



## Biomechanical Analysis of Successful and Unsuccessful Snatch Lifts in Elite Female Weightlifters

by

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*The aim of this study was to identify biomechanical factors affecting successful and unsuccessful snatch attempts in elite female weightlifters during the 2013 World Weightlifting Championships. Fourteen female competitors took part in this study. Their successful and unsuccessful snatch lifts with the same load were recorded with 2 camcorders (50 Hz), and selected points were digitized manually on to the body and the barbell using the Ariel Performance Analysis System. The kinetic and kinematic barbell movement as well as the athlete's body movement variables during the liftoff phase were examined. The results of this study show statistical differences ( $p \leq 0.05$ ) between successful and unsuccessful attempts in relation to the angle values in the knee and hip joints in preparation for the aerial phase position. Similarly, the center of gravity velocity was significantly higher in successful attempts during the catch phase. Thus, coaches should pay particular attention to the accuracy of the execution in preparation for the aerial phase position and to the velocity of the center of gravity of the competitors during the catch phase.*

**Key words:** *weightlifting, barbell, technique, kinematics.*

### Introduction

The snatch is one of the most technical competitions in the sport of weightlifting. It is a continuous movement aimed to lift the bar from the floor to overhead in one motion. This has to be achieved in no more than three trials at each load. Weightlifters strive to be successful at each attempt by conserving energy required to lift heavier weights in order to gain a sporting advantage over other contestants. Although women's weightlifting achieved Olympic status at the 2000 Olympic Games in Sydney, there still remains a scarcity of research attempting to identify factors determining successful or unsuccessful snatch lifts in female athletes. Stone et al. (1998) stated that success in weightlifting was a multifactorial phenomenon. Therefore, many researchers have attempted to describe and identify the most important biomechanical factors of a successful snatch lift. To date a great majority

of published studies investigating the biomechanics of weightlifting have commonly focused upon the kinematics of the barbell and body segments of elite weightlifters who participated in national (Bartonietz, 1996; Garhammer, 1991; Gourgoulis et al., 2004; Harbili and Aritan, 2005) and international competitions including world championships (Akkus, 2012; Campos et al., 2006; Garhammer, 2001; Szyszka and Mastalerz 2014).

Most of these researchers have analyzed the lifting motion of the barbells during weightlifting competitions in terms of horizontal displacement, vertical linear velocity of the barbell, joint angular displacement and extension velocity (Gourgoulis et al., 2000; Harbili and Alpetekin, 2014; Korkomaz and Harbil, 2015). These factors were investigated during six phases of snatch lifts: the start position before liftoff, the

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first pull, transition, the second pull, the catch and finish (recovery to a standing position) predominantly within a successful attempt.

Gourgoulis et al. (2009) reported that elite weightlifters had similar characteristics regarding their limb and barbell movements during the lift, independent of the weight category (Gourgoulis et al., 2000), gender (Gourgoulis et al., 2002), or age (Gourgoulis et al., 2004). Other authors indicate, however, that there are differences between competitors of different weight categories (Shalmanov et al., 2015; Szyszka and Mastalerz, 2014).

It is surprising that only a few studies have examined biomechanical differences between successful and unsuccessful snatch attempts (Gourgoulis et al., 2009; Hoover et al., 2006; Stone et al., 1998).

Stone et al. (1998) reported that during successful attempts international male weightlifters moved the barbell with greater vertical force and began the second pull from a slightly more backward overhead position. The barbell was in a less backward overhead position. Gourgoulis et al. (2009) reported that the only kinematic variable that differed between successful and unsuccessful snatch lifts of elite weightlifters was the angle of the acceleration vector during the first phase of the snatch. Despite the fact that researchers do provide some evidence about barbell displacement and body motion during snatch lifts, knowledge regarding biomechanical differences in men between successful and unsuccessful snatch attempts is lacking. No studies have been conducted on the efficacy of the approach in female competitors during world championships. Data related to factors that distinguish between a successful and an unsuccessful lift at a specific barbell load could increase the frequency of an athlete's successful snatch lifts. Therefore, the aim of this study was to identify biomechanical factors affecting successful and unsuccessful attempts in women weightlifters during the main competition – World Championships.

