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Intra-individual comparison of the jumps of Stefka Kostadinova at the II World Championships in Athletics Rome 1987 and the Games of the XXIV Olympiad Seoul 1988

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"The authors present a very thorough biomechanical analysis and comparison of Stefka Kostadinova's performances at the world's two premier competitions. The purpose is to try to explain the Bulgarian jumper's unexpected failure at a height she had cleared numerous times. According to the authors, a possible explanation can be found in the run-up surface in Seoul that hindered the athlete during the initial phase of the run-up"

1. Introduction

Bulgarian Stefka Kostadinova has been the dominant female high jumper of the past five years. The World Record holder, European Champion, World Champion and winner of nearly every international competition during that period, her only "failure" was at the Games of the XXIVth Olympiad in Seoul. There she received the silver medal after she was surprisingly upset by the American Louise Ritter. Although Ritter's performance of 2.03m was truly excellent and a new Olympic Record, it was a height that Kostadinova had cleared in competition on no less than twenty nine occasions, including her World Record of 2.09m.

The purpose of this study is to investigate whether Kostadinova's defeat in Seoul can be explained by biomechanical characteristics. To do this we have compared biomechanical data from her jumps at the Olympics with those of her jumps at the II World Championships in Athletics in Rome, 1987 where she set her World Record.

2. Methods and procedures

2.1 Filming

The attempts in the women's high jump events in both Rome and Seoul were filmed with 16 mm high speed cameras. Three cameras were used in Rome and two were used in Seoul. In both cases the cameras were synchronized externally. The nominal frame rate was 150 frames per second in Rome and 200 frames per second in Seoul.

The competition in Rome was filmed with fixed cameras. Spatial orientation and three dimensional transformation were made possible by reference landmarks positioned in the background of the competition area as shown in Figure 1. In addition, both before and after the competition, a reference frame was filmed as a backup means of spatial reference.

For the competition in Seoul, both cameras were panned on a common horizontal plane. Land marks and a reference frame were employed in the same ways as in Rome.

For each trial, two views were digitized and saved ''online'' on a computer so that the calculation of the three-dimensional coordinates and the performance-relevant parameters was possible. The attempts listed below (see following page), including clearances (o) and misses (x), were analyzed and the performance-relevant parameters were calculated.

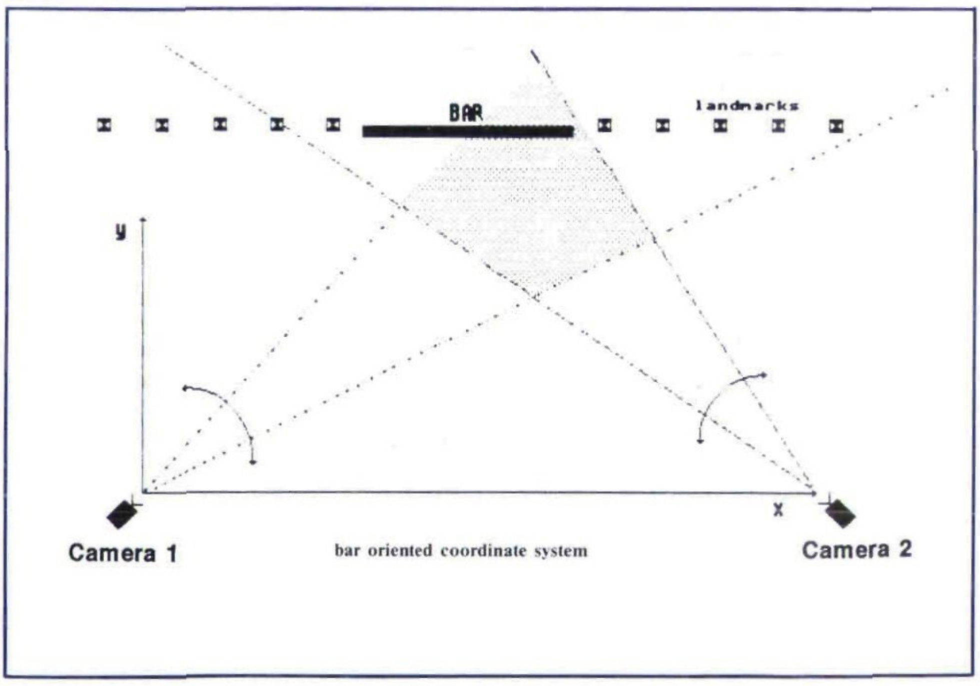

Figure 1: Position of cameras and landmarks for the women's high jump at the II World Championships in Athletics in Rome, 1987

Analysed attempts	
Rome 1987	**Seoul 1988**
2.09m (o)	2.03m (x)
2.09m (x)	2.01m (o)
2.06m (o)	1.99m (o)
2.06m (x)	
2.04m (o)	
2.02m (o)	
1.99m (o)	

