Three-dimensional kinematic analysis of the snatch of elite Greek weightlifters

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We investigated the linear kinematics and the change in energy of the barbell and the angular kinematics of the trunk and leg during the snatch technique of 12 elite male Greek weightlifters under competitive conditions after the new weight classification. Two S-VHS cameras operating at 60 Hz were used to record the lifts. The spatial coordinates of selected points were calculated using the direct linear transformation procedure; after digital filtering of the raw data, the angular displacements and angular velocities were calculated for the hip, knee and ankle joints. The following variables were also calculated for the barbell: vertical and horizontal displacement, vertical linear velocity and acceleration, external mechanical work and power output. The results revealed that all weightlifters flexed their knees during the transition phase, independently of their weight category. This indicates that the athletes use the elastic energy produced during the stretch–shortening cycle to enhance their performance. In nine athletes, we found that the barbell trajectory did not cross a vertical reference line that passed through the initial position of the barbell. The vertical linear velocity of the barbell was increased continuously from the beginning of the movement until the second maximum extension of the knee joint, with no notable dip being observed. Regarding the change in energy of the barbell, we found that the mechanical work for the vertical displacement of the barbell in the first pull was significantly greater than the mechanical work in the second pull. In contrast, the estimated average mechanical power output of the athletes during the vertical displacement of the barbell was significantly greater in the second pull than in the first pull. We conclude that the major elements of the snatch technique of elite Greek weightlifters have not been affected by the new weight classification.

Keywords: barbell kinematics, power, snatch, three-dimensional analysis.

Introduction

Technique, together with explosive strength and flexibility, contributes significantly to performance in weightlifting (Enoka, 1979; Garhammer, 1989). Technique is defined as the optimal coordination of the various limb movements to lift a maximal weight according to the rules of the event.

The snatch technique requires the barbell to be lifted from the floor to a straight-arm overhead position in one continuous movement (Garhammer, 1989). The movement as a whole includes six phases, as shown in Fig. 1: the first pull (a), the transition from the first to the second pull (b), the second pull (c), the turnover under the barbell (d), the catch phase (e) and rising from the squat position (f) (Häkkinen et al., 1984; Baumann et al., 1988).

The first five phases are considered to be the most important phases of the lift (Baumann et al., 1988). They occur in less than 1 s and, as such, involve a high power output (Isaka et al., 1996). According to Garhammer (1991), the average power output for the snatch lift ranges from 1300 to 4000 W in elite male athletes of different weight categories. These values were found to be greater than other power outputs reported in the literature for other activities that began from rest and lasted less than 2 s, such as the bench press or squat (Garhammer, 1991).

Weightlifters use training exercises to improve their snatch technique (Häkkinen and Kauhanen, 1986). These exercises must be specific to maximize the training effect. The design of these specific exercises should be informed by a biomechanical analysis of the
movement and the study of the snatch technique of elite athletes (Vorobyev, 1978).

Previous studies of the snatch technique in competition have been predominantly concerned with the analysis of the trajectory of the barbell and the angular kinematics of the body in the sagittal plane, using only one camera (Enoka, 1979; Garhammer, 1979, 1981, 1985; Rigler and Zsidegh, 1985; Barbas and Fabian, 1989; Isaka et al., 1996). The recording of body movements from the side using one camera generally presents problems. The first concerns the obstructed view of the knees behind the body, while the major portion of movement, particularly at certain critical instants, such as the transition from the first to the second pull (Fig. 1b); this causes inadequate precision in measurement. The second concerns the projection of the three-dimensional body angles into a single sagittal plane; this may overestimate the true values. These problems can be successfully addressed through a three-dimensional analysis using two or more appropriately positioned cameras (Baumann et al., 1988).

A three-dimensional analysis of the snatch movement under competitive conditions was performed by Baumann et al. (1988). They found that the lifters pulled the barbell towards their body during the first pull and the transition phase (Fig. 1a,b). The barbell moved in a vertical and antero-posterior direction at the same time, but its pathway did not cross a vertical reference line that projected upward from the initial position of the bar (Fig. 1). The vertical linear velocity of the barbell was found to increase continuously during the first pull, the transition and the major portion of the second pull (Fig. 1a–c). The mechanical work done on the bar for the vertical displacement of the barbell was greater in the first pull (Fig. 1a); the mechanical power output was greater in the second pull (Fig. 1c).