## **Methods**

To determine biomechanical factors that differentiate a successful from an unsuccessful lift, 24 kinetic and kinematic variables detailing both barbell movements as well as the athlete's body

movements were studied through 3-dimensional kinematic analysis.

### **Participants**

The study sample consisted of 14 female weightlifters (Table 1) competing during the 2013 World Weightlifting Championships. All of the participants provided informed consent approved by the Józef Pilsudski University of Physical Education in Warsaw ethics committee. The official permissions for video recordings were provided by the Polish Weightlifting Federation and the International Weightlifting Federation. Twenty-eight attempts were analyzed (14 successful and 14 unsuccessful). All of the attempts were conducted using the same barbell weight. The study competitors took from the 1<sup>st</sup> to the 8<sup>th</sup> place in the competition.

### **Design and Procedures**

Two digital cameras were positioned at 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 weightlifter. The snatch lifts were recorded using 2 digital cameras (SONY HD HDR-PJ260VE, Tokyo, Japan), which captured images at 50 frames per second. To determine the 3-dimensional kinematic data of the barbell and the angular kinematics of the body during snatch lifts, 2 points on the barbell and 17 points on the body were digitized manually using the Ariel Performance Analysis System (APAS, San Diego, CA, USA). The digitized points included the heel, front of the foot, ankle, knee, hip, shoulder, elbow, wrist and hand on the right and left sides of the body. The digitized point on the barbell was located on the medial side of the right and left hand. The cameras were synchronized using the liftoff of the barbell, and 3-dimensional coordinates were constructed using the direct linear transformation method. A low-pass digital filter with a cutoff frequency of 4 Hz was used to smooth the raw position-time data. To calibrate the viewing area in 3 dimensions, a rectangular cube with 12 control points of 150-cm length, 150-cm breadth, and 200-cm height was used. The mean reconstruction error was calculated as a difference between the real dimensions of the cube and the ones presented by the APAS system. The values obtained were: length - 1,490 m, breadth - 1,982 m, and height - 1,486 m. The mean reconstruction error in any of the planes did not

exceed 1%.

Statistical analysis of the data revealed no movement asymmetry between the right and the left sides of the body. Hence, further analysis of mean values for both sides of the body was conducted. In this work, the snatch movement was divided into 4 phases (Figure 1): the first pull (1), the second pull (2), the turnover under the barbell (3), and the catch phase (4) (Feher, 2006; Ho et al., 2014; Ikeda et al., 2012). Furthermore, positioning of the athlete during the liftoff was defined into 3 key positions: S - the starting position, T - the suspension, P - preparation for the aerial phase.

The kinematic barbell movement as well as the athlete's body movement variables during the liftoff phase were examined. The duration of the attempts (T) was analyzed. The average and maximal velocities in the entire movement (AV/MV), as well as in all particular phases (1, 2, 3, 4) were assessed. The maximum height of the barbell (hB) and the loss of height during the drop under the barbell (hD) were analyzed. Moreover, the average velocity of the athlete's gravity center during the liftoff (AVCG) in all its phases (1, 2, 3, 4) was calculated. The analysis of angle variables in the identified athlete's positions during the liftoff (Figure 2) was conducted in the knee and hip joints.

### Statistical analyses

The mean and standard deviation (SD) of kinematic variables at 4 phases of the barbell and 3 athlete's body movement during the liftoff in the two successful and unsuccessful lifts were compared using a repeated measures analysis of variance (ANOVA). For comparison within successful and unsuccessful lifts one-way ANOVA was used followed by a *post hoc* Tukey's test. The level of significance was set at  $p \leq 0.05$ .