2.2 The biomechanics of the high jump

From a practical point of view, the high jump may be considered as consisting of three consecutive parts:

1. The Approach - from the moment the athlete starts towards the bar until the moment of touch-down (TD) for take-off;

2. The Take-off - from the moment of touch-down until the moment when the take-off foot breaks contact with the ground (the moment of take-off (TO);

3. The Flight - from the moment of TO until the instant of landing;

According to HAY (1973), from a biomechanical point of view, the take-off and the flight in the high jump can be separated into three partial heights:

Take-off height (H1)- the height of the athlete's centre of mass (CM) at the instant of take-off;

Height of CM flight (H2)- the difference between maximum height of the athlete's CM during the flight and H1;

Height over the bar (H3) - the vertical distance between H2 and the height of the bar.

For the following interpretation of relevant parameters of the jumps analysed, a combined procedure of practical and biomechanical approaches has been chosen.

2.3 Parameters calculated

The Take-off height of an athlete is determined by anthropomorphic parameters such as body segment masses, segment lengths, the location of the centres of mass in the body segments. In addition, the Take-off height is influenced by the body angles at the moment when the athlete leaves the ground. Therefore, in addition to the resulting Take-off height, the following parameters are considered in our study:

— knee angle of the take-off leg at TO

— angle of lead leg thigh at TO

— angle of trunk position at TO

— angles of forward/backward and inward lean at TO.

The vertical velocity of the CM at TO determines the height of flight of the CM. The vertical take-off velocity itself is determined by the vertical impulse, the vertical velocity of the CM at TD and the jumper's mass.

For practical purposes the emphasis should be on identifying those parameters which enable the athlete to generate a maximum vertical velocity.

In a first approach, we can separate the conditions at TD and the activities during take-off itself.

The conditions at TD depend on the pattern of the last steps. Therefore the following parameters are considered:

— support and flight times

— stride lengths and frequencies

— path of the CM

— angle of run-up

— horizontal, vertical and resulting velocities.

As far as the take-off itself is concerned, the following aspects are considered:

— support time
— distance from the bar
— vertical path of CM
— angle of take-off
— body segment and body position angles at TD and TO
— horizontal, vertical and resulting velocities.

By using the above listed parameters and aspects, the parameters which are of direct practical relevance to performance may be quantified.

3. Results and discussion

3.1 Partial heights

Traditionally, the final height reached in the high jump is separated into three partial heights as mentioned above (HAY, 1973). The sum of these partial heights is the overall maximum height of the CM.

On her analysed unsuccessful attempt at 2.03m in Seoul, it was determined that Kostadinova reached an overall height of 2.25m, a value never measured before in the women's high jump. Even in her World Record, the overall height was ''only'' 2.15m.

In all the attempts analysed from the final in Rome, her Take-off height was almost constant as it only varied between 1.14 and 1.17m. In Seoul, we found that her Take-off height varied between 1.14 and 1.23m, or 9 cm, which may be regarded as the first indicator of the instability of her technique in this competition.

Nevertheless, her Height of cm flight, which is a result of the vertical impulse produced during take-off, was found to be excellent. Her H2-values of 1.00 and 1.01m have only been matched

Table 1: Partial heights of analysed attempts

	H1	H2	H3
Rome 1987			
2.09m (o)	1.16m	0.96m	0.03m
2.09m (x)	1.17m	0.91m	-0.01m
2.06m (o)	1.17m	0.95m	0.06m
2.06m (x)	1.17m	0.97m	0.08m
2.04m (o)	1.15m	1.00m	0.11m
2.02m (o)	1.16m	0.92m	1.96m
1.99m (o)	1.14m	0.93m	0.11m
Seoul 1988			
2.03m (x)	1.14m	1.00m	0.11m
2.01m (o)	1.23m	0.88m	0.08m
1.99m (o)	1.18m	1.01m	0.20m

once before, namely in her successful attempt over 2.04m in Rome. Even on her World Record jump her H2 was "only" 0.96 m.

From this evidence there is no sign that, in Seoul, Kostadinova was in any worse physical condition than she was in Rome. The data for Height over the bar, however, is interesting. Despite an H3 of 11 cm, Kostadinova failed to properly clear the bar on the analysed 2.03m attempt. On the other hand, on her World Record 2.09m in Rome the H3 was only 3 cm. This indicates that the main focus of our study should, therefore, be on the flight phase and bar clearance. However, the flight phase is not an independent parameter as the path of the CM cannot be changed after the jumper has left the ground.

Thus, the first question must be: Were there any obvious changes in take-off preparation or in the take-off itself that may have been responsible for the poor bar clearance.

3.2 Run-up

A second hint of Kostadinova's technique problems is given by the stride lengths in the final part of her run-up. Her last two strides in Seoul were slightly longer than her norm in previous competitions. There is also a slight tendency towards lengthening of her last step as compared with the penultimate one.

