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Kinematic Characteristics of Snatch Techniques in an Elite World-Record Holder of Weightlifting: A Case Study

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Abstract: Aim: This study aimed to analyze the kinematic characteristics of snatch techniques in a world-class weightlifter who holds the world record in the 73 kg category. Methods: Two high-speed cameras (Sony, Tokyo, Japan, 25 Hz) were used to collect kinematic data at the 2019 Weightlifting World Championships. The SIMI° motion capture system (Simi Reality Motion Systems GmbH, Munich, Germany, 50 Hz) was used to analyze the snatch performance. Results: The lower limb movement during the first pulling stage showed a similar trajectory to elite weightlifters. The athlete showed 5.62° of knee flexion along with continuously increasing barbell velocity (maximal velocity up to 1.90 m/s) in the second pulling. Considering the perimeters of technical stability, the maximal value of the distance between the center of gravity of the human body and that of the barbell was 17.20 cm after the second pull. In addition, the barbell center simultaneously shifted 7.00 cm to the right. Conclusions: These results suggest that the world-record weightlifter possesses special technical characteristics. This personalized technical model provides basic information for the training of other elite weightlifters.

Keywords: elite athlete; snatch techniques; kinematic; performance; weightlifting

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Citation: Cao, W.; Dan, L.; Yan, J.; Li, J.; Liang, Z. Kinematic Characteristics of Snatch Techniques in an Elite World-Record Holder of Weightlifting: A Case Study. *Appl. Sci.* **2022**, *12*, 9679. https://doi.org/10.3390/app12199679

Academic Editors: Sungchan Hong and Byungjoo Noh

Received: 7 September 2022
Accepted: 25 September 2022
Published: 27 September 2022

1. Introduction

Weightlifting has been part of the Olympics since the 1896 Olympic Games in Greece [1,2]. The winner of the Olympic Games and the Weightlifting World Championship is commonly considered to possess the highest level of strength and skill [3]. Analyzing the techniques of the winner would produce a considerable impact on the competitive training of weightlifters. Compared with the clean and jerk, snatch has been regarded as a technical way of lifting weights. Numerous studies using a variety of biomechanical methods have conducted technical analyses on snatch [4–7], amongst which kinematics analysis is one of the most important methods [8].

Today, the kinematic analysis of snatch mainly applies a series of parameters to analyze the weightlifting performance, such as the tracking of the barbell center of gravity, the human center of gravity, the distance between the human center of gravity, and that of the barbell and the angle of the lower limb joints [9]. Previous studies, using the Cartesian coordinate systems, successfully revealed the relationship between the maximum height of the barbell, the maximum velocity of the barbell, and the success rate of the snatch attempts [9]. Many studies adopting kinematics methods have successfully analyzed the snatch performance [9–11] and the maximum mass of the snatch [12–14]. For instance, Hasan et al. and Leslie et al. adopted two-dimensional videos to measure the trajectory of the barbells and found that the horizontal displacement of the barbells of elite weightlifters could be divided into the following three movement patterns: Type1 (most energy-efficient pulling pattern), Type2 (relatively stable pattern), and Type3 (least desirable pulling pattern) [5,15].

Some unavoidable deficiencies were encountered despite the promising results of the aforementioned studies for the improvement of weightlifting competitive performance. For example, elite weightlifters had strikingly individual variations of the snatch technique. The authors of the most previous studies overlooked these differences while analyzing the technical analysis of snatch. Thus, conducting technical analysis of elite weightlifters is remarkably meaningful for the practice and training of athletic weightlifting. This study aimed to investigate the technical characteristics of the 2019 Weightlifting World Championship. The world-record weightlifter of this study was analyzed via the three-dimensional motion analysis, and descriptive methods were adopted to confirm the technique characteristics.

2. Materials and Methods

2.1. Participant

The participant of this study is a world-record weightlifter (age: 26 years, height: 1.67 m, weight: 73 kg, BMI: 26.18 kg/m^2) He has won in the Olympics, is a world champion in the men's 73 kg snatch, and has also set 10 world records. He volunteered to take part in this study. The weightlifter signed the informed consent before data collection. This research was approved by the ethics committee of the Research Academic of Grand Health Ethics Committee (RAGH20160318).