## Results

The entire duration of the liftoff from phase 1 to 4 was 0.02 s shorter during successful attempts when compared to unsuccessful ones. However, these differences were not statistically significant ( $F(1, 26) = 0.53876, p = 0.46952$ ). Average (AV) and maximal (MV) linear velocity of the entire barbell movement did not differ significantly between successful and unsuccessful attempts (Table 2). In successful attempts the maximal height of the barbell (hB) was on average

0.86 cm higher than unsuccessful attempts and was not statistically significant. The mean loss of height during the drop under the barbell (hD) in successful attempts was 1.14 cm higher than in unsuccessful attempts and this difference was also not statistically significant.

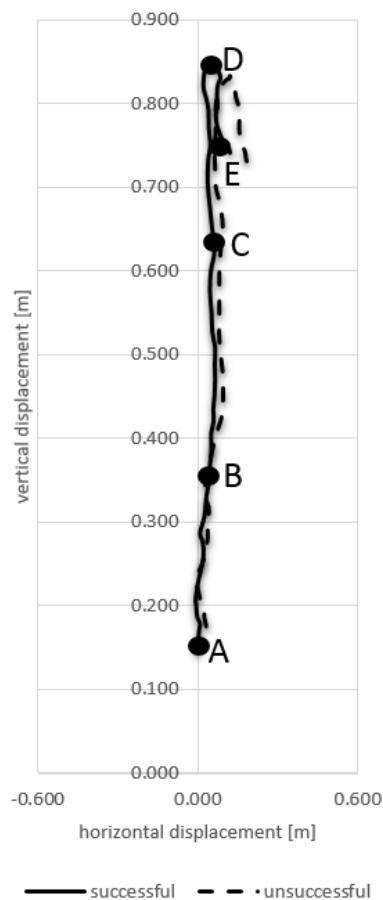
The average and maximal velocities of the barbell were analyzed correspondingly dividing the liftoff into 4 phases. The first three phases were of the same duration in both successful and unsuccessful attempts. The longest phase proved to be the first pull (0.42 s). The following phases were gradually shorter. The second pull lasted 0.31 s, the turnover under the barbell – 0.28 s and the catch phase – 0.24 s for successful and 0.26 s for unsuccessful attempts. The results of ANOVA proved, in both successful and unsuccessful lifts, that the values of AV ( $F(3, 78) = 348.73, p \leq 0.0001$ ) and MV ( $F(3, 78) = 389.59, p \leq 0.0001$ ) were changing congruently in consecutive phases, and were statistically significant (Figure 3). The only exception existed between the second pull and the turnover under the barbell phases where the MV values were not statistically significant in successful attempts ( $p = 0.432$ ). The findings did not show that the AV and MV values in particular phases of the successful and unsuccessful attempts differed significantly. In successful lifts the AV values were lower by 2 cm/s and 1 cm/s in the first and the second pull phase, respectively. They were also identical in the turnover under the barbell phase and were subsequently 3 cm/s higher in the catch phase. In successful attempts, the MV values were lower in the first pull (5 cm/s) and in the turnover under the barbell (3 cm/s). Whereas the higher MV values were observed in the second pull (2 cm/s) and in the catch phase (1 cm/s).

Similarly to the AV and MV values of the barbell, the average velocity of the center of gravity ( $F(3, 78) = 89.326, p \leq 0.0001$ ) in consecutive phases changed significantly (Figure 4). The AVCG in all phases of the snatch was higher in successful attempts ( $F(1, 26) = 4.250, p \leq 0.05$ ). The highest AVCG difference between the successful and unsuccessful lifts occurred in the fourth phase of the snatch (5 cm/s) and was statistically significant (Figure 4).

