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Comparative 3-dimensional kinematic analysis of snatch technique between top-elite and sub-elite male weightlifters in 69-kg category

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Abstract

Objective: The purpose of this study was to determine the differences in technical characteristics between top-elite and sub-elite male weightlifters performing the snatch style in the 69-kg category. The obtained results can provide valuable information for lower level lifters and coaches to achieve better competition performance by altering their training methods accordingly.
Methods: Six top-elite and six sub-elite weightlifters participated in this study. The heaviest successful snatch lift from the three attempts of each subject was analyzed. The video data were recorded under competition conditions at China National Weightlifting Championship and China Olympic Trial, which were analyzed by SIMI°Motion7.50 3D analysis system.

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Results: The results showed that the maximum vertical- and relative vertical height (normalized by athletes' height) of the barbell, the maximal vertical linear velocity and acceleration of the barbell were significantly greater in top-elite lifters ($p < 0.05$). In addition, the flexion angles of the knee joint were significantly greater in top-elite lifters during the first phase and the third phase of the snatch lift. Sub-elite lifters showed less flexion and significantly slower angular velocity in knee joint than top-elite lifters during the second phase of the snatch lift ($p < 0.05$).

Conclusion: The findings of the present study demonstrated the differences in technical characteristics between the two levels. According to these findings, coaches of sub-elite lifters should focus on exercises suitable to the strength characteristics of the first and the third phase of the snatch lift. In addition, the flexor muscles of knee joint among the sub-elite lifters should be strengthened and the ability of generating and utilizing elastic energy during the second phase of the snatch lift should be improved.

Keyword: Physiology

1. Introduction

Male weightlifting is a sport with a long history dating back to being included in the first Olympic Games in 1896. This sport is based on dynamic strength and power, in which two different movements (Snatch and Clean & Jerk) are performed sequentially. The final rank is determined on the total result of the heaviest successful lifts of the two movements. In weightlifting, athletes use their reasonable technique, physical, functional and psychological traits to lift a barbell of maximal weight. Of all weight classes in Olympic weightlifting, only the 69-kg is the category common to both genders. The 69-kg class, which is identified as the category with the greatest depth of lifters from top to bottom is representative of national caliber performance in snatch [1]. The performance pattern of snatch technique requires the barbell to be lifted from the floor to a straight-arm overhead position in a continuous action [2, 3, 4, 5, 6]. In the past four Olympic Games (2004, 2008, 2012, and 2016) Chinese male athletes have won the gold medals in the 69-kg class which provides an adequate ground for our investigation.

The technique of top-elite athletes represents the best performance, and can be considered as excellent technical model or a reference that should be achieved. Previous studies of snatch performance focused mainly on the differences in adult female weightlifters [1, 7, 8], between adult and adolescent males [3], and between genders [4, 9, 10]. They analyzed the kinematic and kinetic parameters by two or three-dimensional methods. However, the lack of data regarding the stability of snatch technique raises questions regarding the appropriateness of using the specific

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assistant exercises for improving the success of the snatch lift. Furthermore, no study was found within the literature that compared the snatch performances between top-elite and sub-elite (lower level athletes) male weightlifters in 69-kg category. Therefore, the purpose of our study was to highlight the differences of technical characteristics between top-elite and sub-elite male weightlifters, to summarize the technical features of top-elite athletes, and to provide valuable information for lower level lifters and coaches to integrate into training and competition.

It was hypothesized that under the condition without considering weight nuances of top-elite and sub-elite weightlifters, the comparative analysis of snatch performances in the 69-kg category would reveal the technical discrepancy between the two levels.

2. Methods

2.1. Subjects

The data were collected during the 2015 men's Chinese National Championship and the 2016 men's Chinese Olympic Trials. The top six place getters at the Olympic were considered to be top-elite athletes in China. These six athletes were members of the Chinese National Weightlifting Team. Between them, they had won three Olympic Games gold medals, two World Championships gold medals, and one Asian Games gold medal. Athletes ranked from second to seventh at the Chinese Championships (second-tier weightlifting event in China) were considered to be sub-elite athletes. The lifter who won the gold medal was eliminated because he was included within the top-elite group. Data on age, body mass, height, and their best result are shown in Table 1. This study was authorized by the Ethics Committee of Zhejiang College of Sports. Before taking part in the study, all subjects were informed of the objectives, experimental procedures and risks associated with this study. All subjects gave consent to participate in this study.

Table 1. The characteristics of subjects.

Subjects	Age (y)		Body mass (kg)		Height (m)		Best result (kg)	
	Top-elite	Sub-elite	Top-elite	Sub-elite	Top-elite	Sub-elite	Top-elite	Sub-elite
1	29	23	68.90	68.50	1.71	1.63	158	151
2	23	21	68.58	68.55	1.69	1.58	157	150
3	27	20	68.92	68.71	1.68	1.65	157	147
4	26	23	68.93	68.47	1.70	1.60	156	145
5	27	20	68.92	68.58	1.68	1.70	155	142
6	26	21	68.71	68.93	1.71	1.66	152	141
Mean (SD)	26.33 (1.97)	21.33* (1.37)	68.83 (0.15)	68.62 (0.17)	1.70 (0.01)	1.64* (0.04)	155.83 (2.14)	146.00* (4.10)

*Statistically significant difference ($p < 0.05$).