The above study took place at the 1985 World Championships before the new weight classification. The ten former weight categories (52, 56, 60, 67.5, 75, 82.5, 90, 100, 110, 110+ kg) were reduced to seven (62, 69, 77, 85, 94, 105, 105+ kg). Because of the new weight classification, some athletes had to increase and others had to decrease their body mass to enter their preferred new category. These changes in body mass might have affected the snatch technique of these athletes. The effect that the new weight classification might have had on the snatch technique and the possible differences in technique of elite Greek weightlifters in comparison to other lifters around the world stimulated the present research.

The aim of the present study was to determine the linear kinematics and change in energy of the barbell, together with the angular kinematics of the trunk and the leg, as indicators of the quality of technique during snatch lifts of elite male Greek weightlifters.

**Methods**

**Participants**

The snatch technique of 12 elite male members of the Greek national weightlifting team (Table 1) was recorded under competitive conditions at an international event held in memory of Tofafos-Kakiousis in 1998 in the city of Patra, Greece. The heaviest successful snatch lift, from the three lift attempts of each lifter, was used for analysis.

**Instrumentation**

Two S-VHS cameras (Panasonic PV-900) operating at 60 Hz were used to record the lifts. The shutter speed
was adjusted between 1/250 s and 1/1000 s according to the brightness of the lifter. The two cameras were positioned in a horizontal plane, 15 m from the participants. The optical axis of each camera formed an angle of 45° with the frontal plane of the lifter (Fig. 2a).

Procedure

To determine the angular kinematics of the hip, knee and ankle joints (Fig. 2b) and the barbell kinematics, selected points on the body and barbell were digitized using the Ariel Performance Analysis System (Ariel Dynamics, USA). These points corresponded to the great toe, ankle, knee, hip and shoulder of the two sides of the body. Two additional points were digitized on the barbell at the medial side of the grip of each hand (Fig. 2a). Because of the arrangement of the two cameras, all points were always clearly visible from both cameras.

A metal framework, which formed a rectangular cube 180 cm long, 90 cm wide and 180 cm high, was recorded by both video cameras and used for the calibration of the movement space. The calibration cube was videotaped in lift location and then removed. The three-dimensional spatial coordinates of the selected points were calculated using the direct linear transformation procedure with 23 control points (Abdel-Aziz and Karara, 1971). The raw position-time data were smoothed using a low-pass digital filter. The residual analysis of the difference between filtered and unfiltered data over a wide range of cut-off frequencies was used to select a cut-off frequency of 4 Hz (Winter, 1990).

Table 1. Characteristics of the weightlifters and barbell

<table>
<thead>
<tr>
<th>Lifter</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Body mass (kg)</th>
<th>Weight category (kg)</th>
<th>Barbell mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27</td>
<td>157</td>
<td>61.75</td>
<td>62</td>
<td>130.5</td>
</tr>
<tr>
<td>2</td>
<td>22</td>
<td>158</td>
<td>61.85</td>
<td>62</td>
<td>115.0</td>
</tr>
<tr>
<td>3</td>
<td>25</td>
<td>162</td>
<td>67.20</td>
<td>69</td>
<td>137.5</td>
</tr>
<tr>
<td>4</td>
<td>28</td>
<td>168</td>
<td>65.95</td>
<td>69</td>
<td>132.5</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>171</td>
<td>76.70</td>
<td>77</td>
<td>150.0</td>
</tr>
<tr>
<td>6</td>
<td>22</td>
<td>173</td>
<td>76.20</td>
<td>77</td>
<td>147.5</td>
</tr>
<tr>
<td>7</td>
<td>27</td>
<td>179</td>
<td>84.85</td>
<td>85</td>
<td>165.0</td>
</tr>
<tr>
<td>8</td>
<td>25</td>
<td>181</td>
<td>91.85</td>
<td>94</td>
<td>157.5</td>
</tr>
<tr>
<td>9</td>
<td>22</td>
<td>179</td>
<td>92.60</td>
<td>94</td>
<td>160.0</td>
</tr>
<tr>
<td>10</td>
<td>29</td>
<td>188</td>
<td>94.05</td>
<td>105</td>
<td>150.0</td>
</tr>
<tr>
<td>11</td>
<td>19</td>
<td>180</td>
<td>104.35</td>
<td>105</td>
<td>160.5</td>
</tr>
<tr>
<td>12</td>
<td>23</td>
<td>178</td>
<td>110.75</td>
<td>105+</td>
<td>145.0</td>
</tr>
</tbody>
</table>