The angles in the knee and hip joints in successful and unsuccessful lifts were compared in relation to the athlete's position during the

snatch (Figure 5). In both successful and unsuccessful attempts, the angles in these joints increased significantly (knee:  $F(2, 52) = 1215.5, p \leq 0.0001$  and hip:  $F(2, 52) = 9196.1, p \leq 0.0001$ ) in consecutive positions (Figure 5). In all positions, the angle values in the knee and hip joints were

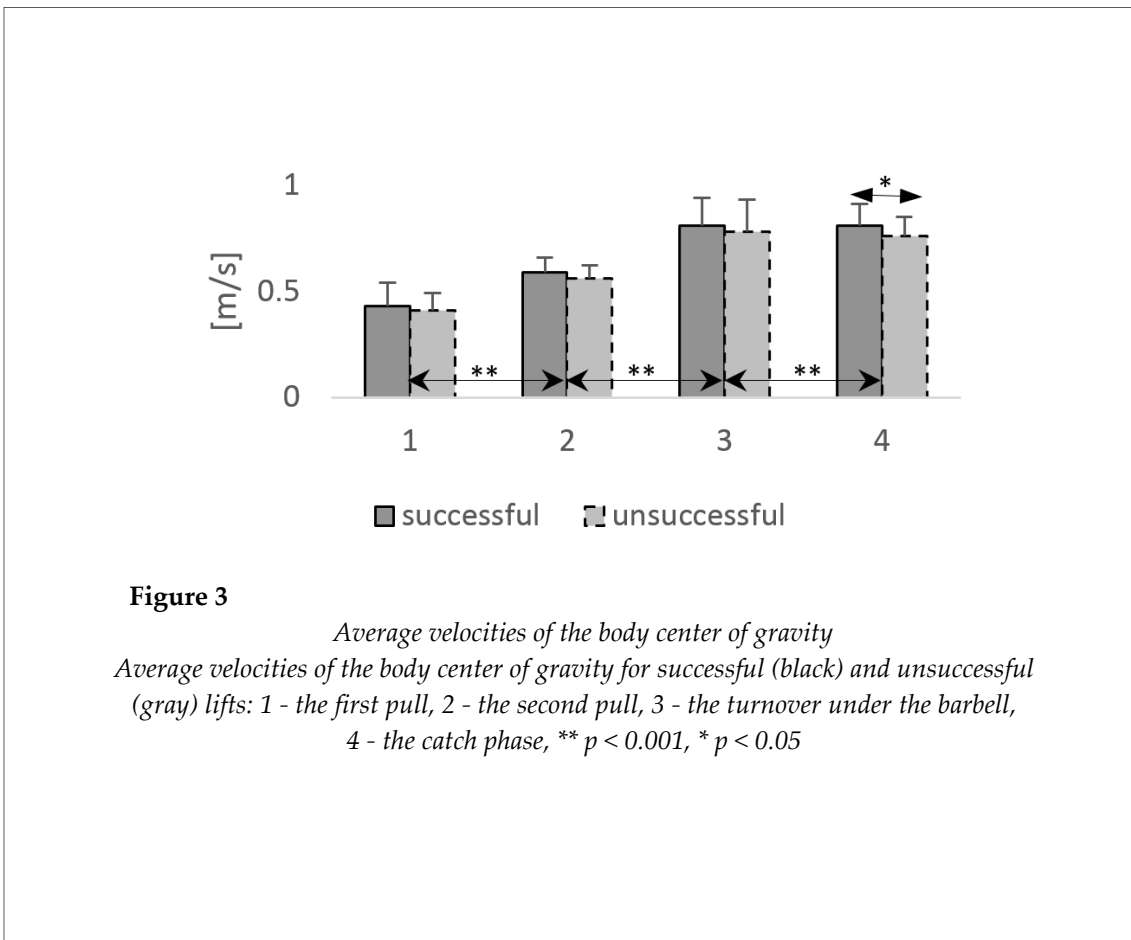
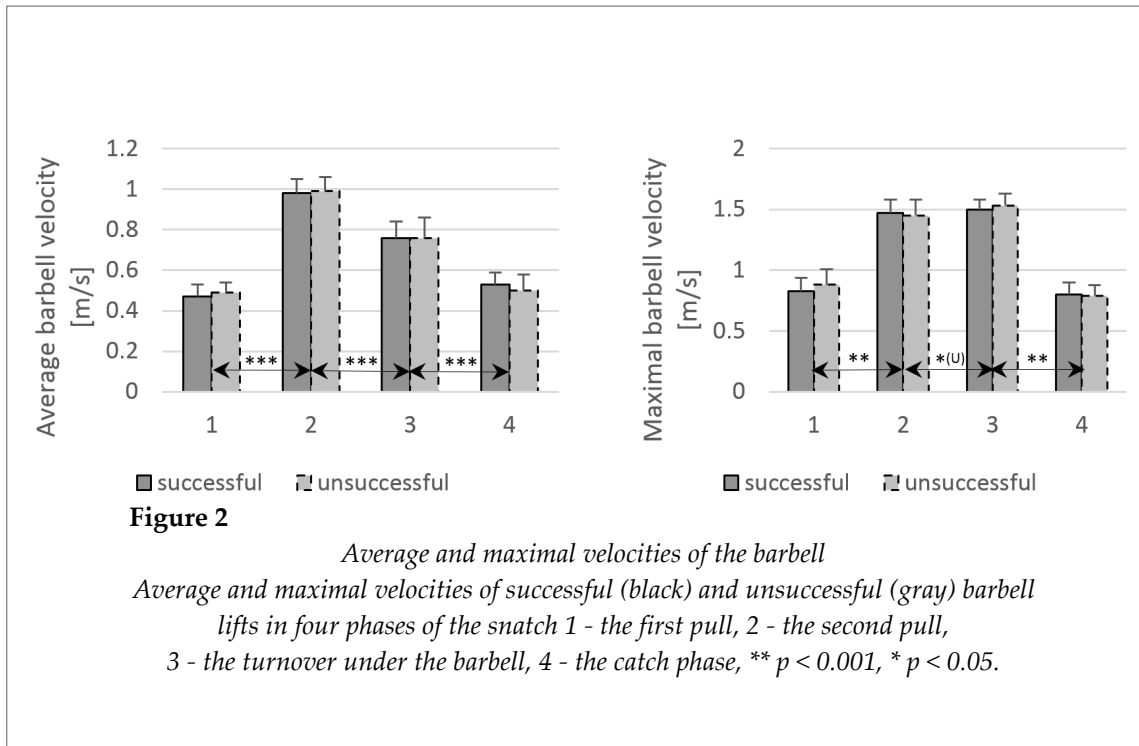
higher during successful attempts (knee:  $F(1, 26) = 5.1870, p \leq 0.05$  and hip:  $F(1, 26) = 4.877, p \leq 0.05$ ). However, statistically significant differences were observed only in preparation for the aerial phase.