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2.2. Experimental design

According to comparative method, this study was conducted to determine the differences in technical characteristics between top-elite and sub-elite athletes in male weightlifting for the snatch style. The heaviest successful snatch lifts from three attempts for each subject were chosen for analysis. 3D analysis was carried out to investigate the kinematics of the barbell and angular kinematics of the lower limb. The video data were captured under completion conditions. In video parsing, it is common that body joints are hidden by local limbs or are not visible on the side camera. In this case, it is determined by the estimated method. The staff who processed video data is familiar with human anatomy, and they have more than ten years of experiences in using SIMI°Motion7.50 3D analysis software. These facts guarantee the accuracy of the data.

2.3. Procedures

In order to determine the kinematic parameters of the barbell and the lower limb, video and a computerized technique were employed. Two cameras (SONY HDR-FX1000 at 50 Hz) were set up in the horizontal plane, approximately 10 meters away from the subjects. The optical axis of each camera formed an angle of 45° with the frontal plane of the subject (Fig. 1-a). The position and focal length of the cameras remained unchanged during the whole process of snatch lift. The methodology of our study focused on video recording, conversion of video capture into AVI format and the kinematic variables which were analyzed by SIMI°Motion7.50 3D analysis system (Germany). Before the start of the competition, a PEAK 3D framework was used to calibrate the movement space (Fig. 1-b). The spatial coordinates of various points were calculated from the collected video by means of direct linear transformation (DLT) method (Fig. 1-c). The raw position-time data were smoothed by a low-pass digital filter with a cut-off frequency of 4 Hz [4, 10].

Previous researchers have divided the snatch action into six phases, including the first pull, the transition, the second pull, the turnover under the barbell, the catch phase, and the rising from squat position, based on the changes in the direction of

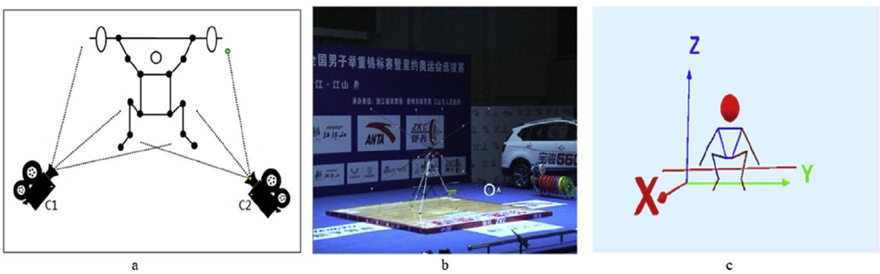

Fig. 1. Experimental setup and 3D coordinate system.

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knee angle and the height of the barbell [2, 5, 10, 11, 12]. The first five phases were considered to be the most important phases of the snatch lift [3, 4, 5, 6]. In the present study, the snatch process (from start position to squat position) was divided into six phases based on the changes in direction of the knee angle, the vertical velocity of barbell, and the vertical height of barbell, as follows (Fig. 2):

1. The first phase (M1, a-b): from start position to the instant of first maximum knee extension angle;
2. The second phase (M2, b-c): the instant of knee angle from maximum to minimum;
3. The third phase (M3, c-d): from the end of M2 to the maximum vertical rising velocity of barbell;
4. The fourth phase (M4, d-e): from the end of M3 to the maximum vertical height of barbell;
5. The fifth phase (M5, e-f): from the end of M4 to the maximum vertical falling velocity of barbell;
6. The sixth phase (M6, f-g): from the end of M5 to squat position.

2.4. Definition of variables

In order to acquire the kinematic parameters during the snatch lifts, seventeen key points on the barbell and the body were selected, which were manually digitized using the SIMI°Motion7.50 3D analysis system. These points included the head (midpoint of the line connecting left and right acoustic meatus), left shoulder, right shoulder (think of the upper arm including acromion as a 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

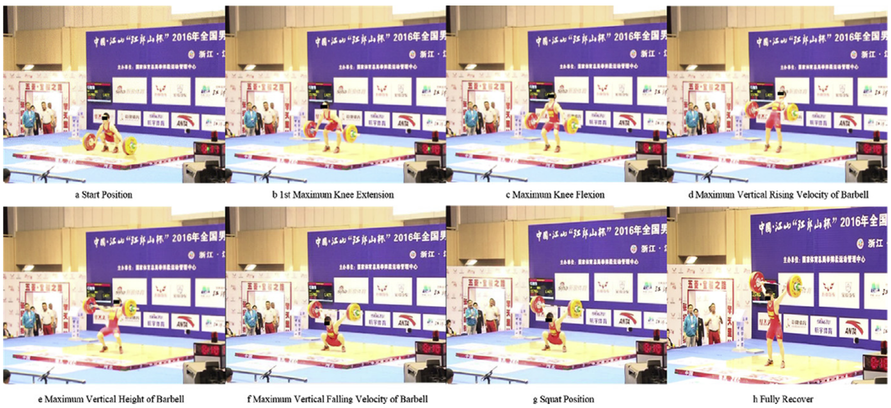

Fig. 2. The characteristic pictures at each phase of snatch lift.

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bone (fibula lateral condyle or medial malleolus), left tiptoe, right tiptoe, left and right endpoints of barbell [13]. COG position of body was calculated using Hanavan Body Mathematical Model in the SIMI°Motion7.50 3D analysis software. COG position of the barbell was obtained by calculating the geometric center from the coordinates of the two endpoints in the SIMI°Motion7.50 3D analysis software.

