Kinematic Analysis of the Snatch Lift With Elite Female Weightlifters During the 2010 World Weightlifting Championship

Hasan Akkuş

School of Physical Education and Sports, University of Selçuk, Alaaddin Keykubat Campus, Konya, Turkey

Abstract

Hasan Akkuş. Kinematic analysis of the snatch lift with elite female weightlifters during the 2010 World Weightlifting Championship. *J Strength Cond Res* 26(4): 897–905, 2012–The objectives of this study were to determine the mechanical work, the power output, and the angular kinematics of the lower limb and the linear kinematics of the barbell during the first and second pulls in the snatch lift event of the 2010 Women's World Weightlifting Championship, an Olympic qualifying competition, and to compare the snatch performances of the women weightlifters to those reported in the literature. The heaviest successful snatch lifts of 7 female weightlifters who won gold medals were analyzed. The snatch lifts were recorded using 2 Super-Video Home System cameras (50 fields·s^{-1}), and points on the body and the barbell were manually digitized using the Ariel Performance Analysis System. The results revealed that the duration of the first pull was significantly greater than the duration of the transition phase, the second pull, and the turnover under the barbell ($p < 0.05$). The maximum extension velocities of the lower limb in the second pull were significantly greater than the maximum extension velocities in the first pull. The fastest extensions were observed at the knee joint during the first pull and at the hip joint during the second pull ($p < 0.05$). The barbell trajectories for the heaviest snatch lifts of these elite female weightlifters were similar to those of men. The maximum vertical velocity of the barbell was greater during the second pull than in the first pull ($p < 0.05$). The mechanical work performed in the first pull was greater than the second pull, and the power output during the second pull was greater than that of the first pull ($p < 0.05$). Although the magnitudes of the barbell's linear kinematics, the angular kinematics of the lower limb, and other energy characteristics did not exactly reflect those reported in the literature, the snatch lift patterns of the elite women weightlifters were similar to those of male weightlifters.

Key Words bar trajectory, kinematic, power, women

Introduction

The 1987 World Weightlifting Championship was the first such event in which female weightlifters participated as competitors (9,16). Not until the 2000 Olympic Games in Sydney did female weightlifters contest the snatch and clean and jerk at an Olympic event (21). Despite increasing interest in female weightlifting after 1987, the number of studies focused on the snatch performances of female weightlifters in World Championships and Olympic games is relatively limited compared with the number of studies focused on males.

The results of female weightlifters in 9 categories in the 1987 World Weightlifting Championship showed that women could generate higher short-term power outputs than previously documented; however, their powers were lower than those of men both in absolute terms and relative to body mass (9). According to reported values from the 1998 World Championship, women lifted greater loads and exerted more power in the second pull than men, but the duration of their second pull, their maximum vertical barbell velocity, and their maximum barbell height were lower (14). The authors of another study found that the mechanical work done by men to vertically displace the barbell was greater in the first pull than in the second pull and that the mechanical work done by women was similar in both phases. Additionally, female weightlifters flexed their knees less and more slowly than men during the transition phase, in which elastic energy is stored, and they dropped under the barbell more slowly in the turnover and catch phases (16). The larger horizontal displacement of the barbell by women in the 69-kg category of the 1999 US Men's and Women's Weightlifting Championships was accounted for by the inconsistent or irregular displacement of the barbell, and less than half of the females' snatch attempts displayed the optimal toward-away-toward horizontal bar trajectory. Moreover, as the load of the barbell increased, the drop-under time also increased, whereas the drop-under displacement, the maximum vertical displacement,

Address correspondence to: Hasan Akkuş, hakkus@selcuk.edu.tr.

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Table 1. The characteristics of elite female weightlifters.

Subjects	Weight category (kg)	Age (y)	Height (cm)	Body weight (kg)	Result (kg)
1	48	27	150	47.88	93
2	53	19	162	52.84	100
3	58	25	156	57.67	103
4	63	28	163	62.59	112
5	69	27	171	68.23	116
6	75	24	175	74.67	134*
7	+75	19	176	96.93	145†
Mean ± SD		24.14 ± 3.76	164.71 ± 9.79	65.83 ± 16.43	114.71 ± 18.81

*Senior world record.
†Senior and junior world record.

and the maximum vertical velocity of the barbell decreased (21). The differences between the characteristics of snatch lifts by male and female weightlifters have been reported to be caused by women's recent participation in weightlifting, a lack of experience and weightlifting skills, insufficient training, and other variables (9,12,14,16,21).