**Figure 1**

*Barbell's trajectory*

*A – B = first pull, B – C = second pull, C – D = turnover under the barbell, D – E = catch phase, A - starting position (S), B - suspension position (T), C - position in the preparation for the aerial phase (P).*



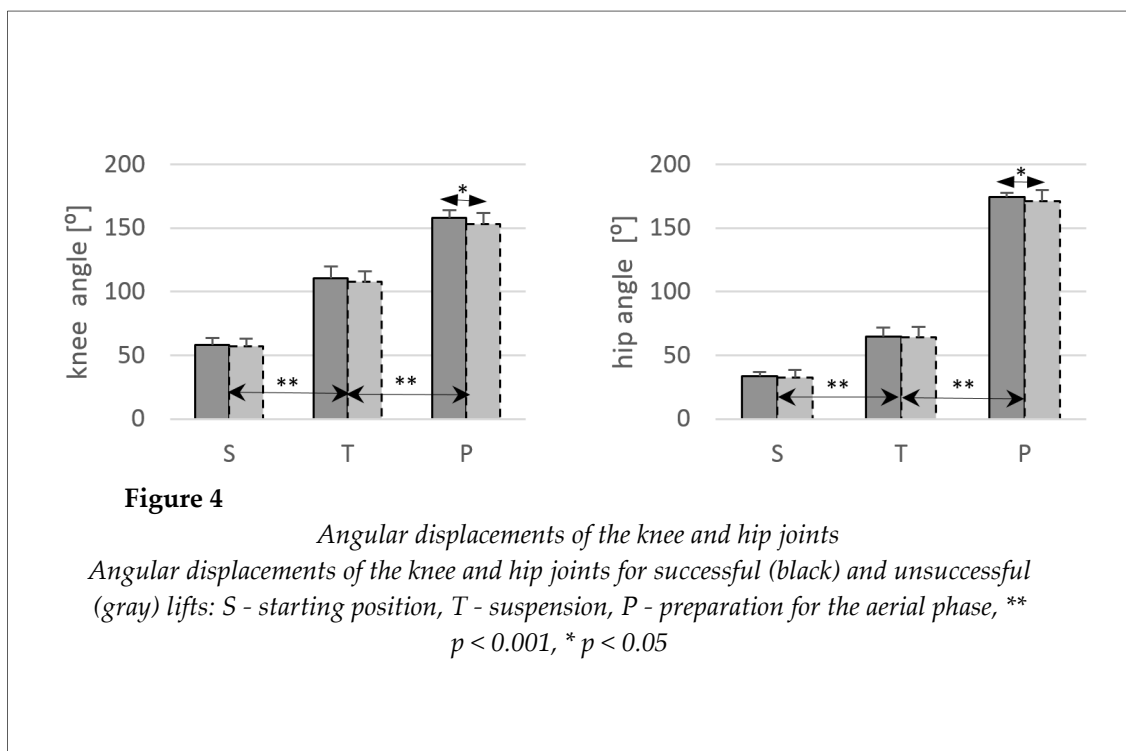


Table 1

*Participants' characteristics*

Place	Body mass [kg]	Body height [cm]	Age [y]	Barbell mass [kg]
1	47.67	149	21	84
3	47.63	153	28	78
6	47.55	160	23	77
7	51.77	150	21	85
1	57.57	157	20	108
5	57.59	159	31	96
3	60.73	162	23	105
5	62.31	160	27	103
7	61.87	163	27	100
7	67.92	158	26	100
8	68.7	163	23	105
2	74	168	20	122
3	74.08	169	28	125
6	91.28	166	36	110

**Table 2***The average values (SD) of barbell variables during successful and unsuccessful attempts*

	Successful	Unsuccessful	F	p
AV [m/s]	0.68 (0.05)	0.68 (0.04)	F(1. 26) = 0.00109	0.97397
MV[m/s]	1.15 (0.06)	1.16 (0.06)	F(1. 26) = 0.22510	0.63914
hB [cm]	88.18 (8.27)	87.32 (7.59)	F(1. 26) = 0.08170	0.77727
hD [cm]	10.00 (3.40)	8.86 (3.40)	F(1. 26) = 0.79050	0.38210

*AV - average velocities of the barbell, MV - maximal velocities of the barbell, hB - maximal height of the barbell, hD - loss of height during the drop under the barbell*

## Discussion

The aim of this study was to identify biomechanical factors affecting successful and unsuccessful attempts in female weightlifters during the World Championships. It was hypothesized that it would be possible to differentiate between successful and unsuccessful snatch attempts by examining barbell and body kinematics and kinetics in particular pull phases. Previous results suggest that women demonstrate performance characteristics that differ subtly from those reported in men weightlifters (Harbili, 2012; Hoover et al., 2006). Stone et al. (1998) noticed that there were many factors that might influence snatch attempt results. Hence, several kinematic variables were examined in this study in order to assist coaches and competitors to better understand Olympic Weightlifting (Burdett, 1982; Kauhanen et al., 1984; Schilling et al., 2002). There are numerous studies examining kinematic and kinetic vertical and horizontal displacement of the barbell in men (Baumann et al., 1988; Garhammer, 1985; Schilling et al., 2002; Stone et al., 1998). However, only limited evidence exists regarding women (Garhammer, 1991, 1998; Gourgoulis et al., 2002). This trend is slowly changing with the emergence of new research analyzing the technique of women weightlifters (Akkus, 1996; Hoover et al., 2006; Ikeda et al., 2012; Korkomaz