The present study focused on the snatch technique from the liftoff to the squat position (M1-M6). The choice of parameters were based on theoretical and practical requirements used in training. Our study selected several variables to evaluate the spatial-temporal characteristics of the snatch lift, to analyze kinematic characteristics of the lower body, and to investigate the stability of the snatch technique. Table 2 shows the selected variables.

2.5. Statistical analyses

The hypotheses of normal distribution and homogeneity of variance were analyzed via Kolmogorov- Smirnov and Levene's tests, respectively. Age, body mass, height, best result, relative vertical height of the barbell, and vertical acceleration of the barbell were analyzed using *t*-tests for independent samples. Duration of the phases, stability variables, vertical linear velocity of the barbell, and vertical height of barbell were analyzed by a two-way (level × phase) analysis of variance (ANOVA, repeated measures). The angular kinematics were compared by a two-way (level × joint)

Table 2. Experimental variables.

Symbol (unit)	Definition
M1−M6	Phases of snatch lift
TD (s)	Time of duration
HB (cm)	Vertical height of barbell
HBR (%)	Relative vertical height (normalized by lifters' height) of barbell
VB ($m \cdot s^{-1}$)	Vertical linear velocity of barbell
AB ($m \cdot s^{-2}$)	Vertical acceleration of barbell
KA (degree)	Angle of knee joint
KAV ($deg \cdot s^{-1}$)	Angular velocity of knee joint
HA (degree)	Angle of hip joint
HAV ($deg \cdot s^{-1}$)	Angular velocity of hip joint
BBCOG-X (cm)	Displacement between COG of barbell and COG of body in the X axis
BCOG-X (cm)	Displacement of COG of barbell in the X axis
BCOG-Y (cm)	Displacement of COG of barbell in the Y axis

COG: center of gravity.

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ANOVA. When significant main effects or interactions were found, Post-hoc tests were performed to determine the effects by means of a Bonferroni test. Effect size (η^2) and statistical power analysis values were used to interpret the magnitude of the main and interaction effects. Significance level was set at $p \leq 0.05$. The results of the statistical analysis were acquired by means of IBM SPSS statistics software, version 20.0 (SPSS Inc., Chicago, IL, USA).

3. Results

The characteristics of top-elite and sub-elite lifters are presented in Table 1. As shown, the average age, height, and best result were significantly greater in top-elite lifters ($t_{10} = 5.115$, $p < 0.05$; $t_{10} = 3.151$, $p < 0.05$; $t_{10} = 5.211$, $p < 0.05$, respectively).

No significant interaction was observed between level and phase factors in TD ($F_{5,60} = 0.894$, $p > 0.05$, $\eta^2 = 0.069$, power = 0.298) (Table 3). On the other hand, there was a significant main effect of the phase factor in TD ($F_{5,60} = 53.670$, $p < 0.05$, $\eta^2 = 0.817$, power = 1.000). The results revealed that the duration of M1 was the longest and M2 was the shortest in all lifters.

There was no significant interaction between level and phase factors in HB ($F_{5,60} = 0.537$, $p > 0.05$, $\eta^2 = 0.043$, power = 0.186). However, significant differences could be found between levels in HB at the end of M2 ($F_{1,10} = 10.473$, $p < 0.05$,

Table 3. Spatial-temporal characteristics of snatch lift (SD).

Variables (unit)	Phase	Top-elite (n = 6)	Sub-elite (n = 6)
TD (s)	M1	0.48 (0.06)	0.53 (0.09)
	M2	0.10 (0.03)	0.13 (0.04)
	M3	0.21 (0.07)	0.17 (0.06)
	M4	0.25 (0.02)	0.26 (0.03)
	M5	0.15 (0.02)	0.15 (0.02)
	M6	0.34 (0.16)	0.31 (0.07)
HB (cm)	M1	51.92 (3.26)	45.93 (5.78)
	M2	66.38 (2.51)	55.80 (7.61)*
	M3	89.90 (2.89)	81.60 (10.76)
	M4	117.97 (2.81)	104.68 (8.19)*
	M5	110.92 (2.27)	102.22 (9.85)
	M6	100.55 (2.62)	93.15 (5.18)*
HBR (%)	M4	69.61 (2.06)	63.98 (5.04)*
VB ($m \cdot s^{-1}$)	M1	1.05 (0.11)	0.71 (0.20)*
	M2	1.27 (0.07)	1.00 (0.18)*
	M3	1.74 (0.10)	1.44 (0.28)*
	M5	−0.73 (0.11)	−0.56 (0.18)
AB ($m \cdot s^{-2}$)	M3	4.59 (0.85)	2.99 (1.01)*

*Statistically significant difference ($p < 0.05$).
Falling velocity.

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$\eta^2 = 0.512$, power = 0.830), M4 ($F_{1,10} = 14.119$, $p < 0.05$, $\eta^2 = 0.585$, power = 0.922), and M6 ($F_{1,10} = 9.744$, $p < 0.05$, $\eta^2 = 0.494$, power = 9.744). The HB at the end of M2, M4, and M6 were significantly greater in top-elite group. Furthermore, maximum HBR at the end of M4 was significantly greater in top-elite lifters ($t_{10} = 2.600$, $p < 0.05$). It must be mentioned that significant differences were detected between phases in HB in top-elite ($F_{5,30} = 530.904$, $p < 0.05$, $\eta^2 = 0.989$, power = 1.000) and in sub-elite ($F_{5,30} = 54.682$, $p < 0.05$, $\eta^2 = 0.901$, power = 1.000). The HB at the end of M4 was significantly greater than those of other phases in top-elite. Besides, the HB at the end of M4 was significantly greater than those of the end of M1, M2, and M3 in sub-elite.