In weightlifting, a higher performance level can be achieved by decreasing the total work done and by more effectively utilizing the power-generating ability of the muscles (21). A comparative analysis detecting the changes in the recent performances of elite female weightlifters in the snatch lift event in comparision to previous data reported in the literature can show the importance of different kinematic variables in achieving a higher performance.

In conlusion, there has been considerable research into the variables involved in weightlifting for men and relatively few studies for women. And the latest one of those few studies analyzed data taken from national-level women weightlifters competed in 1999, more than a decade ago (21). Hence, analyzing data obtained from elite female weightlifters competed in 2010 can demonstrate the development of the snatch technique in women weightlifters and provide additional and useful information for coaching. The objective of this study was to determine the kinematics of snatch lifts by elite female weightlifters who won gold medals in the 2010 World Weightlifting Championship, an Olympic qualifying competition, and compare the results with previous data reported for men and women.

The research hypothesis of this study was that the analysis of the snatch lift performances of elite female weightlifters in this study would exhibit important differences in kinematic variables when compared with previously reported data for weightlifters, providing useful information for athletes and their coaches to utilize in training and competition.

Methods

Experimental Approach to the Problem

This study was descriptive in nature. The data for this study were collected only from female world champion weightlifters in 7 categories in the 2010 World Weightlifting Championship. To determine the development of female snatch performance, the collected data were then analyzed and compared with data for male and female weightlifters reported since the 1987 World Weightlifting Championship, the first event in which female weightlifters participated as competitors.

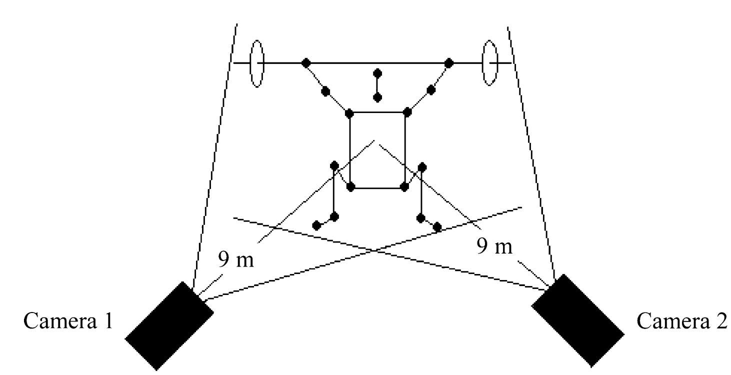

Figure 1. The camera set-up.

Subjects

This study was conducted in accordance with the guidelines set forth by the Institutional Review Board of Selcuk University.