Determination of the phases of the lift

The analysis focused on the snatch technique from the beginning of the barbell lift-off to the instant at which the lifter dropped under the barbell and caught the barbell overhead. This motion (Fig. 1a–e) is considered to be the most important and technically the most difficult part of the whole movement (Baumann et al., 1988). The movement was divided into five phases (Fig. 1a–e), according to the change in direction of movement of the right knee angle (Häkkinen et al., 1984) and the height of the barbell (Baumann et al., 1988), as follows:

• **The first pull**: from the barbell lift-off until the first maximum right knee extension.
The transition from the first to the second pull: from the first maximum right knee extension until the first maximum right knee flexion.

The second pull: from the first maximum right knee flexion until the second maximum extension of the right knee.

The turnover under the barbell: from the second maximum extension of the right knee until the achievement of the maximum height of the barbell.

The catch phase: from achievement of the maximum height of the barbell until stabilization in the catch position with the barbell overhead.

Data analysis

The angular displacements and velocities of the ankle, knee and hip joints in the sagittal plane were calculated to determine the movement of the leg and the trunk (Fig. 2b). To study the barbell’s movement, the vertical components of linear displacement, velocity and acceleration of the barbell were calculated, using the point on the barbell at the medial side of the grip of the right hand. The horizontal displacement of the barbell was also calculated from a vertical reference line that passed through the position of the barbell before lift-off (Isaka et al., 1996). The work done on the barbell during the first and the second pull was calculated from the change in the barbell’s potential and kinetic energy. The power output of the lifter during the first and the second pull was estimated by dividing the work for each phase by the duration of the corresponding phase (Garhammer, 1993).

A t-test for dependent samples was used for the statistical treatment of the joint angular velocity, mechanical work and power output data. One-way analysis of variance for dependent samples was used to assess the differences between the duration of the various phases of the lift. Moreover, the coefficient of variation (CV) was calculated from the equation:

\[
CV = \frac{s}{\bar{x}} \times 100
\]

where \(\bar{x}\) and \(s\) are the mean and standard deviation respectively. The coefficient of variation was used to determine the variation in the barbell’s horizontal and vertical displacements in the sagittal plane among the athletes.

Results

Joint angular displacements

During the first pull, the knee joint is extended (Fig. 3). The mean (± s) knee angle at the end of the first pull (Fig. 1a) was 143 ± 5.19°. During the following transition from the first to the second pull (Fig. 1b), the knee angle was decreased about 22.2 ± 4.45° and the knee was moved forward by 15.5 ± 3.03 cm. After achievement of the minimum knee angle, which marked the start of the second pull (Fig. 1c), the knee was explosively extended and reached its maximum extension (Table 2) at the end of the second pull. The ankle joint was extended continuously during the first pull and then decreased during the transition phase. During the second pull, the ankle joint was explosively extended and reached its maximum at the end of the second pull (Table 2). The angle at the hip increased continuously over the first pull, the transition and the second pull, to a maximum that coincided well with the maximums of the other two joint angles. In fact, all three lower limb angles reached their maximums within 40 ms of one another, at the end of the second pull (Fig. 1c).