No significant interaction was found between level and phase (M1-M3) factors in VB ($F_{2,30} = 0.166$, $p > 0.05$, $\eta^2 = 0.011$, power = 0.073). On the other hand, significant differences between levels in VB at the end of M1 ($F_{1,10} = 13.359$, $p < 0.05$, $\eta^2 = 0.572$, power = 0.908), M2 ($F_{1,10} = 11.067$, $p < 0.05$, $\eta^2 = 0.525$, power = 0.850), and M3 ($F_{1,10} = 6.140$, $p < 0.05$, $\eta^2 = 0.380$, power = 0.609) could be detected. The VB at the end of M1, M2, and M3 were significantly greater in top-elite lifters. Furthermore, maximum AB was significantly greater in top-elite lifters ($t_{10} = 2.983$, $p < 0.05$). In addition, significant differences were found between phases in VB in top-elite ($F_{2,15} = 82.831$, $p < 0.05$, $\eta^2 = 0.917$, power = 1.000) and in sub-elite ($F_{2,15} = 16.099$, $p < 0.05$, $\eta^2 = 0.682$, power = 0.997). The VB at the end of M3 was significantly greater than those of the end of M1 and M2 in both levels. Moreover, the VB at the end of M2 was significantly greater than that of M1 in both levels.

No significant interaction was found between level and joint factors in the angle of the lower limb during all phases (Table 4). With regard to the knee angle, there were significant differences between levels in KA at the end of M1 ($F_{1,10} = 9.417$, $p < 0.05$, $\eta^2 = 0.485$, power = 0.790), M2 ($F_{1,10} = 8.404$, $p < 0.05$, $\eta^2 = 0.457$, power = 0.743), and M3 ($F_{1,10} = 7.501$, $p < 0.05$, $\eta^2 = 0.429$, power = 0.695). The extension KA at the end of M1 and M3 were significantly greater in top-elite lifters. In addition, the knee joint flexed approximately 12° in top-elite lifters and 8° in sub-elite lifters during M2, and the KA at the end of M2 was significantly greater in top-elite lifters. Besides, significant differences were observed between joints in the lower limb angle in top-elite ($F_{1,10} = 37.525$, $p < 0.05$, $\eta^2 = 0.790$, power = 1.000) and in sub-elite ($F_{1,10} = 20.068$, $p < 0.05$, $\eta^2 = 0.667$, power = 0.980) at the end of M1. The extension KA was significantly greater than HA at the end of M1 in both levels. Furthermore, there were significant differences between joints in the lower limb angle in top-elite ($F_{1,10} = 61.242$, $p < 0.05$, $\eta^2 = 0.860$, power = 1.000) and in sub-elite ($F_{1,10} = 28.817$, $p < 0.05$, $\eta^2 = 0.742$, power = 0.998) at the end of M4. The flexion HA was significantly greater than KA at the end of M4 in both levels. Moreover, significant differences were found between joints in the lower limb angle in top-elite at the end of M5

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Table 4. Kinematic characteristics of lower limb (SD).

Variables (unit)	Phase	Top-elite (n = 6)	Sub-elite (n = 6)
KA (degree)	Start position	64.92 (13.28)	58.99 (13.65)
	M1	127.20 (9.12)	109.73 (10.56)*
	M2	115.13 (5.39)	101.45 (10.23)*
	M3	154.79 (8.91)	138.11 (11.96)*
	M4	70.68 (6.71)	70.87 (6.12)
	M5	42.78 (6.03)	47.94 (7.02)
	M6	37.67 (5.31)	40.36 (5.85)
HA (degree)	Start position	45.84 (8.10)	49.70 (8.61)
	M1	89.63 (11.94)	81.18 (11.50)
	M2	117.92 (7.39)	103.99 (18.91)
	M3	147.05 (8.20)	146.01 (10.72)
	M4	105.47 (8.57)	112.20 (17.84)
	M5	54.35 (10.35)	61.01 (13.79)
	M6	48.32 (7.81)	47.73 (9.44)
KAV ($deg \cdot s^{-1}$)	M1	188.93 (46.10)	173.31 (50.23)
	M2	104.06 (29.33)	58.79 (35.54)*
	M3	307.31 (124.69)	295.75 (124.24)
	M4	471.50 (102.96)	458.38 (114.53)
	M5	343.09 (75.77)	317.54 (127.84)
	M6	40.96 (36.83)	21.62 (19.53)
HAV ($deg \cdot s^{-1}$)	M1	184.86 (45.22)	144.92 (37.10)
	M2	300.68 (39.10)	224.47 (107.97)
	M3	279.64 (58.32)	352.11 (91.27)
	M4	494.29 (56.94)	376.37 (82.54)*
	M5	504.36 (55.20)	422.51 (91.88)
	M6	18.10 (15.55)	14.60 (15.49)

*Statistically significant difference ($p < 0.05$).