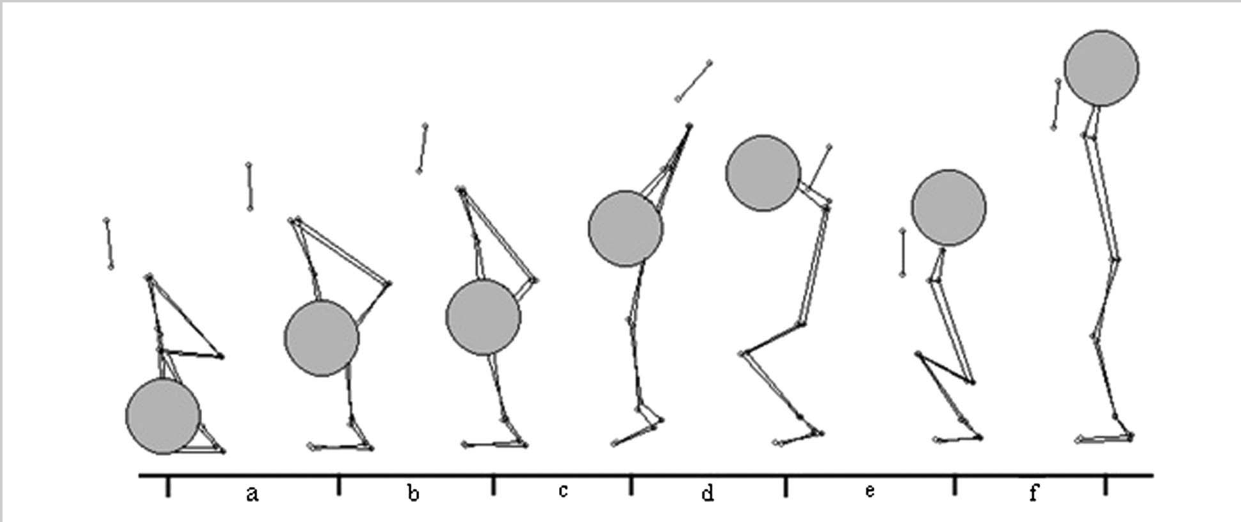

Figure 2. The phases of the snatch: (A) the first pull, (B) the transition, (C) the second pull, (D) the turnover under the barbell, (E) the catch phase, and (F) the rising from the squat position.

The data used in this study were obtained from the 2010 World Weightlifting Championship in Antalya, Turkey. Necessary permissions for visual recordings were obtained from the Turkish Weightlifting Federation and the World Weightlifting Federation. The heaviest successful lifts of 7 women who won gold medals were analyzed (Table 1). The snatch lift in the female 75-kg category was a senior world record (134 kg), and the snatch lift in the female kg category was a senior junior world record (145 kg).

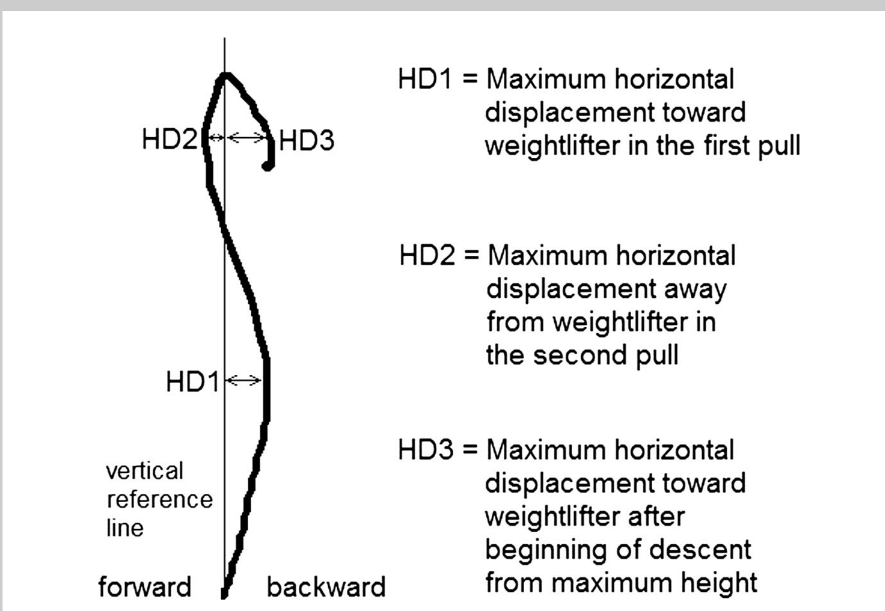

Figure 3. Three key horizontal positions of the barbell in the snatch lift.

Procedures

Two digital cameras were positioned on the diagonal level of the platform at a distance of 9 m from the weightlifters, forming an approximate 45° angle with the sagittal plane of the weightlifters (Figure 1). The snatch lifts were recorded using 2 digital cameras (Sony DCR-TRV18E, Tokyo, Japan), which captured images at 50 fields per second. The lift-off of the barbell was used to synchronize the 2 cameras.

To determine the 3-dimensional kinematic data of the barbell and the angular kinematics of the hip, knee, and ankle joints during the snatch lifts, 1 point on the barbell and 5 points on the body were digitized using the Ariel Performance Analysis System (APAS, San Diego, CA, USA). The digitized points included the little toe, ankle, knee, hip, and shoulder on the right side of the body. In addition to these points, the digitized point on the barbell was located on the medial side of the right hand.

A rectangular cube with a length of 250 cm, a depth of 100 cm, and a height of 180 cm was used to calibrate the movement space. The 3-dimensional spatial coordinates of the

Table 2. Angular kinematics of the ankle, knee, and hip joints in the first and second pulls.

