhibited a mirrored "S" shape pattern. (Figure 2).

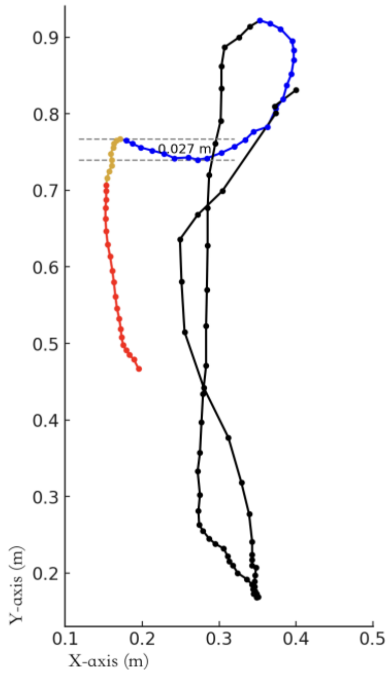

Figure 2: Hip Joint Trajectory in Frontal-Lateral View

At the beginning of the second pull phase, the hip joint trajectory of all athletes initially showed a slight descent, followed by an accelerated ascent. A comparison of the snatch attempts under different weight conditions for the same athletes revealed that Athlete A and Athlete C exhibited significantly greater hip joint vertical displacement during submaximal snatches compared to maximal snatches. In contrast, Athlete B demonstrated an opposite trend, with a greater vertical displacement amplitude observed during maximal snatches. (Figures 3, 4, and 5).

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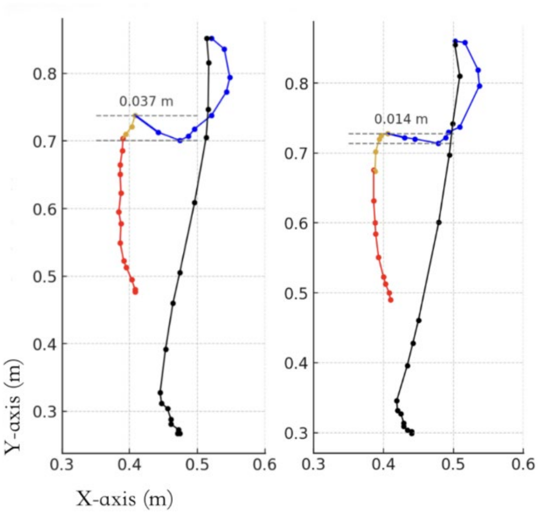

Figure 3: Hip Joint Trajectory of Athlete A – Sub-Maximum Load (Left) vs. Maximum Load (Right)

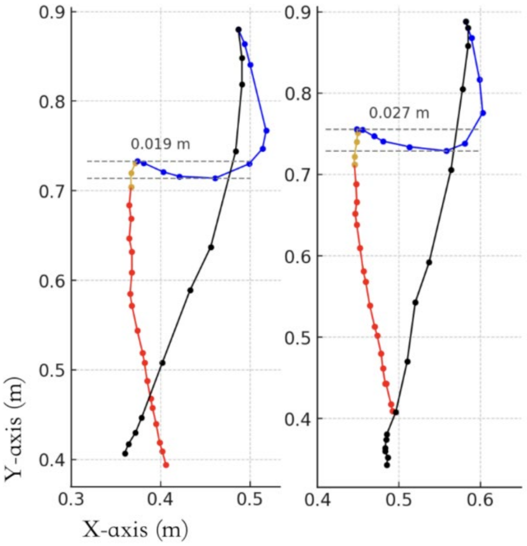

Figure 4: Hip Joint Trajectory of Athlete B – Sub-Maximum Load (Left) vs. Maximum Load (Right)