2.2. Protocol

The kinematic analysis for snatch was executed at the 2019 World Weightlifting Championships in Pattaya, Thailand. Two SONY DCRHC52E (Sony, Tokyo, Japan) cameras captured the video for whole-body snatch performance. A peak 3D calibration framework was established using the 3D space coordinates of the competition venue on the weightlifting platform. A 3D motion analysis system was then used to analyze kinetic performance. All staff were forbidden to talk to the weightlifter to avoid interfering with his optimal performance during the competition.

2.3. Motion Capture

The equipment for motion capture included two cameras placed 15 m away from the lifting platform to capture the snatch performance, and these cameras were fixed at 45° of the left and right sides of the lifting platform. The two cameras maintained a focal length, with a synchronous collection of the complete snatch movements of the weightlifter. The camera position, focal length, and other capturing conditions were maintained during the calibrated shot process (Figure 1).

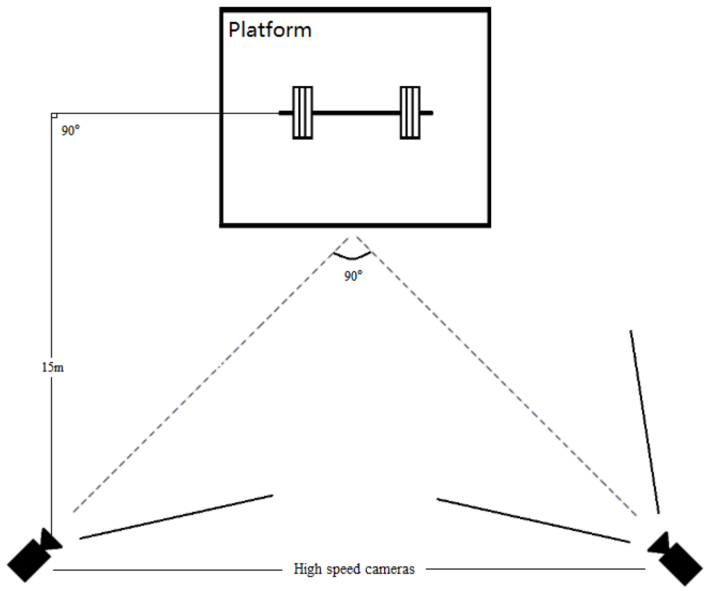

Figure 1. Schematic of the motion capture setup with two high-speed cameras.

2.4. Analysis of the Snatch Performance

The video of the third snatch technique of the weightlifter was analyzed using a SIMI°-motion 7.5 3D motion software (Simi Reality Motion Systems GmbH, Munich, Germany). The sampling frequency was 50 Hz, and the low-pass filtering method was 6 Hz and used to smooth the original data. DLT was also utilized to calculate the spatial coordinates [16]. The X-, Y-, and Z-axes of the 3D coordinate system were the sagittal, coronal, and vertical axis directions, respectively.

The biomechanical model of the weightlifter was built from the SIMI°-motion 7.50 3D software, which requires the establishment of 17 motion centers of human joint links. These markers were manually determined frame-by-frame. These markers included the following: head (midpoint of the line connecting the left and right acoustic meatus), left shoulder, right shoulder (the upper arm including the acromion as spherical geometry; its center is approximately defined as the shoulder motion center), left elbow, right elbow (distal humerus medial/lateral epicondyle), left wrist, right wrist (horizontal midpoint of styloid process height), left hip, right hip (vertex of greater trochanter), left knee, right knee (femoral medial/lateral epicondyle), left ankle bone, right ankle bone (fibula lateral condyle or medial malleolus), left toe-tip, right toe-tip, and left and right endpoints of the barbell (Figure 2). The joint angle consisted of the relative angles of two adjacent segments, which is consistent with the study by Liu et al. [16]. The center of gravity, barbell center of gravity, joint angle, and joint angular velocity were calculated by the software.

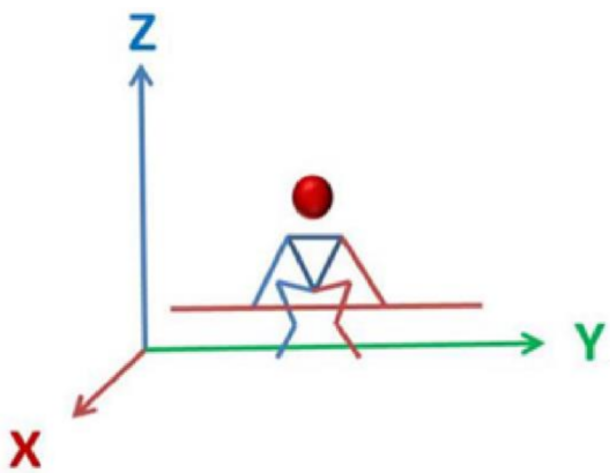

Figure 2. Experimental setup of the three-dimensional motion analysis.