and Harbili, 2015). However, the published research does not relate to the biomechanics of successful and unsuccessful snatch attempts of elite women of the same barbell mass during world championship competitions. The results of this study reveal significant differences in the barbell kinematics of the lift between successful and unsuccessful attempts. Regarding the duration of the separate phases of the lift, no significant differences were found between successful and unsuccessful lifts. The duration of the first pull was significantly longer than the other phases of the lift. The movement of the barbell occurs as a result of the rotary motions produced in the lifter's joints and some adequate coordination is needed to minimize any adjustments during the movement of the barbell. The larger the variation in the displacement of the barbell during its movement, the more energy an athlete must expend to control the barbell (Isaka et al., 1996). The reason for this is that any adjustments performed during the lift are of less mechanical efficiency (Hoover et al., 2006). In order to improve a weightlifter's technical skills, various exercises differentiating the barbell velocity are used (Feher, 2006; Urso, 2014). The power snatch is performed with lighter weights at greater speeds when compared to the competitive snatch lift (Waller and Gattone, 2007). In order to improve the speed of the barbell coaches use

snatch modalities such as the hang power snatch and the hang snatch, where the track of the bar is shortened to obtain the optimal speed (Urso, 2014). The present study did not demonstrate any differences in the linear vertical kinematics of the barbell between successful and unsuccessful lifts, except for the maximum vertical linear velocity of the barbell between the second and the third pull. In these two phases a non-significant change of maximum vertical linear velocity for successful lifts was noticed. The linear vertical velocity of the barbell was significantly greater during the second pull, which proves consistent with other studies (Akkus, 2012; Shalmanov et al., 2015). The data from this study indicate that the maximum height of the barbell in female weightlifters in this study was lower than those reported in previous research (Gourgoulis et al., 2009; Harbili, 2012; Hoover et al., 2006; Shalmanov et al., 2015). The height loss from the maximum height of the barbell until the squat position was similar to the drop displacement recorded for men lifters (Hadi et al., 2012; Harbili, 2012; Shalmanov et al., 2015), but less than that of females (Hadi et al., 2012; Harbili, 2012; Hoover et al., 2006). Lifting the barbell effectively requires minimizing two factors: 1) the maximum height of the barbell at the end of the turnover; 2) the loss of height during the drop under the barbell to the catch position (Garhammer, 1985; Gourgoulis et al., 2002; Isaka et al., 1996). A lower maximum height and the drop displacement distance are some of the most important determining factors of an effective maximal snatch lift technique amongst elite female weightlifters. The factors described above are typically not within the lifter's direct control (or that control is minimal) during the snatch. The maximal barbell height is determined by the barbell's velocity achieved through the performance of the snatch, as well as the body kinematics. The motion of the body during the snatch lift affects the path of the bar. Garhammer (1985) demonstrated that anthropometric variables such as segmental lengths and muscle attachment points influenced the optimal barbell path both horizontally and vertically. These variables differ for males and females. For instance, the barbell height in particular phases depends on the angles in the joints, especially of lower limbs, as well as on anthropometric variables (body type). Gourgoulis et al. (2009)

investigated angle positions in the knee joint and did not identify any significant differences in successful and unsuccessful attempts during particular phases of movement. The present study, however, demonstrated that successful and unsuccessful lifts differed in the values of the angles in the knee and hip joints in preparation for the aerial phase. In the remaining positions the differences between the angles in the lower limb joints were not statistically significant. Akkus (2012) analyzed the heaviest successful snatch lifts of 7 female weightlifters who won gold medals at the 2010 World Weightlifting Championships, which was a qualifying competition for the London Games. He noted that the fastest extensions were at the knee joint during the first pull and at the hip joint during the second pull. These findings suggest that the first pull should be executed whilst maintaining the same hip angle throughout the lift. This will enable the lifter to later utilize the conserved power of the legs as well as the hip and back during the second pull. This shows that the first pull is supposed to be performed keeping the same hip angle throughout the lift as it will allow the lifter to use the remaining of her legs in the second pull on top of using her hip and back very powerfully.