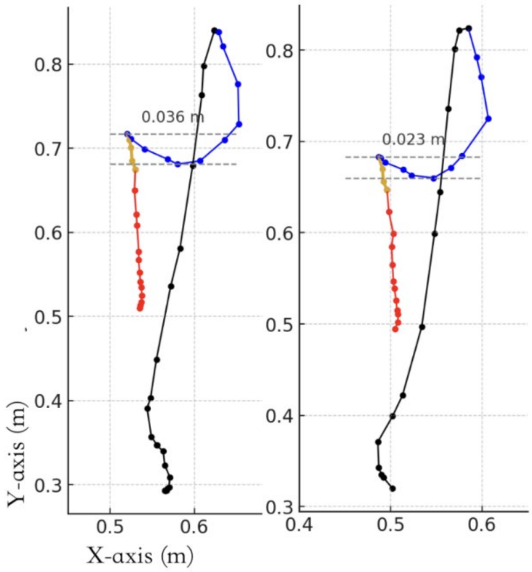

Figure 5: Hip Joint Trajectory of Athlete C – Sub-Maximum Load (Left) vs. Maximum Load (Right)

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In the angle variation graphs of the hip, knee, and ankle joints during the first three phases of the squat snatch, this study uses triangles to represent the hip joint angle (the angle between the thigh and torso), crosses to represent the knee joint angle (the angle between the thigh and calf), and circles to represent the ankle joint angle (the angle between the calf and toes). Additionally, to facilitate phase analysis, the different stages in the angle variation graphs are distinguished using the same color scheme as the hip joint trajectory graphs (Figures 6, 7, and 8).

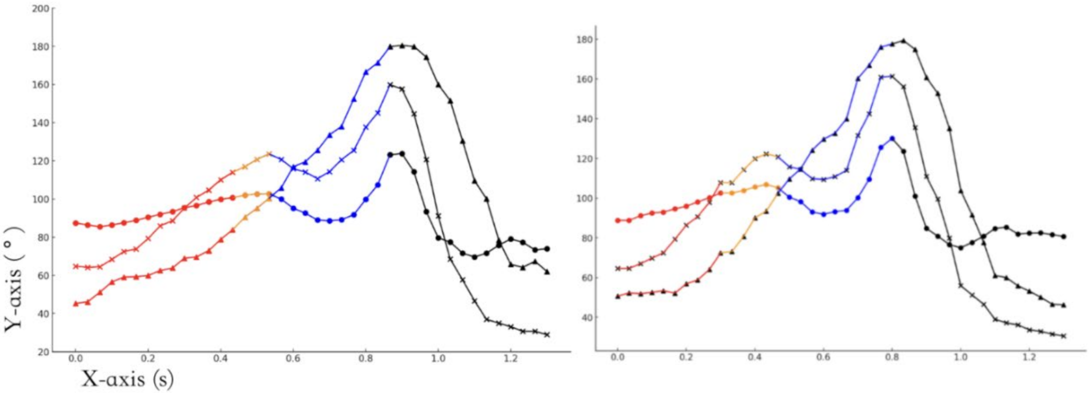

Figure 6: Angle Variation of Hip, Knee, and Ankle Joints for Athlete A – Sub-Maximum Load (Left) vs. Maximum Load (Right)

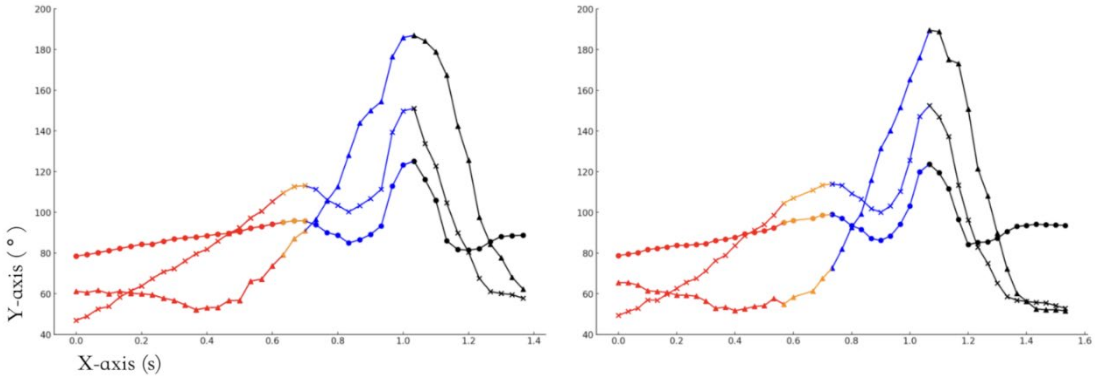

Figure 7: Angle Variation of Hip, Knee, and Ankle Joints for Athlete B – Sub-Maximum Load (Left) vs. Maximum Load (Right)