	First pull	Second pull	
Maximum ankle extension angle (°)	120.95 ± 3.95	149.06 ± 5.23	13.234*
Maximum knee extension angle (°)	134.14 ± 4.73	159.09 ± 2.74	12.845*
Maximum hip extension angle (°)	88.09 ± 7.87	185.86 ± 5.39	27.151*
Decrease in knee angle during the transition phase (°)	11.02 ± 5.32		
Maximum ankle angular velocity ($rad \cdot s^{-1}$)	1.42 ± 0.41	5.96 ± 1.34	8.828*
Maximum knee angular velocity ($rad \cdot s^{-1}$)	3.79 ± 1.11	5.92 ± 1.05	4.619*
Maximum hip angular velocity ($rad \cdot s^{-1}$)	2.56 ± 0.63	7.86 ± 1.52	9.615*

*$p < 0.05$.

Table 3. Linear kinematics of the barbell.

	Mean ± SD
Vertical kinematics	
Barbell height at the end of the first pull (cm)	52.16 ± 6.36
Barbell height at the end of the second pull (cm)	92.60 ± 6.12
Maximum barbell height (m)	1.18 ± 0.19
Drop displacement (cm)	13.72 ± 2.94
Maximum vertical velocity of the barbell in the first pull ($m \cdot s^{-1}$)	0.99 ± 0.19
Maximum vertical velocity of the barbell in the second pull ($m \cdot s^{-1}$)	1.68 ± 0.14
Horizontal kinematics	
Horizontal displacement toward weightlifter in the first pull (cm)	5.92 ± 3.11
Horizontal displacement away from weightlifter in the second pull (cm)	1.83 ± 4.62
Horizontal displacement toward weightlifter after beginning of descent from maximum height (cm)	4.39 ± 3.43

Table 4. Mechanical work and power output in the first and second pulls.

	First pull	Second pull	*t*-Value
Absolute work (J)	391.50 ± 84.25	314.65 ± 42.76	3.499*
Relative work (J/kg)	6.02 ± 0.79	4.90 ± 0.75	4.057*
Absolute power (W)	642.74 ± 159.04	1847.62 ± 336.06	13.472*
Relative power (W/kg)	9.85 ± 1.35	28.95 ± 3.02	15.625*

*$p < 0.05$.

selected points were calculated using the direct linear transformation procedure with 12 control points. The calibration cube was placed on the platform before the competition, recorded, and then removed. The raw position and time data were smoothed using a low-pass digital filter. Based on the residual analysis, a cut-off frequency of 4 Hz was selected (15,16).

The snatch lift was divided into 6 phases: (a) the first pull, (b) the transition, (c) the second pull, (d) the turnover under the barbell, (e) the catch phase, and (f) the rising from the squat position (Figure 2). The phases were determined according to the change in direction of the knee angle and the height of the barbell (2,15,19). The first 5 phases of the lift, from the lift-off of the barbell to the catch phase, were studied as follows– "the first pull:: from barbell lift-off until the first maximum knee extension; "the transition phase": from the first maximum knee extension until the first maximum knee flexion; "the second pull": from the first maximum knee flexion until the second maximum extension of the knee; "the turnover under the barbell": from the second maximum extension of the knee until the achievement of the maximum height of the barbell; "the catch phase": from the achievement of the maximum height of the barbell until stabilization in the catch position.

The angular displacements and velocities of the ankle, knee, and hip joints were analyzed to investigate the angular kinematics of the lower body. In addition, the kinematics of the barbell were calculated. A vertical line drawn through the starting position of the barbell was used as a reference to