The transition from the first to the second pull is recognized as a particularly important phase. To be effective, it should be rapidly executed and with minimal bending of the knees. The motor control of the snatch is dictated by the interaction of key joints or anatomical reference points (Schutts et al., 2017). The effective control of these leading joints will directly influence the success of the various positions and phases of the snatch lift. According to LJJ theory, there is one leading joint that creates a dynamic foundation for the motion of the entire limb (Dounskaia, 2010). The ability to control the location of the leading joint may determine the efficiency of the lifts and is a deciding factor as to whether an attempt is successful or not. However, this study did not reveal such a particular joint. The angular location of both the hip and the knee joints in the entire movement was lower in unsuccessful lifts and in preparation for the aerial phase. Differences in the latter position were statistically significant. The results of Gourgoulis et al. (2002) revealed that between the first and the second pulls, there was less knee flexion amongst women



and that this was also slower in comparison to male lifters. When the body and the barbell are elevated together as one systematic unit, the height and the vertical velocity of the barbell decrease as the barbell weight increases. The kinematics of the body at this stage also change. The most significant indication of this change is the vertical velocity of the CG during the turnover under the barbell. When kinematic characteristics of the above mentioned system were investigated, it was observed that the full extension of the body was realized at the end of the second pull (Hadi et al., 2012). When comparing the angle locations in the joints of the athletes, it can be observed that at the end of the second pull (T- position) in successful lifts the angle values were close to the full extension. Contrary to Gourgoulis et al. (2002) and Korkomaz and Harbili (2015), female weightlifters in the present study showed relatively lower values of extension in the knee and hip joints during the first and the second pulls. This inconsistency with literature was not indicative of a lower level of flexibility in women. Rather, it suggested a weakness in the angular kinematics of the lower limb. In unsuccessful lifts, the lower joints angles in the consecutive positions were accompanied by lower CG velocities, which resulted in the statistically significant difference in the catch phase.

It seems that skilled weightlifters show stable movement patterns of both their limbs and the barbell in successful and unsuccessful lifts. In the present study, however, the significant difference in the position of the knee and hip joint angles and the velocity of the center of gravity between successful and unsuccessful lifts were observed during the fourth pull. This shows the key importance of the appropriate ending of the fourth pull of the lift. Although no significant differences were found in the remaining phases, body kinematics in unsuccessful lifts were slower and the angles in the knee and hip joints were smaller in the entire movement. On the contrary, Gourgoulis et al. (2002) claimed that the

appropriate beginning of the lift was the key factor determining a successful lift.

The differences between these findings and the present study most probably result from the choice of research material, as well as the competition level. Finally, in the present study, based upon the observed differences between successful and unsuccessful lifts, it can be concluded that elite female weightlifters have a greater ability to control kinematics of the barbell rather than their own body. The limitation of this study is that anthropomorphic variables were not taken into consideration.

The limitations observed in this study, as well as in the broader understanding of the swing phenomenon, should be taken into consideration by coaches that work with female weightlifters. This study's results suggest that control of the body movement as well as its analysis are crucial for performance of the snatch lift. Furthermore, the efficacy of the snatch depends upon the optimal execution of all its phases.

## Conclusions

The results of this study confirm that in successful attempts, the angle in the knee and hip joints in preparation for the aerial phase position was higher than in unsuccessful attempts. Weightlifting training should focus on the accuracy of the execution of this position in all the used exercises (snatch pull, power snatch, etc.). Weightlifting training should consider using exercises which demand the correct position of preparation for the aerial phase, for instance a power snatch and a snatch from the hang position. When these exercises are used, the velocity of the barbell during the snatch movement will improve. It was observed that in successful lifts, the center of gravity of the competitor during the catch phase was higher. Hence, exercises such as the drop snatch for instance, that perfect this element, should be included within the training plan.

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