The ratio of support times to flight times in the final strides, however, is even more important. Although a comparison of high jumpers in the finals in both Rome and Seoul shows that, as far as this ratio is concerned, there is no common tendency, an intra-individual analysis of Kostadinova's jumps reveals the following trend for her jumps in Rome. Normally, in the last three strides the support time gets longer, whereas the flight time gets shorter.

These findings contrast with the Seoul results. Twice the flight time of Kostadinova's last stride is longer than that of her penultimate stride, and these are followed by extremely short take-off times.

The comparison of the CM heights during the run-up reveals a surprising result. During Kostadinova's successful attempts over 1.99m and 2.01m in Seoul, the heights of the CM at the moment of TD, maximum amortization and TO are markedly higher (5 - 10 cm) than in her unsuccessful attempt over 2.03m. However, in this attempt over 2.03m, the values measured are almost identical with the values measured on her winning jump in Rome.

Therefore, the general lowering of the CM in the 2.03m jump cannot be regarded as a decisive indicator.

The lowering of overall CM height on this attempt goes hand in hand with a reduction of run-up speed by about 0.5 m/s as compared with her previous jumps in Seoul. However, the values of 7.1 m/s for the penultimate stride and 7.3 m/s for the last stride are still within Kostadinova's normal variation.

As far as her body-lean angles are concerned, the situation is similar: Both the inward lean and the forward/backward lean do not deviate very much from the mean values of the Rome jumps.

To sum up: There were some differences between Kostadinova's run-ups in Seoul and Rome. However, these differences cannot really explain the enormous deficits in the flight phase and bar clearance.

3.3 Take-off

The differences between the support times during Take-off are greater than those between the run-ups. In Seoul, Kostadinova's support times were 115-125 m/s on the analysed jumps, which is extremely short when compared with her normal support time of about 140 ms, which is itself not very long.

Such short contact times as Kostadinova displayed in Seoul require a short amortization during take-off. Consequently, her knee angle, which is an indicator of amortization, remains at about 150 degrees, which is 10 degrees more than measured during her jumps in Rome. However, these differences cannot be interpreted as faults. Kostadinova's vertical take-off velocity of 4.43 m/s in her jump over 1.99m and 4.43 m/s in her unsuccessful attempt over 2.03m are values never measured before for women, not even in her World Record jump. These velocities are about the same as the mean recorded by male jumpers.

Table 2: Support times at take-off

Rome 1987	
2.09m (o)	0.140 s
2.09m (x)	0.140 s
2.06m (o)	0.140 s
2.06m (x)	0.133 s
2.04m (o)	0.133 s
2.02m (o)	0.127 s
1.99m (o)	0.127 s
Seoul 1988	
2.03m (x)	0.125 s
2.01m (o)	0.115 s
1.99m (o)	0.125 s

Table 3: Vertical velocities at take-off

Rome 1987	
2.09m (o)	4.34 m/s
2.09m (x)	4.23 m/s
2.06m (o)	4.31 m/s
2.06m (x)	4.37 m/s
2.04m (o)	4.42 m/s
2.02m (o)	4.26 m/s
1.99m (o)	4.27 m/s
Seoul 1988	
2.03m (x)	4.43 m/s
2.01m (o)	4.10 m/s
1.99m (o)	4.46 m/s

These findings confirm the above statement that insufficient Height of flight was not responsible for Kostadinova's failure.

Therefore, the cause of Kostadinova's failure at a height she would have been expected to clear easily must be incorrect distance from the bar at TO. On the three analysed jumps, this distance ranged between 0.54m and 0.77m, far closer than the 0.87m to 0.98m of the analysed jumps in Rome. Considering that Kostadinova's take-off angle was 46 degrees, her closeness to the bar in Seoul created difficulties for efficient clearance of the bar as the highest point of her flight curve was not reached over the bar, but 0.07 to 0.56m behind it.

To sum up: During the women's high jump final at the Games of the XXIVth Olympiad in Seoul, Stefka

Kostadinova was in excellent physical condition. This can be proved by the extraordinary Heights of flight she reached on all her jumps. Both her preparation and her execution of the Take-off were also free of faults. However, there was one decisive deviation from her normal technique pattern: the toe to bar distance at TO was much too short.

The most reasonable explanation of this very untypical fault in a top level high jumper may be the run-up surface. In Seoul, where the landing pit was placed just inside the curve of the track, the first, preparatory strides of Kostadinova's run-up were conducted on grass, and her real run-up started at the demarcation line between the grass and the synthetic surface. This made it difficult for Kostadinova to start her run-up in a proper and consistent way.

This can be regarded as an explanation, not only for the great amount of intra-individual variation but also for the incorrect take-off point, and was confirmed sometime after the Olympics in a personal conversation with Kostadinova and her coach who also agreed that an inconsistent run-up had been the cause of the problems in Seoul. □

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