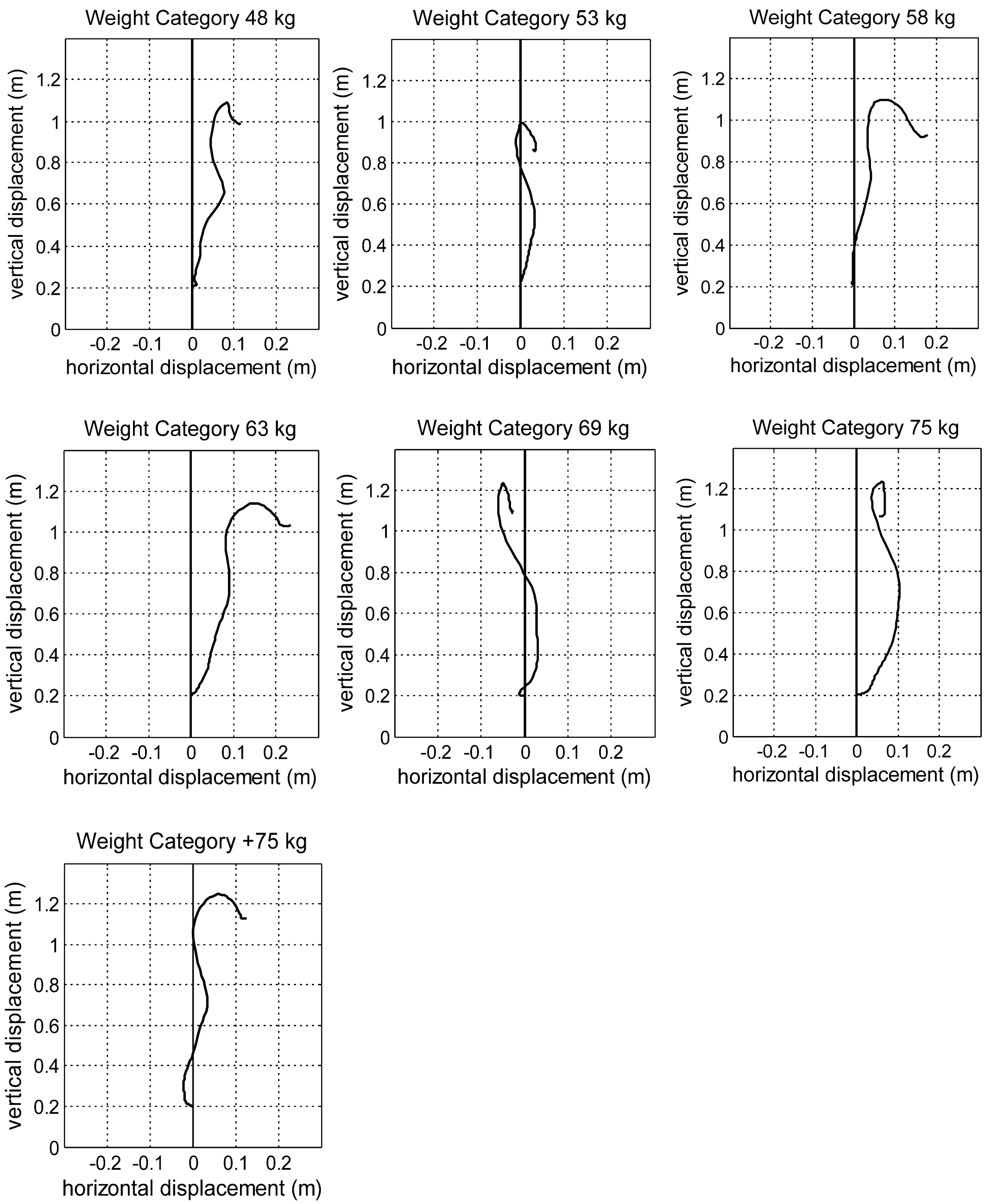

Figure 4. Barbell trajectories for various female weight categories.

determine the horizontal displacement of the barbell (8). Movement of the bar toward the lifter was regarded as a positive horizontal displacement, and movement of the bar away from the lifter represented a negative horizontal displacement (Figure 3).

The work performed on the barbell during the first and the second pulls was calculated from changes in the barbell's potential and kinetic energies. These calculations included the vertical work done by lifting the barbell. The power output of the weightlifter was calculated by dividing the work done in each phase by the duration of the phase. The relative power and work values were calculated by dividing the absolute work and power values by the lifter's body mass. The calculated power outputs only included the vertical work done by lifting the barbell (11).

Statistical Analyses

The assumption of normally distributed data was checked using a *p*-plot and the Anderson-Darling test. The paired *t*-test was used to determine the kinematic differences between the first and second pulls, and the multivariate Wilks' Lambda (λ) test with Bonferroni correction was used to compare the angular kinematics during the first and second pulls and the differences between the durations of the phases. A significance level of $p \leq 0.05$ was used.