($F_{1,10} = 5.598$, $p < 0.05$, $\eta^2 = 0.359$, power = 0.570) and M6 ($F_{1,10} = 7.628$, $p < 0.05$, $\eta^2 = 0.433$, power = 0.702). The flexion HA were significantly greater than KA at the end of M5 and M6 in top-elite.

No significant interaction was detected between level and joint factors in the angular velocity of the lower limb in all phases. On the other hand, there were significant differences between levels in maximum flexion KAV during M2 ($F_{1,10} = 5.792$, $p < 0.05$, $\eta^2 = 0.367$, power = 0.584) and HAV during M4 ($F_{1,10} = 8.298$, $p < 0.05$, $\eta^2 = 0.453$, power = 0.738). The maximum flexion KAV in M2 and HAV in M4 were significantly greater in top-elite lifters. In addition, significant differences were detected between joints in maximum angular velocity in top-elite ($F_{1,10} = 97.093$, $p < 0.05$, $\eta^2 = 0.907$, power = 1.000) and in sub-elite ($F_{1,10} = 12.748$, $p < 0.05$, $\eta^2 = 0.560$, power = 0.895) during M2. The maximum extension HAV were significantly greater than flexion KAV during M2 in both levels. Besides, there was a significant difference between joints in maximum angular velocity in top-elite ($F_{1,10} = 17.756$, $p < 0.05$, $\eta^2 = 0.640$, power = 0.966) during M5. The maximum flexion HAV was significantly greater than KAV during M5 in top-elite.

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No significant interaction was observed between level and phase factors in maximum BBCOG-X ($F_{5,60}$ = 1.857, $p > 0.05$, η^2 = 0.134, power = 0.594), BCOG-X ($F_{5,60}$ = 0.171, $p > 0.05$, η^2 = 0.014, power = 0.087), and BCOG-Y ($F_{5,60}$ = 0.163, $p > 0.05$, η^2 = 0.013, power = 0.085) (Table 5). On the other hand, there were significant main effects of the phase factor in maximum BBCOG-X ($F_{5,60}$ = 49.240, $p < 0.05$, η^2 = 0.808, power = 1.000), BCOG-X ($F_{5,60}$ = 12.141, $p < 0.05$, η^2 = 0.503, power = 1.000), and BCOG-Y ($F_{5,60}$ = 3.788, $p < 0.05$, η^2 = 0.240, power = 0.915). The results revealed that the maximum BBCOG-X of top-elite in M3 and sub-elite in M4 were the largest, and in M5 were the smallest in both levels. Besides, the maximum BCOG-X and BCOG-Y in M6 were the longest and in M1 were the shortest in both levels.

4. Discussion

The purpose of this study was to highlight the differences in technical characteristics between top-elite and sub-elite athletes in male weightlifting of snatch style in the 69-kg category. The results revealed that the technical patterns of the two levels have differences in the analyzed parameters.

4.1. Spatial-temporal characteristics of barbell

It was reported in a previous study that higher skilled lifters employed an optimum sequential pattern of intersegmental coordination and executed longer barbell positive acceleration phases compared with less skilled [14, 15]. Fig. 3 showed the

Table 5. Stability of snatch technique (SD).

Variables (unit)	Phase	Top-elite (n = 6)	Sub-elite (n = 6)
BBCOG-X (cm)	Start position	8.20 (1.12)	6.27 (3.15)
	M1	7.50 (1.44)	6.10 (1.29)
	M2	4.13 (0.62)	5.05 (2.11)
	M3	12.83 (2.57)	10.20 (3.20)
	M4	10.90 (1.12)	10.65 (1.23)
	M5	1.48 (0.99)	2.37 (1.87)
	M6	4.93 (2.83)	2.92 (1.73)
BCOG-X (cm)	M1	4.40 (2.51)	7.32 (3.01)
	M2	6.33 (2.29)	8.78 (2.65)
	M3	6.88 (2.09)	7.62 (3.30)
	M4	8.95 (3.22)	10.62 (5.03)
	M5	12.57 (3.30)	14.25 (6.78)
	M6	17.08 (6.32)	17.25 (6.82)
BCOG-Y (cm)	M1	2.28 (1.61)	2.48 (1.78)
	M2	2.68 (1.61)	2.95 (2.62)
	M3	3.57 (2.13)	3.71 (3.33)
	M4	4.77 (3.34)	4.68 (2.85)
	M5	5.13 (4.30)	6.22 (2.68)
	M6	5.90 (4.81)	7.65 (3.37)

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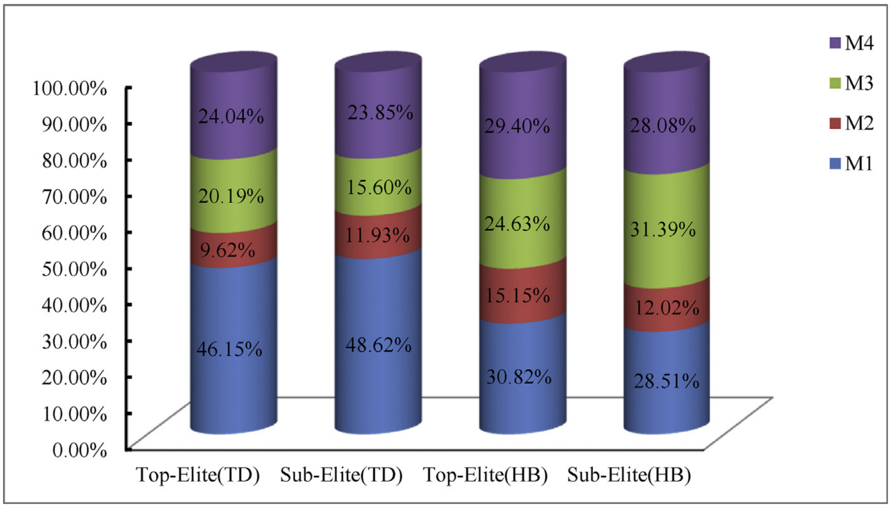