2.5. Movement Phase Division

The snatch phases were divided into six phases according to the barbell trajectory and the angle movement of the extremity limb joints, considering different research purposes [3,4,17,18] (Figure 3).

2.6. Parameter Definition

Spatial and temporal parameters of barbell and the variation of lower limb joints were selected in the current study. Specific variables include the following: time of each stage (DT, s), vertical height of the barbell at the end of each phase (HB, cm), maximal vertical velocity of the barbell in each phase (VB, m/s), flexion and extension angles of the hip (HA, deg), flexion and extension angles of the knee (KA, deg), flexion and extension angles of the ankle (AA, deg), angular velocity of hip joint (HV, deg·s^{-1}), angular velocity of the knee joint (KV, deg·s^{-1}), angular velocity of the ankle joint (AV, deg·s^{-1}), the center of gravity of the human body (CGH, cm), the barbell center of gravity (CGB, cm), distance between the center of gravity of the human body and that of the barbell on the sagittal (DHB-X, cm), and distance of the barbell center on the coronal (DB-Y, cm).

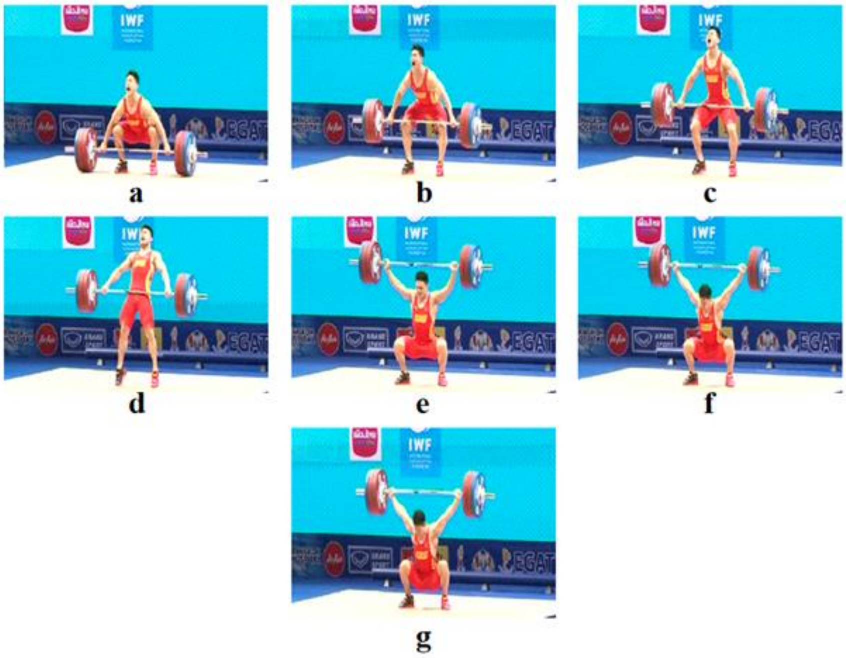

Figure 3. Analysis definition of the phase division in snatch (M1 (**a**,**b**) is from start position to the instant of first maximal knee extension angle; M2 (**b**,**c**) is the instant of the knee angle from maximum to minimum; M3 (**c**,**d**) is from the end of M2 to the maximal vertical rising velocity of barbell; M4 (**d**,**e**) is from the end of M3 to the maximal vertical height of the barbell; M5 (**e**,**f**) is from the end of M4 to the maximal vertical falling velocity of the barbell. M6 (**f**,**g**) is from the end of M5 to squat position).