Results

A significant difference was found between the durations of the first 4 phases ($\lambda = 0.024$; $p < 0.05$). The duration of the first pull (0.60 ± 0.08 s) was significantly greater than the durations of the transition phase (0.14 ± 0.01 s), the second pull (0.17 ± 0.01 s), and the turnover under the barbell (0.21 ± 0.02 s). The duration of the turnover was greater than the durations of the second pull and the transition phase ($p < 0.05$).

The angular displacements and velocities of the ankle, knee, and hip joints in the second pull were greater than those in the first pull. The average knee angle was 66.32 ± 12.96° in the starting position and 134.14 ± 4.73° at the end of the first pull, followed by flexion of approximately 11.02 ± 5.32° in the transition phase and 159.09 ± 2.74° at the end of the second pull. The differences between the angular velocities of the ankle, knee, and hip joints during the first pull ($\lambda = 0.135$; $p < 0.05$) were significant. Significant differences were also found in the joint angular velocities during the second pull ($\lambda = 0.231$; $p < 0.05$). During the first pull, the maximum knee angular velocity was greater than the maximum ankle and hip angular velocities ($p < 0.05$). The maximum hip angular velocity was also greater than the maximum ankle angular velocity in the first pull ($p < 0.05$). During the second pull, the maximum hip angular velocity was greater than both the maximum knee angular velocity ($p < 0.05$) and the maximum ankle angular velocity ($p < 0.05$). The angular velocities of the knee during the first pull and the hip during the second pull were greater than those of the other 2 joints (Table 2).

The vertical displacement of the barbell during the first pull (from lift-off until the end of the first pull) was 29.34 ± 6.24 cm and during the second pull, it was 25.91 ± 2.81 cm (Table 3). Although the distance of the barbell from the point of lift-off to the end of the first pull was greater than that in the second pull, no significant difference was found between the displacement of the 2 phases ($t = 1.215$; $p = 0.270$). Conversely, the maximum vertical linear velocity of the barbell was greater in the second pull than in the first pull ($t = 10.533$; $p < 0.05$). The barbell moved between 4 cm(21 to 3 cm for Subject 5) and 9 cm(0 to 9 cm for Subject 4) toward the body during the second pull (Figure 3). During this pull, however, the barbell also moved between 1 cm (9–8 cm for Subject 4) and 9 cm (3 to 26 cm for Subject 5) away from the body, crossing the vertical reference line of the barbell before lift-off. After the drop from the maximum height, the barbell moved from 0 cm (6–6 cm for Subject 6) to 10 cm (7–17 cm for Subject 3) toward the body, and a negative value was observed for 1 weightlifter (69 kg), as the barbell was fixed in front of the vertical reference line.

The work values during the first pull were significantly higher than those of the second pull. Conversely, the power output during the second pull was significantly higher than that of the first pull (Table 4). The work values of the first pull were greater than the power values of the second pull.

Discussion

In weightlifting, load is an important variable that plays a determining role in the magnitudes of the vertical and horizontal kinematics of the barbell. Previous work has shown the most distinctive effect of increased barbell weight to be an increase in the pull duration and a decrease in the maximum and average pull velocities, the maximum barbell height, and the power output (13). The average value of the barbell weights of the heaviest snatch lifts in the 2010 Women's World Weightlifting Championships was greater than those in the 1987 and 1998 competitions by 45% and 18%, respectively (9,14). The duration of the first pull in the current study, which was the longest of all 4 phases, was significantly greater than previously reported results due to the maximal lift performance of the female weightlifters (15,16). Conversely, the duration of the second pull was shorter than that in the 1987 Women's World Weightlifting Championship (9) and longer than that in the 1998 event (14). The duration of the first pull for national-level female weightlifters in the 69-kg category was shorter than that found in this study, but the duration of the second pull for these women was nearly twice as long as that found in this study (21). The relatively longer duration of the first pull detected in this study was attributed to the maximal barbell weights. In addition, the increased average snatch lift indicated an increase in the skills and strength of the female weightlifters (Figure 4).