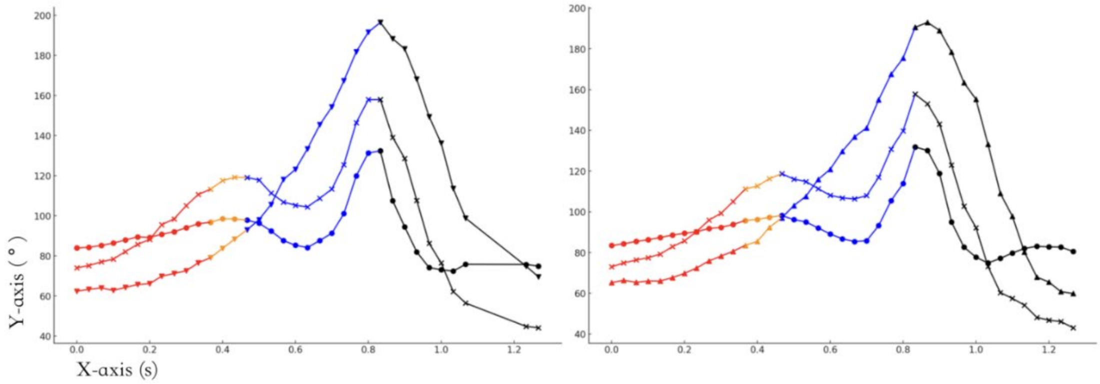

Figure 8: Angle Variation of Hip, Knee, and Ankle Joints for Athlete C – Sub-Maximum Load (Left) vs. Maximum Load (Right)

By observing the line graphs, it was found that all athletes exhibited an “extension-flexion-extension” movement pattern during the first three phases of the squat snatch. Additionally, during this phase, athletes A and C maintained an extension pattern at the hip joint throughout, while athlete B showed a “flexion-extension” movement pattern at the hip joint. To further quantify the flexion amplitude of the

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three joints during the Second Pull phase and its relationship with the hip joint dip, this study presents the specific values for the changes in flexion angles and the corresponding trajectory dip distances (Table 1).

Table 1: Changes in Joint Flexion Angle and Corresponding Dip Distance

Athlete	Load	Ankle Joint Flexion	Knee Joint Flexion	Hip Joint Flexion	Dip Distance
A	Sub-Maximum	13.6°	11.4°	--	3.7cm
	Maximum	11.4°	10.7°	--	1.4cm
B	Sub-Maximum	11.0°	12.9°	9.6°	1.9cm
	Maximum	12.7°	13.9°	13.8°	2.7cm
C	Sub-Maximum	14.4°	14.7°	--	3.6cm
	Maximum	12.8°	12.4°	--	2.3cm

The barbell trajectories of the three athletes were plotted and overlaid with a vertical reference line corresponding to the barbell's initial position, resulting in a barbell trajectory diagram (Figure 9). This diagram provides a basis for analyzing and identifying the squat snatch technique type utilized by each athlete.

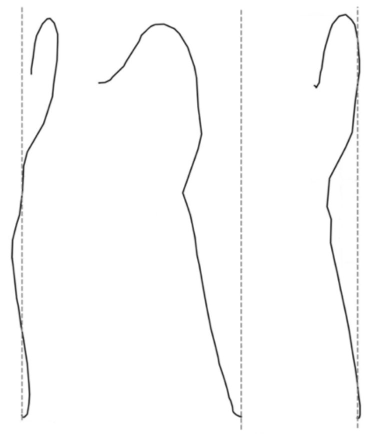

Figure 9: Barbell Trajectory Graphs – Athlete A (Left), Athlete B (Middle), Athlete C (Right)

The comparison results indicate that Athlete B's barbell trajectory distinctly exhibits a backward shift in the center of mass, with the barbell no longer intersecting the vertical reference line after being lifted. In contrast, Athletes A and C strive to maintain a vertical bar path, with the barbell trajectory intersecting the vertical line multiple times.