3. Results

3.1. Vertical Trajectory of the Barbell Center of Gravity

The barbell kinematic data are presented in Table 1. The result demonstrated that the duration times of M1 and M2 were respectively the longest and the shortest (DTM1 = 0.38 s, DTM2 = 0.12 s). The duration time of M3 was 0.16 s and that of M4 was 0.26 s after the first two phases. Considering the parameters of the barbell, the first peak value of HB appeared in M4 (HBM4 = 125.10 cm), and the value of HBM4 accounts for 73.59% of the weightlifter's height. The vertical drop distance of HB was 14.7 cm (HBM4 = 125.10 cm, HBM5 = 110.40 cm) during the M4–M5 stage. VB continuously increased (VBM1 = 1.21 m/s, VBM2 = 1.50 m/s, VBM3 = 1.90 m/s) in the M1–M3 stage. VB increased the first peak value (VBM3 = 1.90 m/s) in the M3 phase. Meanwhile, VB reduced the first valley value (VBM5 = −0.61 m/s) in the M5 phase.

3.2. Angular Change of the Lower Limb

The kinematic data of the three joints of lower limb are presented in Table 2. In the M1 phase, the maximal value of KV was larger than that of HV and AV (HVM1 = $188.78°\cdot s^{-1}$; KVM1 = $215.84°\cdot s^{-1}$; AVM1 = $76.19°\cdot s^{-1}$). The movement of HA maintained a continuous extension (HAM1 = 82.90°, HAM2 = 100.07°, HAM3 = 152.48°) during the M1–M3 stage. However, the movement of KA consistent with AV demonstrated extension–flexion–extension (KAM1 = 108.11°, KAM2 = 102.49°, KAM3 = 147.52°; AAM1 = 106.74°, AAM2 = 101.67°, AAM3 = 137.20°). The M2 phase demonstrated the flexion of joint angles (KAM1-M2 = −5.62°, AAM1-M2 = −5.07°) and a slight decline in joint angular velocity (KVM1-M2 = $-52.24°\cdot s^{-1}$, AVM1-M2 = $-122.22°\cdot s^{-1}$). The angular velocity of the three joints of lower limbs reached the maximum (HVM3 = $409.04°\cdot s^{-1}$, KVM3 = $393.96°\cdot s^{-1}$, AVM3 = $257.55°\cdot s^{-1}$) during the M3 phase. The three joints presented different flexion degrees of angle (HAM4-M6 = 108.34°, KAM4-M6 = 110.68°, AAM4-M6 = 43.62°) and maximal value of angular velocity (HVM4-M6 = $-563.86°\cdot s^{-1}$, KVM4-M6 = $-603.26°\cdot s^{-1}$, AVM4-M6 = $-464.01°\cdot s^{-1}$) during the M4–M6 stage.

Table 1. Kinematic performance of the barbell during the snatch (M1 was from the start position to the instant of the first maximal knee extension angle; M2 was the instant of the knee angle from maximum to minimum; M3 was from the end of M2 to the maximal vertical rising velocity of barbell; M4 was from the end of M3 to the maximal vertical height of barbell; M5 was from the end of M4 to the maximal vertical falling velocity of barbell; M6 was from the end of M5 to squat position. DT is the time of each stage, HB is the vertical height of the barbell at the end of each phase, VB is the maximal vertical velocity of the barbell in each phase, HA the is flexion and extension angles of the hip, KA the is flexion and extension angles of the knee, AA is the flexion and extension angles of the ankle, HV is the angular velocity of hip joint, KV is the angular velocity of the knee joint, AV is the angular velocity of the ankle joint).

Index	Phase					
	M1	**M2**	**M3**	**M4**	**M5**	**M6**
DT (s)	0.38	0.12	0.16	0.26	0.08	0.38
HB (cm)	52.50	68.40	95.80	125.10	121.50	110.40
VB (m/s)	1.21	1.50	1.90	0.00	−0.61	0.00
HA (°)	82.90	100.07	152.48	70.62	51.15	44.14
KA (°)	108.11	102.49	147.52	52.61	43.81	36.84
AA (°)	106.74	101.67	137.20	94.02	93.37	93.58
HV ($^\circ \cdot s^{-1}$)	188.78	295.43	409.04	−563.86	−488.06	−56.85
KV ($^\circ \cdot s^{-1}$)	215.84	−52.24	393.96	−603.26	−230.11	−76.27
AV ($^\circ \cdot s^{-1}$)	76.19	−122.22	257.55	−464.01	114.44	−63.78

Table 2. Technical stability of the snatch (DHB-X is the distance between the center of gravity of the human body and the barbell on the sagittal plane, DB-Y is the distance between the center of gravity of the human body and the barbell center on the coronal plane).