Our results were not consistent with those of Gourgoulis et al (16), who reported that the mechanical work performed during the first pull was less than that performed during the second pull for women. However, the snatch lift results for men were similar as follows: the mechanical work performed during the first pull was greater than that performed during the second pull, and the power output during the second pull was greater than that of the first pull (2,7–9,15). The greater work values during the first pull in the current study suggest an increase in the strength of female weightlifters and the use of a snatch pattern similar to that of male weightlifters. During the first pull of the snatch lift, changes in the barbell's kinetic and potential energies were greater, and the lifters had to exert a considerable amount of work over a long period to overcome the inertia of the barbell (15). During the second pull, the lifters had to work much more quickly than in the first pull because of the short duration of the second pull. The first phase of the total pull is relatively slow and can be considered to be strength oriented, whereas the second pull is faster and can be considered to be more power oriented

(9,17,18). The power output generated for the vertical displacement of the barbell during the second pull, an indicator of explosive strength, was lower for female than for male weightlifters, and this can be explained by the relatively lower vertical velocity of the barbell when used by women (16). The large improvements observed in the performance of female weightlifters between 1987 and 1998 are connected to technique changes during the second pull (14). The relative power output during the second pull has increased by 80% according to the relative power output in total pull in female weightlifters, and by 53% in men weightlifters. The power values of faster and slower movements for women, such as the second and complete pulls, were consistently higher percentages of the values for men (12).

In previous studies, an optimal barbell trajectory has been taken as an indicator of a mechanically effective pull and a proper technique (1,3,8,20–24). The horizontal displacement of the barbell during the snatch is one of the kinematic variables used to assess weightlifting technique (21). The horizontal movement of the barbell during the pull phase should be considered an effective application of muscle power (22). As the horizontal displacement of the bar increases during the lift, the lifter must exert more energy to control the loaded barbell (4,21). The optimum trajectory is affected by relative body segment lengths and other leverage factors, such as muscle attachment points (8). However, the role that anthropometric factors play in the determination of the optimal barbell trajectory is unclear (21).

As shown in Figure 3, 3 key position values have been identified for the horizontal movement of the barbell during the snatch (8). The first horizontal movement of the barbell is toward the weightlifter, away from the vertical reference line drawn through the position of the bar just before lift-off during the first pull. This value was always found to be positive. The second value was often negative, indicating movement of the bar away from the lifter toward the opposite side of the vertical reference line during the second pull. The third value, the distance of the bar from the vertical reference line just after the beginning of descent from the maximum height, was usually positive. These 3 horizontal movements of the barbell have been described as positive-negative-positive or toward-away-toward displacement patterns (8,21). The horizontal displacement of the barbell by men has been reported to be between 3 and 9 cm in the first pull, between 3 and 18 cm in the second pull, and between 3 and 9 cm just after the beginning of descent from the maximum height (8). The average horizontal displacement of the barbell has been reported to be 3.65 cm during the first pull and the transition phases for national-level female weightlifters and 6.29 cm for men at the Olympic level. During the second pull, the average horizontal displacement was −1.88 cm for women and 3.87 cm for men (16). The toward-away-toward displacement pattern of the barbell during the first and second pulls was similar for men and women, and no significant differences were observed between the genders (16). A gender-based difference was found in the horizontal movement of the barbell during the second pull: the barbell moved away from female lifters and crossed the vertical reference line, whereas it moved horizontally away from male lifters without crossing the vertical line (16). In another study, the barbell trajectory of female lifters was different from that of males, and an optimal toward-away-toward pattern was observed in less than half of the female lifters (6 of the 14 lifts, approximately 43%) (21). In the present study, only 2 of the 7 elite female weightlifters (53 kg and 69 kg categories) exhibited an optimal toward-away-toward pattern. Hoover et al (21) have reported that most of the literature pertaining to optimal trajectories during the snatch has considered skilled to elite men. The horizontal displacement values of the barbell for highly skilled female weightlifters in this study were within the recommended limits for an effective snatch technique. However, the observed trajectory of the barbell was consistent with the results of Gourgoulis et al (15) for male weightlifters. In most cases, the barbell did not cross the vertical reference line before lift-off in the current study (Figure 4).

It was found that the maximum height of the barbell in women weighlifters in this study was lower than those reported but greater than the results found for men (8,9,14,16). The height loss from the maximum height of the barbell until the squat position was similar to the drop displacement recorded for men lifters but smaller than that of females (16,21). Lifting the barbell effectively requires minimizing both the maximum height of the barbell at the end of the turnover and the loss of height during the drop under the barbell to the catch position (8,16,22). A lower maximum height and the drop displacement distance are among the most important indicators of an effective technique for a maximal snatch lift in elite female weightlifters.