Fig. 3. Proportion of TD and HB during M1−M4.

percentage of duration of phases and vertical displacement of the barbell during M1-M4. The analysis of the time sequence of phases revealed that the two levels used different time structures. Sub-elite lifters used a longer initial phase (M1) and transition phase (M2). On the contrary, top-elite lifters used a longer decisive phase (M3). Therefore, it seemed that sub-elite lifters tended to increase the concentric muscle activity in M1 and the eccentric muscle activity in M2. However, top-elite lifters tended to increase the decisive phase.

In general terms, a longer propulsive trajectory allows lifters to act upon the barbell longer, and this results in a better condition to apply force on the barbell. Previous studies reported that shorter lifters moved the barbell less than taller lifters, which was disadvantageous for driving the barbell [16]. However, the maximum vertical height of the barbell for a successful lift for shorter lifters does not need to be as high as taller lifters. From this perspective, athletes with lower height can translate this into an advantage. In the present study, the maximum vertical height and maximum relative vertical height (normalized by athletes' height) of the barbell at the end of M4 were significantly greater in top-elite lifters. It was reported that the maximum vertical height of the barbell in the snatch lift of male elite lifters was 1.25 m, although this value was 1.15 m in another study [3, 4]. In our study, the maximum vertical height of the barbell was 1.18 m (HBR: 69.61%) in top-elite lifters and 1.05 m (HBR: 63.98%) in sub-elite lifters. The main reason for the inconsistency for the maximum vertical height of the barbell might be due to the physical differences of the subjects.

The movement of the barbell is as a result of the force that a lifter can exert on it. The displacement-time, velocity-time relationships, and acceleration of the barbell are often seen as important criterions for both coaches and athletes to evaluate

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weightlifting technique [2, 17]. There were two types of velocity curves for the snatch lift of elite weightlifters that are worthy to discuss and analyze in details. The first one, with a continuous increase of the barbell's vertical velocity from M1 to M3, was characterized by better weightlifters, and the second was that the barbell's vertical velocity had a slight decrease in M2 [2]. In the present study, the barbell's vertical velocity increased continuously from M1 to M3 both in top-elite and sub-elite lifters (Fig. 4), which were consistent with the better velocity curve patterns of previous study.

It was reported that the increase of the mass of the barbell could result in a decrease in vertical velocity and maximum height of the barbell [1]. In our study, although the barbell mass was significantly greater in top-elite, the maximal vertical linear velocity, the maximal vertical height, the maximal vertical acceleration, and maximum relative vertical height (normalized by athletes' height) of barbell were significantly greater in top-elite athletes. Firstly, these were inconsistent with previous findings since the data in literature obtained from same group of subjects, however, the data in our study were regained from different groups of subjects. Moreover, these inconsistencies might be attributed to the higher ability of the top-elite lifters included in our study.

4.2. Angular kinematics

Earlier studies reported that the knee joint in M2 and the hip joint in M3 have great importance during the snatch lift [5, 17], and the extensor muscles around knee and hip joints can conduce to the control of antagonistic muscles in a sequence motion of the snatch lift, especially the first three phases [17]. In the present study, top-elite showed significantly greater extension values than sub-elite at the knee joint at the end of M1 and M3 and significantly greater flexion values than sub-elite at the knee joint at the end of M2.

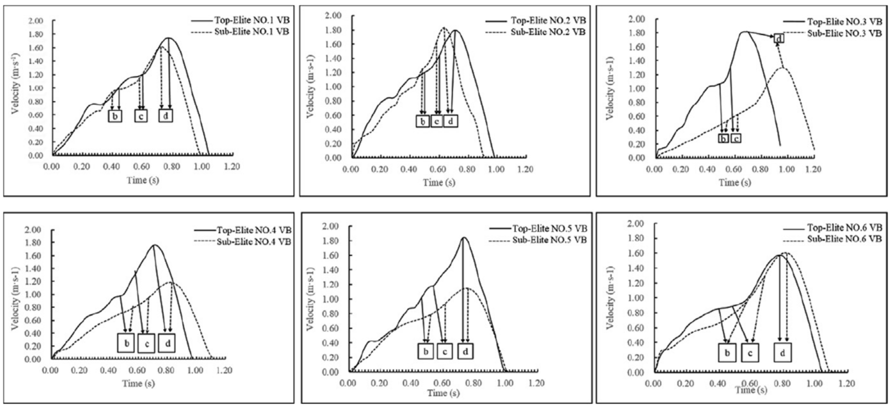

Fig. 4. Variation of VB during M1−M4 of the subjects included in the present study. Each figure depicted the comparison of one top-elite and one sub-elite lifter of the same rank in the list of Table 1. The points (b, c and d) correspond to the same instants in the snatch phases in Fig. 2.