4. Discussion

Based on the research findings above, it was observed that all athletes demonstrated hip joint vertical displacement during the second pull phase of the squat snatch technique. To explore the underlying mechanisms, a further analysis of the joint angles of the hip, knee, and ankle during the squat snatch was conducted to investigate the causes and significance of the hip joint descent. Regarding the relationship between vertical displacement of the hip joint and weight variation, Athletes A and C exhibited opposite trends compared to Athlete B. To identify the causes of these differences, this study combines the barbell trajectory diagrams of the three athletes to explore the relationship between squat snatch technique, hip joint descent, and the variation in weight.

The following sections will discuss in two parts: the causes and significance of the hip joint descent, and the reasons for the differences in the relationship between hip joint vertical displacement and weight variation.

4.1. Mechanism of Hip Joint Descent

Through the analysis of hip joint motion trajectories and joint angle data, it was observed that during the Second Pull phase of the squat snatch, the hip joint typically experiences a slight drop of 1-3 cm before entering triple extension to drive the barbell upward. This phenomenon is primarily related to the

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movement patterns of the knee and ankle joints. Unlike the continuous extension observed in the hip joint, the knee and ankle joints exhibit distinct movement patterns during the first three phases of the squat snatch, characterized by “extension-flexion-extension” and “plantarflexion-dorsiflexion-plantarflexion,” respectively. At the beginning of the Second Pull phase, both joints demonstrate flexion angles greater than 10 degrees.

Further joint angle analysis reveals that the greater the knee and ankle joint flexion, the larger the drop of the hip joint. The brief vertical displacement of the hip joint serves the following three purposes: adjusting the COG, preparing for force storage, and optimizing the force generation structure.

4.1.1. Adjusting the COG and Maintaining the Vertical Barbell Path

From a biomechanics perspective, the slight vertical displacement of the hip joint optimizes the mechanical relationship between the body and the barbell. After the First Pull phase, the body’s COG shifts toward the heels. As the hip joint moves forward and slightly descends, it effectively repositions the COG toward the midfoot, providing a stable foundation for the Second Pull phase. Additionally, due to the fixed length of the upper limbs, athletes need to lower the hip joint to bring the COG down, ensuring the shoulders are directly above the barbell and keeping the barbell close to the body. This adjustment not only helps to improve stability but also significantly enhances movement efficiency by concentrating force in the vertical direction.

4.1.2. Triple Extension Preparation and Coordinating Lower Limb Angles

The vertical displacement of the hip joint can be regarded as a preparatory movement for the triple extension phase. This movement not only facilitates the storage of elastic potential energy in the muscles but also ensures the optimal positioning of the body, allowing for maximal force production during the subsequent extension phase. This mechanism is analogous to the squat phase that precedes the take-off in a standing long jump. During the end of the transition phase and the beginning of the Second Pull, the ankle joint slightly dorsiflexes while the knee joint simultaneously flexes moderately. The associated extensor muscles quickly elongate, storing elastic potential energy passively. During the subsequent triple extension phase, these muscles release their elastic potential energy, significantly enhancing explosive power and completing a lengthening-shortening cycle.

Furthermore, during the first pull phase, the knee and ankle joints have already undergone some extension and dorsiflexion. Within their range of motion, the remaining extension angles are insufficient to generate enough force to lift the barbell. Therefore, knee flexion and ankle dorsiflexion, which drive the hip joint descent, allow the muscles to reach the optimal muscle length before triple extension, creating greater space for force production and ensuring smooth energy transfer.

4.1.3. Optimizing Force Transfer during Triple Extension

In the First Pull phase of the snatch, the quadriceps primarily generate the force to lift the barbell. During the Second Pull, the vertical displacement of the hip joint aids in redistributing the force output, positioning the load and center of gravity over the midfoot, rather than slightly anteriorly. Thus, enhancing the contribution of the hip joint while reducing the load on the quadriceps. This process optimizes the distribution of force by adjusting the joint levers, effectively transferring sufficient power to elevate the barbell without increasing energy consumption. Additionally, reducing the load on the quadriceps not only lowers the risk of injury to the knee joint and related muscles but also maximizes the explosive power of the gluteus maximus, further improving overall performance.