Joint angular velocities

Figure 4 illustrates typical curves for joint angular velocities. The maximum extension velocities of the hip, knee and ankle joints in the second pull were significantly greater (hip: \(t_{11} = 19.5, P < 0.001\); knee: \(t_{11} = 10.7, P < 0.001\); ankle: \(t_{11} = 16.2, P < 0.001\)) than their maximum extension velocities in the first pull (Table 2). In the second pull, the maximum extension velocity of the hip joint was significantly greater than the respective maximum extension velocities of the knee joint \(t_{11} = 5.89, P < 0.001\) and the ankle joint \(t_{11} = 14.0, P < 0.001\).

Barbell trajectory

The results show that, during the first pull and the transition from the first to the second pull (Fig. 1a, b), the barbell was moved about 6.20 ± 2.23 cm in an

<table>
<thead>
<tr>
<th>Table 2. Joint angular kinematics (mean ± s)</th>
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<tbody>
<tr>
<td><strong>Joint angular displacement (°)</strong></td>
</tr>
<tr>
<td>First knee extension (end of first pull)</td>
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<tr>
<td>Decrease in knee angle (during the transition phase)</td>
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<tr>
<td>Maximum knee extension (end of second pull)</td>
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<tr>
<td>Maximum ankle extension</td>
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<tr>
<td>Maximum hip extension</td>
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<tr>
<td><strong>Maximum joint angular velocity (rad · s⁻¹)</strong></td>
</tr>
<tr>
<td>Knee extension velocity in the first pull</td>
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<td>Knee extension velocity in the second pull</td>
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<td>Ankle extension velocity in the first pull</td>
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<td>Ankle extension velocity in the second pull</td>
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<tr>
<td>Hip extension velocity in the first pull</td>
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<td>Hip extension velocity in the second pull</td>
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antero-posterior direction towards the lifter. During the second pull, the barbell was moved about 3.17 ± 4.18 cm away from the lifter, without crossing the vertical reference line passing through the position of the bar before lift-off in nine athletes (Fig. 5).

After achieving maximum height of the barbell (1.21 ± 0.08 m), which marked the end of the turnover phase, stabilization in the catch position followed. In the catch phase, the height of the barbell was decreased by about 13.5 ± 2.77 cm (Table 3).
The results also reveal that the horizontal displacements of the barbell in the sagittal plane showed the greatest variations between athletes. The coefficient of variation for the horizontal barbell displacement towards the lifter in the first pull and the transition was 35.9% and for the horizontal displacement away from the lifter in the second pull the coefficient of variation was 132%. On the other hand, the coefficient of variation for the normalized maximum height of the barbell (maximum barbell height/lifter height) was only 3.3%; the respective coefficient for the loss of the barbell's height in the catch phase was 22.1%.

**Vertical linear velocity of the barbell**

The vertical linear velocity of the barbell reached its maximum (1.67 ± 0.10 m·s⁻¹) approximately 30 ms before the end of the second pull (Fig. 6). At the end of the first pull, the vertical linear velocity of the barbell was 74.4 ± 7.66% of its maximum. In six of 12 lifters, a slight decrease in velocity (0.05 ± 0.04 m·s⁻¹) was observed during the transition from the first to the second pull, resulting in negative values of the barbell’s vertical linear acceleration. However, the decrease in velocity during the transition phase was only 2.71 ± 1.96% of the barbell’s maximum linear velocity.

**Duration of the phases of the lift**

The durations of the four critical phases were significantly different ($F_{1,11} = 223.76, \ P < 0.001$). A Scheffé post-hoc test showed that the duration of the first pull (0.47 ± 0.06 s) was significantly greater than the duration of the second pull (0.16 ± 0.01 s), the transition phase (0.15 ± 0.01 s) and the turnover under the barbell (0.23 ± 0.02 s).

**External mechanical work and power output**

The external mechanical work for the vertical displacement of the barbell during the first and second pulls and from the initiation of the lift to achievement of the
The barbell’s maximum vertical velocity is shown in Table 3, together with the estimated power output of the lifter for the same periods. The mechanical work for the vertical displacement of the barbell in the first pull was significantly greater ($t_{11} = 6.34, P < 0.001$) than the mechanical work in the second pull. On the other hand, the estimated power output of the lifters was significantly greater ($t_{11} = 18, P < 0.001$) during the second pull than during the first pull.