Index (cm)	Movement Phase						
	a	**b**	**c**	**d**	**e**	**f**	**g**
DHB-X	4.90	0.90	6.10	17.20	12.70	5.50	3.00
DB-Y	0.00	4.00	7.00	6.00	1.20	3.00	1.10

3.3. Shifting of the Barbell Center of Gravity

CGB always remained in front of the CGH, and DHB-X maintained a positive value during the entire stage of the snatch (M1–M6) (Figure 4). The value of DHB-X maintained sustained growth and the maximal value appeared in d–e (17.20–12.70 cm) during barbell raising (M1–M4). In another stability parameter of DB-Y, CGB always shifted into the right side and maintained a positive value. The maximal value of DB-Y was 7 cm during the second pull (c–d).

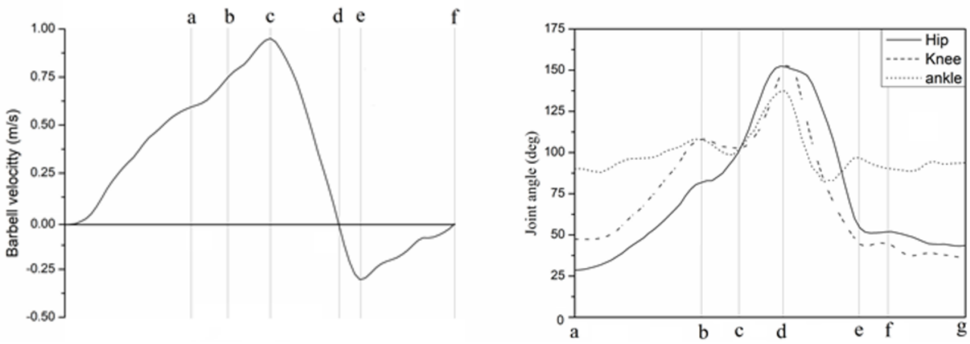

Figure 4. Changes of the velocity of the CGB and the lower-limb joint angle in a different phase (the left plot is the velocity of the CGB at different phases, the right plot is the description of the lower-limb joint angle at different phases).

4. Discussion

This study is the first to use a 3D kinematic technique to analyze the characteristics of snatch for a world-record elite weightlifter in a real competitive environment. The results showed the kinematic characteristics of the technical details in snatch.

4.1. Analysis of the Barbell Centre of Gravity

The weightlifter pulled the barbell from static to moving in the first pull. Thus, additional time is needed for the weightlifter to pull the barbell in the ML phase. As reported, there are two barbell speed curves observed for the elite weightlifter [19]. The first pattern is that the VB continuously increased in M1–M3. Another pattern is that the VB dropped in M2. Compared with the second pattern, the first pattern has more optimized energy consumption through simplification of the weightlifter's body. The VB in the present study is consistent with the first pattern (Figure 3a), this indicates that the successful snatch has maximal energy output and efficiency in the second pull [19]. A previous study indicated that the maximal value of VB decreased when the weightlifter lifted a barbell with the great heavy weight [20]. Elite weightlifters in the maximum vertical velocity are 0.3 m/s faster than the sub-elite group (elite: 1.74 ± 0.10 m/s, sub-elite: 1.44 ± 0.28 m/s) [16]. In the present study, we found that the maximal barbell velocity of the weightlifter reached 1.90 m/s during lifting of the extreme barbell weight, suggesting that the weightlifter most likely has more power capacity than the elite weightlifters in previous studies.

Previous research reported that the first peak value of HB in top-elite weightlifters should reach 70% of the weightlifter's height. In the present study, the weightlifter reached 73.59%, which indicated that the weightlifter could likely snatch additional weight [16]. However, excessively high maximal values of HB may not be conducive to the completion of catch (M5–M6) [21]. A previous study indicated that the drop distance of the barbell in successful snatch attempts was significantly smaller than that of unsuccessful snatch attempts [9]. There were also significant differences between the snatched weight of the barbell and the drop distance of HB (60%RM = 0.24 m, 80%RM = 0.16 m, 100%RM = 0.13 m) [22]. During the present study, results showed that the weightlifter snatch had a shorter drop distance of HB than the lifted 1RM barbell weight. Therefore, the weightlifter should improve the success rate of snatch by reducing the maximal value of HB.