4.2. Differential Analysis of Hip Joint Trajectories

Through the analysis of the data for Athlete A and Athlete C, it was found that during the snatch with maximum weight, the amplitude of the hip joint vertical displacement was smaller compared to the snatch with sub-maximal weight. However, Athlete B exhibited the opposite trend in this regard. This may be related to the different snatch techniques employed by the athletes. The following sections will analyze the snatch techniques of the three athletes, using their barbell trajectory diagrams, in order to explore the underlying causes of these differences.

4.2.1. Squat Snatch Technique Classification

Comparing the hip joint trajectory data of Athlete A, C, and Athlete B reveals that Athlete B’s starting hip joint position is significantly lower than that of Athlete A and C. Additionally, the joint angle data indicates that Athlete B exhibits slight hip joint flexion during the first pull phase, relying primarily on the quadriceps for lifting, unlike Athlete A and C, where the hip and knee joints work in synergy.

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To further confirm the technical characteristics of Athlete B, we compared the snatch trajectories of the three athletes with the four mainstream snatch technique models summarized by Cunanan et al. The results show that Athlete A and C follow the “Vertical Bar Path Snatch” (third type of trajectory), where the bar path follows a “far-close-far-close” pattern, crossing the bar’s initial vertical line multiple times. In contrast, Athlete B exhibits the “Backward COG Snatch” (second type of trajectory), where the bar path follows a “close-far-close” pattern, without crossing the bar’s initial vertical line. According to Cunanan et al., 50% of top athletes adopt the third type, and 30% use the second type, both of which are mainstream techniques in international snatching.[8]

The above characteristics indicate that Athlete B exhibits significant differences in snatch technique compared to Athletes A and C, with each employing distinct squat snatch techniques. Based on the features of these two techniques, the following sections will analyze the different mechanisms underlying the relationship between hip joint vertical displacement and load.

4.2.2. Analysis of Hip Joint Vertical Displacement in Vertical Trajectory Technique

In the squat snatch technique with vertical bar path adopted by Athletes A and C, the amplitude of hip joint vertical displacement in the second pull phase is smallest during maximal weight attempts, while it is greater during sub-maximal attempts.

When attempting a maximal snatch weight, any unnecessary adjustments could reduce the efficiency of force transmission. However, as previously discussed, an appropriate hip joint vertical displacement is crucial for the second pull. In the vertical trajectory squat snatch technique, the primary goal is to minimize horizontal displacement of the bar, allowing it to rise vertically. Excessive vertical displacement of the hip joint causes the body’s COG to shift backward. Although the hip joint moves forward during the descent, the extent of this movement is limited by the knee and ankle joint flexion and plantarflexion that drive the hip joint descent. An excessive vertical displacement is compensated by a greater extension of the hip joint, resulting in an upright torso and a backward shift of the COG. This increases horizontal displacement from the vertical optimal path and reduces movement efficiency. Therefore, the heavier the squat snatch attempt, the more important it is to carefully control the vertical displacement of the hip joint, ensuring that the vertical displacement is sufficient to meet the preparatory demands for triple extension without causing any adverse effects.

The vertical trajectory squat snatch technique heavily relies on the quadriceps. This is because the contraction of the gluteus maximus leads to violent hip extension, which transmits force forward, causing the bar to deviate from the body. On the other hand, the quadriceps, by extending the knee, help maintain the vertical rise of the body, with the force being transmitted vertically upward, minimizing horizontal displacement of the bar and adhering more closely to technical requirements. Therefore, a smaller vertical displacement of the hip joint helps reduce the involvement of the gluteus maximus, allowing the quadriceps to function more directly.

4.2.3. Analysis of Hip Joint Vertical Displacement in Backward COG Technique

Athlete B’s backward COG technique demonstrates a different pattern: the hip joint descent is largest during maximal weight attempts, while it is smaller during sub-maximal attempts.