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During the lift, a common pattern of leg action was observed. In both levels, the knee angle reached the first maximum extension value at the end of M1 and then decreased slightly in M2. At the end of M3, the second maximum extension angle of knee occurred. The second phase (M2) is highly critical and should be performed quickly with a small knee flexion to be effective in the snatch lift [5, 6, 17, 18]. The flexion of the knee joint during M2 should be executed rapidly enough to store recoverable elastic energy and to elicit stretch reflex facilitation immediately following the concentric contraction of knee joint extensor muscles [19]. In the present study, the sub-elite lifters showed less flexion (8° vs. 12°) and significantly slower angular velocity of the knee joint than top-elite lifters during M2.

It was reported that the maximum extension velocity of the hip joint was greater than the maximum extension velocity of the knee joint during M3, which could increase the acceleration of the barbell and contribute to the execution of an explosive second pull [6]. In the present study, the maximum angular velocity of the hip joint was significantly greater than that of the knee joint during M3 in sub-elite, which in line with previous studies. However, the finding was opposite in top-elite. This difference between the two levels may be due to the barbell weight of top-elite group being significantly greater than that of sub-elite group.

4.3. Stability of snatch technique

Regarding the characteristics of stability in the snatch technique, the horizontal (anterior-posterior) movement proved to be an important factor in performing a successful snatch technique. The extent of the horizontal movement of the barbell indicated the instability involved or the correction required to complete the lift, and the horizontal displacement caused an additional acceleration and work during lift [2, 20]. Therefore, the anterior-posterior displacement of the barbell during the pull phase was considered an effective application of muscle power, and a small horizontal movement is essential for good lifting technique and unnecessary energy consumption [6, 17]. In our study, maximum BBCOG-X, BCOG-X, and BCOG-Y (Table 5) were used to evaluate the stability of the snatch lift. A previous study reported that the barbell displaced horizontally by 10−20 cm during the snatch lifts in elite lifters [21]. These BCOG-X values were close to those in the present study (top-elite: 17.08 cm and sub-elite: 17.25 cm, respectively). In addition, no significant difference was found between top-elite and sub-elite lifters in the three parameters. This result revealed that sub-elite lifters used their energy as effectively as top-elite.

With respect to barbell trajectory, several researches investigated the optimal lifting motion patterns for snatch weightlifting [2, 22, 23]. However, there was no unified point of view between researchers because of the different optimization criterion such as actuating torque and power consumption cost. In a previous study, the barbell trajectory of elite athletes moved to the rear of the body, not through the

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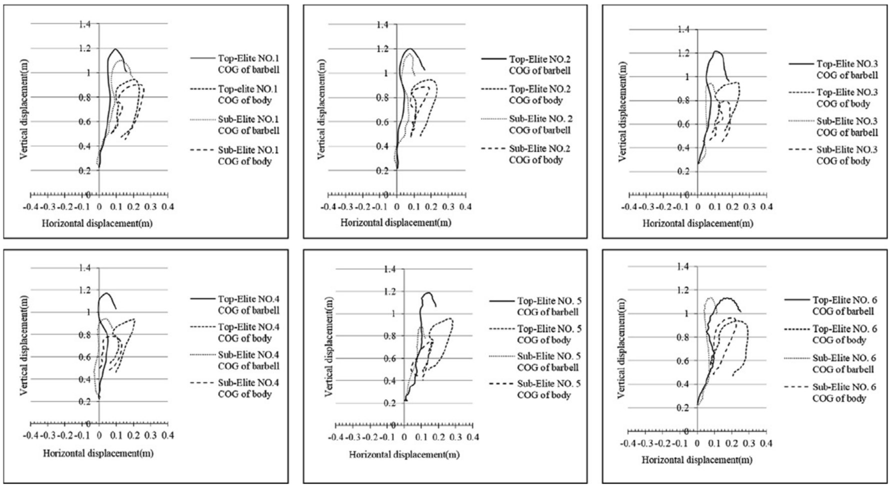

Fig. 5. Trajectories of COG of barbell and body during snatch lifts of the subjects included in the present study. Each figure depicted the comparison of one top-elite and one sub-elite lifter of the same rank in the list of Table 1.

vertical reference line that projected upward from the initial position of the barbell [2]. In the present study, the trajectories of all the six top-elite lifters did not pass the vertical reference line (Fig. 5) which were in line with the findings of this study.

4.4. Limitations

A number of limitations exist in the current study. Only Chinese weightlifters were analyzed, which lead to a relatively small number of subjects included into the study. In addition, the video data were captured under completion conditions. In video parsing, it is common that body joints are hidden by local limbs or are not visible on the side camera.

5. Conclusions

The results of our study described important aspects of snatch technique. Since the data were recorded under competition conditions, they could be used as reference not only for athletes and coaches to integrate into training and competition but also for future biomechanical research.

The findings of the present study demonstrated the similarities of the technical characteristics of snatch lift between the two levels. The major differences were observed in maximum HB, HBR, VB, and AB. Values of these parameters were significantly greater in top-elite lifters, which indicated that sub-elite lifters need to develop their skills in these parameters in order to reach the top-elite level. Coaches of sub-elite lifters should focus on exercises suitable to the strength characteristics of the M1 and M3. In addition, sub-elite lifters showed significantly slower angular velocity

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of the knee joint compared with top-elite lifters in M2. Therefore, sub-elite lifters' flexor muscles of knee joint should be strengthened and their ability of generating and utilizing elastic energy in M2 should be improved.