4.2. Analysis of the Lower Extremity

In the first three phases (M1–M3), the angle hip joint maintained continuous extension, and the angular velocity of the hip continuously increased (Figure 3b). A previous study reported that the power of the snatch relied on the coordination of the three joints of the lower limbs [23]. However, the weightlifter demonstrated flexion in M2 (KA c-d = 5.62°). The value of KA generally had a slight flexion between the first and second pulls. Meanwhile, previous research indicated that the KA variation model of the elite weightlifter was extension-flexion-extension in the first three phases (M1–M3) [2]. The purpose of KA flexion during the M2 phase was to reduce the value of DHB-X and improve force efficiency [20]. Thus, the KA flexion is conducive to generate the maximal value of VB. The technique of KA flexion in a previous study was considered to have optimal energy expenditure [24]. The angle of the elite weightlifter and the angular velocity of the three joints of the lower extremity reached the maximum in the second pull (M3) [25].

The maximal values of KA and HA of the weightlifter respectively appeared in the first and second pulls. These results are consistent with previous findings, wherein the first and second pulling were respectively generated primarily by KA and hip extensions [16]. The three joints of the lower extremity should be rapidly flexed in the catch stage (M5–M6), and the elite weightlifter in this study had faster HV than the sub-weightlifters [20]. Therefore, elite weightlifters have a similar model to the three joints of the lower limbs.

4.3. Analysis of the Lower Extremity

DHB-X and DB-Y were crucial factors considering the success rate of snatch [9]. The maximum value of DHB generally occurs at the end of the second pull. This study found that the maximal value of DHB-X was 17.20 cm after the second pull. From a mechanical perspective, the weightlifter should reduce the DB-Y [5]. However, pulling the barbell should be consistent with the biomechanical characteristics of the human body, and the trapezius and bicep muscle arms required certain initial lengths.

Previous studies revealed that the value of DHB-X should be controlled at 10–20 cm for the group of elite weightlifters [9,16,17,26]. Meanwhile, the CGB should be close to the CGH of the weightlifter, which is necessary to maximize the vertical velocity of the barbells. In future practice, training, and competition, the training of the weightlifter should include additional high pulls and maintain the closeness of the barbell center of gravity to the human body. DB-Y, which represents the offset of the barbell at the left and right sides, is a core factor to determine the stability of the snatch technique. The DBY of the weightlifter shifted 7.00 cm to the right in the second pull. This shift may be due to uneven strength of the left and right arms. Thus, the muscle mass on the left and right sides of the weightlifter will be tested in future studies.

5. Limitations

This study has some limitations. This study only represents the technical characteristics of the weightlifter and only had some reference significance to other weightlifters. Notably, the limitation of the individual case study of the top-elite weightlifter is its unnecessary applicability to all weightlifters. Second, we did not measure the data on human morphology, which leads to some interesting technique points that cannot be clearly interpreted. This would be further investigated in our future study.

6. Conclusions

This study aimed to provide individual technical characteristics using the 3D kinematics method to analyze a world-record weightlifter during a real competition. The results showed that the lower-limb joints of the elite weightlifter in the first three phases have a similar motion pattern of extension-flexion-extension, and the maximum values of DHB-X and VB were 17.20 and 7.00 cm, respectively. However, the VB was relatively faster than in the second pulling. Thus, the performance of VB and HB are a key index to show the ability of the weightlifter to snatch substantially heavy barbells. Notably, all of these results indicate that world-record weightlifters possess unique technical characteristics. Therefore, to scientifically train elite weightlifters, personalized technical models should be adopted.

Author Contributions: Data curation, W.C. and L.D.; formal analysis, J.L.; funding acquisition, J.L. and Z.L.; investigation, L.D.; methodology, W.C.; resources, Z.L.; writing—original draft, L.D., J.Y. and Z.L.; writing—review and editing, J.Y. and Z.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and was approved by the Research Academic of Grand Health Ethics Committee (RAGH20160318).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. The athlete provided written informed consent to publish this paper.

Acknowledgments: We are thankful to the elite professional weightlifter who took part in this study and for his efforts. We are grateful to the Team China of Weightlifting, Beijing, China for providing the opportunity to conduct analysis and motion capture during a real sports competition.

Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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