In this technique, the key to the second pull phase is the hip joint extension, which drives the body’s COG backward, fully utilizing the explosive power of the posterior chain. To enhance hip extension, the athlete needs to significantly increase the hip joint descent to complete a more effective lengthening-shortening cycle. Analysis of the hip, knee, and ankle joint angles for Athlete B shows that the “flexion-extension” movement pattern of the hip joint in the second pull phase adds extra hip extension in triple extension, optimizing the gluteus maximus’ lengthening effect and contributing to greater force generation in the hip.

Full extension of the hip joint does help the bar move vertically relative to the body. As the COG shifts backward, the body tends to “lie back,” and this position allows the bar to rise along the vertical plane. Excessive quadriceps involvement would cause the bar to move backward with the body, which does not align with the goal of increasing the bar height in the snatch. Greater activation of the gluteus maximus during the lift can drive the barbell forward during the triple extension phase, counteracting the backward shift of the body’s COG. This ensures that the barbell maintains an upward trajectory rather than moving backward. This distinguishes the backward COG technique from the vertical trajectory technique. Since the backward COG technique relies more on the explosive power of the gluteus maximus, athletes in this technique will significantly increase the hip joint descent during maximal weight attempts to store more elastic potential energy, ensuring a greater explosive force during the triple

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extension phase.

5. Conclusion

This study investigated the hip joint trajectory of weightlifters during the squat snatch from a side-rear view, with a focus on the force structure of the hip, knee, and ankle joints during the triple extension phase. The findings provide valuable theoretical guidance for coaches and athletes. Specifically, the study highlights the role of hip joint trajectory changes, particularly the descent during the second pull phase, in reflecting the efficiency of force transmission and COG adjustment during the snatch. These changes also serve as an indicator of whether the force structure is optimized and mechanically sound.

Furthermore, the study explores the relationship between hip joint trajectory and snatch weight. In the vertical bar path snatch technique, most athletes demonstrate a reduced hip joint descent during maximal weight attempts. This reduced descent is beneficial as it aids in optimizing the snatch technique by storing elastic potential energy, which enhances explosive power, and by improving the mechanical relationship between the gluteus maximus and quadriceps. This results in increased activation of the quadriceps and knee joint, contributing to a more efficient vertical bar path. In contrast, athletes using the backward COG snatch technique exhibit a larger descent in the hip joint during maximal weight attempts. This greater descent facilitates the lengthening-shortening cycle of the gluteus maximus, thereby maximizing explosive force during the triple extension phase, which ultimately enhances snatch performance.

6. Practical application

By analyzing the barbell trajectory and hip joint motion trajectory, this study provides theoretical support for personalized guidance in sports training. In actual training, coaches and athletes can use the hip joint trajectory to assess the technical movements and potential of each athlete. Coaches can observe the amplitude of hip joint descent to determine whether the athlete has reached their limit, allowing them to adjust the training plan accordingly, prevent injury, and enhance performance. Additionally, by analyzing the hip joint trajectory changes corresponding to the squat snatch technique employed by the athlete, coaches can determine whether adjustments to the training strategy are needed. If abnormal hip joint trajectories are observed, it serves as a reminder for coaches and athletes to adjust the force generation pattern, modify the hip and leg force structure, and strengthen the training of specific muscle groups. Additional considerations should be acknowledged such as athlete anatomical structure and snatch technique.

7. Limitations

Due to the limitations of the Tracker video analysis software, which cannot generate the complete barbell trajectory and only displays displacement data along the X and Y axes, this study utilized Chat-GPT for data analysis to generate the barbell trajectory. During the tracking process with Tracker, some tracking points failed due to factors such as clothing folds and lighting changes, requiring manual analysis, which may introduce slight deviations.

The video analysis in this study was conducted from a 45-degree rear-side angle, whereas most research analyses use front-side 45-degree or lateral views. The sample size in this study is relatively small, limiting the persuasive power of the findings. Additionally, this study did not fully account for individual differences such as arm length and torso proportions, which may introduce bias into the results. Future research will seek opportunities for collaboration with a professional weightlifting team to increase the sample size and better account for individual athlete differences, thereby enhancing the scientific rigor and generalizability of the results.

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