**Discussion**

**Joint angular displacement and extension velocity**

The same pattern of leg and trunk movement was observed in all weightlifters, independently of their weight category. The knee angle reached a first maximum extension in the first pull and then decreased briefly in the transition from the first to the second pull. In this phase, the knees were pushed towards the barbell, helping the lifter ease into the second pulling phase, while the hips were continuously extended. The smallest knee angle marked the beginning of the second pull, in which the ankle, knee and hip joints extended explosively, reaching maximum extension during this phase. The hip was the first joint to achieve its maximum angular velocity early in the second pull. Then, the knee reached its maximum extension velocity followed by the ankle (Fig. 4).

The flexion of the knee during the transition phase before its maximum extension during the second pull has similar effects to those observed in the counter-movement in vertical jumping (Garhammer, 1992). It permits the use of stored elastic energy and facilitates the stretch reflex of the knee extensors to develop the explosive muscle power required during the lift (Enoka, 1979; Garhammer, 1989; Isaka et al., 1996). Consequently, the transition phase is very critical and should be executed quickly with a small knee flexion to be effective (Bartonietz, 1996).

The results also show that the maximum extension velocities of the knee and hip joints during the second pull were greater than in the first pull. The instantaneous values of hip extension velocity were greater than the respective values for knee extension velocity during the transition and the first half of the second pull (Fig. 4). Faster execution of the second pull, compared to the first pull, both at the hip and knee joints, was also reported by Baumann et al. (1988), showing the explosiveness of the second pull. As mentioned earlier, during the second pull, the hip was explosively extended followed by extension of the knee. Then, the lifters used a powerful ankle plantar flexion, raising the heels. According to Weide (1989), this powerful plantar flexion has been used by many elite weightlifters and is essential for the vertical acceleration of the barbell, contributing about 10% of the maximum barbell velocity.

**Kinematic characteristics of the barbell**

Movement of the barbell is the result of forces applied on it by the weightlifter. The displacement-time and velocity-time relationships are often seen practically as the most important criteria for assessing lifting technique (Baumann et al., 1988; Garhammer, 1989).

**Barbell trajectory.** During the first pull and the transition from the first to the second pull, the barbell was moved towards the lifter. The horizontal displacement of the barbell, according to the vertical reference line passing through the position of the barbell before lift-off, had a mean value of 6.20 cm, which is in close agreement with the results of Garhammer (1989). During the second pull, the barbell was moved away from the lifter, whereas it was moved towards the lifter again at the turnover under the bar (Fig. 5).

During the lift, the rapid extension of hip, knee and ankle joints pull the athlete’s body backwards, mainly because of the larger contribution of the hip extensors. These joint movements induce a great amount of the barbell’s vertical displacement, but also a small horizontal displacement of the barbell, because the lifter's
Fig. 6. Typical curves of the barbell’s vertical linear velocity and acceleration.

upper limbs are almost fully extended. This unavoidable horizontal displacement of the barbell during the lift may be considered an estimate of the effective application of muscle power, provided that it is minimal (Isaka et al., 1996). According to Baumann et al. (1988), the extent of these horizontal movements indicates the instability involved or the correction required to complete the lift. This parameter also serves as a measure of the additional horizontal mechanical work that must be produced, which should also be minimal.

The maximum height attained by the barbell at the end of the turnover phase depends on the height of the lifter and, on average, it was found to be 70.7% of the lifter’s height, with a small variation of 1.6%, similar to the findings of Baumann et al. (1988).

The vertical drop from maximum height achieved to catch position had a very small mean value of 11.3% of the maximum height of the bar. This is in line with the results of previous studies (Baumann et al., 1988; Isaka et al., 1996). Minimization of the barbell’s
vertical drop from maximum height achieved to catch position is considered to be important for effective technique (Isaka et al., 1996). A large vertical drop of the barbell, in relation to the maximum height achieved, shows that the barbell was lifted much higher than was necessary to permit the athlete to drop under the barbell.