Declarations

Author contribution statement

Gongju Liu: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Gusztáv Fekete: Analyzed and interpreted the data; Wrote the paper.

Hongchun Yang: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Jing Ma: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Dong Sun: Performed the experiments.

Qichang Mei: Analyzed and interpreted the data.

Yaodong Gu: Conceived and designed the experiments; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

References

[1] D.L. Hoover, K.M. Carlson, B.K. Christensen, C.J. Zebas, Biomechanical analysis of women weightlifters during the snatch, J. Strength Cond. Res. 20 (2006) 627.

https://doi.org/10.1016/j.heliyon.2018.e00658

[2] W. Baumann, V. Gross, The snatch technique of world class weightlifters at the 1985 world championships, J. Sports Biomech. (1988) 69−89. http://www.humankinetics.com/acucustom/sitename/Documents/DocumentItem/7986.pdf.

[3] V. Gourgoulis, N. Aggeloussis, V. Kalivas, P. Antoniou, G. Mavromatis, Snatch lift kinematics and bar energetics in male adolescent and adult weightlifters, J. Sports Med. Phys. Fit. 44 (2004) 126−131.

[4] V. Gourgoulis, N. Aggeloussis, P. Antoniou, C. Christoforidis, G. Mavromatis, A. Garas, Comparative 3-dimensional kinematic analysis of the snatch technique in elite male and female Greek weightlifters, J. Strength Cond. Res. 16 (2002) 359−366.

[5] V. Gourgoulis, N. Aggelousis, G. Mavromatis, A. Garas, Three-dimensional kinematic analysis of the snatch of elite Greek weightlifters, J. Sports Sci. 18 (2000) 643−652.

[6] V. Gourgoulis, N. Aggeloussis, A. Garas, G. Mavromatis, Unsuccessful vs. successful performance in snatch lifts: a kinematic approach, J. Strength Cond. Res. 23 (2009) 486−494.

[7] H. AkkuŞ, Kinematic analysis of the snatch lift with elite female weightlifters during the 2010 world weightlifting championship, J. Strength Cond. Res. 26 (2012) 897−905.

[8] Y. Ikeda, T. Jinji, T. Matsubayashi, A. Matsuo, E. Inagaki, T. Takemata, M. Kikuta, Comparison of the snatch technique for female weightlifters at the 2008 Asian championships, J. Strength Cond. Res. 26 (2012) 1281−1295.

[9] J. Garhammer, A comparison of maximal power outputs between elite male and female weightlifters in competition, Int. J. Sport Biomech. 7 (1991) 3−11.

[10] E. Harbili, A gender-based kinematic and kinetic analysis of the snatch lift in elite weightlifters in 69-kg category, J. Sport Sci. Med. 11 (2012) 162−169.

[11] E. Harbili, A. Alptekin, Comparative kinematic analysis of the snatch lifts in elite male adolescent weightlifters, J. Sport Sci. Med. 13 (2014) 417−422.

[12] S.M.A. Rahmati, M. Mallakzadeh, Prediction of weightlifter's motor behavior to evaluate snatch weightlifting techniques based on a new method of investigation of consumed energy, Hum. Mov. Sci. 38 (2014) 58−73.

[13] Aiyun Lu, Sports Biomechanics, first ed., Peoples Sports Publishing House, Beijing China, 2010.

 https://doi.org/10.1016/j.heliyon.2018.e00658

[14] R.M. Enoka, Load- and skill-related changes in segmental contributions to a weightlifting movement, Med. Sci. Sports Exerc. 20 (1988) 178−187. http://www.ncbi.nlm.nih.gov/pubmed/3367754.

[15] R.M. Enoka, Muscular control of a learned movement: the speed control system hypothesis, Exp. Brain Res. 51 (1983) 135−145.

[16] J. Campos, P. Poletaev, A. Cuesta, C. Pablos, V. Carratalá, Kinematical analysis of the snatch in elite male junior weightlifters of different weight categories, J. Strength Cond. Res. 20 (2006) 843.

[17] T. Isaka, J. Okada, K. Funato, Kinematic analysis of the barbell during the snatch movement of elite Asian weight lifters, J. Appl. Biomech. 12 (1996) 508−516.

[18] R.M. Enoka, The pull in olympic weightlifting, Med. Sci. Sports 11 (1979) 131−137.

[19] J. Garhammer, R. Gregor, Propulsion forces as a function of intensity for weightlifting and vertical jumping, J. Strength Cond. Res. 6 (1992) 129.

[20] B.K. Schilling, M.H. Stone, H.S. O'Bryant, A.C. Fry, R.H. Coglianese, K.C. Pierce, Snatch technique of collegiate national level weightlifters, J. Strength Cond. Res. 16 (2002) 551−555.

[21] M.H. Stone, H.S. Bryant, F.E. Williams, R.L. Johnson, K.C. Pierce, Analysis of bar paths during the snatch in elite male weightlifters, Strength Cond. J. 20 (1998) 56−64.

[22] J. Garhammer, Biomechanical profiles of olympic weightlifters, Int. J. Sport Biomech. 1 (1985) 122−130.

[23] S.L. Nejadian, M. Rostami, F. Towhidkhah, Optimization of barbell trajectory during the snatch lift technique by using optimal control theory, Am. J. Appl. Sci. 5 (2008) 524−531.

 https://doi.org/10.1016/j.heliyon.2018.e00658