The absence of a notable dip during the transition phase is characteristic of better weightlifters (2) and indicates an effective technique (1,22). During the transition, the vertical force on the barbell diminishes. This, in turn, decreases the vertical velocity of the barbell although smoothing and accelerating the transition and produces a smaller decline in velocity (8). The presence of 2 clear peaks in the vertical velocity of the barbell is suggestive of an ineffective technique (2). In the present study, an ineffective technique was detected in only 1 (48 kg) of the 7 weightlifters. The vertical linear velocity of the barbell decreased by 13% in the transition phase, and 2 distinct peaks were observed. In an earlier study, the maximum vertical linear velocity during the second pull and the maximum height of the barbell after the second pull were higher in national-level female than in male Olympic champions (16). In addition to gender, skill level affected this result, and the vertical kinematics of the barbell decreased in elite weightlifters, especially in men (14). Skill-related factors affected snatch performance, and highly skilled weightlifters achieved a relatively lower barbell height during the catch phase and faster drop during the turnover under the barbell (4,16).

In this study, the maximum extension of the knee angle during the first pull was lower than that reported for men, whereas it was greater than that reported for female weightlifters (16). Knee flexion during the transition phase for female weightlifters was similar to the values reported in the literature, whereas it was lower than values reported for men (16). The maximum extension angle of knee joints during the first pull affects explosive strength during the second pull. By flexing the knee joint at a greater extension angle at the end of the first pull, the biomechanics of the phase are maximized and elastic energy is effectively used. During the transition from the first pull to the second pull, knee flexion is used to realign the lifter relative to the barbell, and this movement is referred to as the double knee bend (5,6). Knee flexion during the transition phase has similar effects to that observed during the countermovement in vertical jumps (16). This countermovement and the second bending flexion of the knees during the snatch lift may be performed rapidly enough to store recoverable elastic energy and elicit a stretch reflex immediately after the concentric contraction of the knee and hip joint extensor muscles (10).

The extension angle of the ankles during the second pull, which is used to increase power output, was considerably higher in this study than the values reported for women in the literature, whereas the values of the extension angle of the hip and knee joints were similar (16). Furthermore, the extension velocities of the hip, knee, and ankle joints during the second pull, when explosive strength is needed, were much greater than the extension velocities of the same joints during the first pull. The knee extension velocity during the first pull was greater than that of the ankle and hip, and the hip extension velocity was greater than that of the ankle. The hip extension velocity was greater than both the ankle and the knee extension velocities during the second pull. Thus, the knee angular velocity was the greatest during the first pull, whereas the hip angular velocity was the greatest during the second pull. This finding was consistent with the results of Baumann et al (2) who suggested that faster execution of the second pull contributed to the explosiveness of the second pull (15).

Although the magnitudes of the linear kinematics, the angular kinematics of the lower limbs, and the other energetic characteristics found in this study were not entirely consistent with those reported in the literature, the performances of the elite female weightlifters in the 2010 World Weightlifting Championships were improved compared with reported values, and a snatch-lift pattern similar to that of male weightlifters was observed.

Practical Applications

The snatch techniques of elite female weightlifters in the 2010 World Weightlifting Championships were analyzed in this work. The women weightlifters in this study exhibited superior performances when compared with previously reported results since 1987. Although their pulling velocities and explosive strength values were less than those of male weightlifters, the increase in the average load lifted, the mechanical energy during the first pull, and the power output during the second pull indicated an increase in strength and skill levels of female weightlifters since then. On the other hand, although relatively similar to those of men, the barbell trajectories of the successful snatch lifts performed by the world champion women weightlifters were different from each other. This finding of the present study suggest that successful lifts are not necessarily dependent on a single and specific barbell trajectory pattern but that they are more a result of power output. In addition, it was found that the greater the power output, which is related to vertical velocity of the barbell, the more consistent the horizontal barbell displacement patterns were with those reported for men weightlifters. As a result, coaches can focus more on training techniques that develop maximum strength for greater mechanical work during the first pull and increase the explosive strength of the extensor muscles about the hip, knee, and ankle joints during the second pull.

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