Addressing the coefficients of variation of the horizontal and vertical barbell displacements, we can see that the greatest variations between the athletes were in the horizontal displacements of the barbell in the sagittal plane, as reported by Rigler and Zhidegh (1985).

In this study, the trajectory of the barbell did not cross the vertical reference line projected upward from the initial position of the bar in most cases. Rather, the barbell was pulled towards the lifter during the snatch movement, especially from the first pull to the transition phase. This technique – used during the first pull and the transition phase – probably requires the body to be inclined away from the vertical; the resulting barbell trajectory follows the inclination of the body. A similar pattern of barbell trajectory was reported by Garhammer (1985, 1989), but his results showed the trajectory crossed the vertical reference line. The patterns of barbell trajectory seen in this study were similar to those of top male Asian weightlifters (Isaka et al., 1996) and world-class weightlifters at the 1985 World Weightlifting Championships (Baumann et al., 1988). All the lifters jumped backwards, momentarily leaving the ground in the turnover phase, after pulling the barbell towards them. This was also observed by Baumann et al. (1988) and Isaka et al. (1996), although it was previously considered to be an undesirable technique by Vorobyev (1978).

**Vertical linear velocity of the barbell.** The curve of the vertical linear velocity of the barbell is important for assessing lifting technique (Baumann et al., 1988; Isaka et al., 1996). From a biomechanical point of view, an effective snatch lift is characterized by a velocity–time relationship of the barbell in which the vertical linear velocity of the barbell increases continuously between the first and the second pull (Bartonietz, 1996).

In the present study, the vertical linear velocity of the barbell increased almost continuously, until a single maximum was reached during the second pull phase. No notable dip in velocity was observed during the transition phase. This is an indicator of a good and effective technique and means that the lifter is able to pull the barbell smoothly during the transition phase, with no marked deceleration of the barbell (Bartonietz, 1996; Isaka et al., 1996). On the other hand, the existence of two clear velocity peaks indicates an ineffective technique (Baumann et al., 1988).

The negative vertical linear acceleration of the barbell during the transition phase should be considered thoroughly. Even elite weightlifters sometimes show a decrease in barbell velocity during the transition phase, possibly because of too fast a starting movement or fatigue (Bartonietz, 1996). In the present study, the weightlifters who decelerated the barbell during the transition phase were characterized by higher percentages of their maximum velocities at the end of the first pull. However, the loss of the barbell’s vertical linear velocity was only a small percentage of its maximum vertical linear velocity and did not cause any notable decrement in performance.

**External mechanical work and power output**

The snatch lift occurs very rapidly, with propulsion of the barbell against gravity taking less than 1 s. Weightlifters are required to generate great muscular power during the lift and to transfer this power effectively to the barbell (Garhammer, 1985, 1993).

As shown in the present study, in the first pull the mechanical work done on the bar to achieve vertical displacement of the barbell was significantly greater than the mechanical work done in the second pull. In contrast, the mechanical power output was significantly greater in the second pull than in the first pull, because of the very short duration of the second pull. During the first pull, the changes in the barbell’s kinetic and potential energy were greater and the lifters had to produce considerable work over a long period to overcome the inertia of the barbell. On the other hand, the second pull had a shorter duration and the lifter had to produce work much faster than in the first pull. In line with Garhammer (1991), the first pull is considered to be strength-oriented, whereas the second pull is considered to be more power-oriented.

**Conclusion**

The characteristics of the snatch technique of elite male Greek weightlifters were examined after the new weight classification. The results revealed that all weightlifters flexed their knees during the transition phase, independently of their weight category. This indicates that the lifters use the elastic energy produced during the stretch–shortening cycle to enhance their performance. In most cases, the trajectory of the barbell did not cross the vertical reference line that passed through the position of the barbell before lift-off. The barbell’s vertical linear velocity was increased continuously with no notable dip. During the shorter second pull, the lifters produced less mechanical work but greater power output than in the first pull. The above results
are in accordance with the results of previous studies conducted with other elite athletes before the change in weight classification.

References


