A KINEMATIC ANALYSIS OF AN ELITE FEMALE TRIPLE JUMPER

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The long jump and the triple jump are the two horizontal jumping events in track and field. While a considerable amount of attention has been given to the analysis of the long jump, only a few biomechanical research studies have been devoted to the analysis of the triple jump (Fukashiro et al., 1981, 1983,; Hay, 1975; Hay, Miller, 1985; Knoedel, 1985; Ramey, 1982; Smith, Haven, 1980). None of these studies, however, has included the analysis of changes in a jumper's performance over time and none has included women triple jumpers. Hay and Miller (1985, p. 135) state that the paucity of research on the triple jump "is somewhat surprising, given that with three times as many takeoffs and landings the event makes much greater technical demand on those who compete in it than does the long jump."

The triple jump is a new event for women in national and international competition and performance levels are changing rapidly. Of particular interest are the specific technique changes which will contribute to the athlete's attainment of the highest level of performance.

The subject of this study had a previous outstanding record as both a long jumper and a high jumper. With the advent of competitive opportunities for women in the triple jump the subject began training for this event in 1983. The principal author of this study was serving as an assistant track coach in the fall of 1984. He had observed this athlete and predicted that with appropriate training and practice, she had potential for becoming an outstanding triple jumper. With that as a possibility, the authors of this study were interested in recording her progress prior to extensive training and practice in the triple jump at the beginning of the 1984-1985 track season and again, near the end of the 1984-1985 track season, and one year later during the 1986 Big Ten Track and Field Championships.

The purpose of this study was to analyze the film records taken at the beginning of the 1984-85 track season and to make specific recommendations related to improving the subject's triple jump technique. The subject was filmed again 5 months later, in order to compare pre and post season kinematic characteristics and relate those kinematic characteristics to changes in each phase and to that total length of the jump. The third analysis was undertaken to determine the phase ratio characteristics during actual competition and to compare the results with the prior two analyses.

At the time of the first filming session in October, 1984, the subject's best triple jump distance was 11:15 m. Based on the results of the analysis obtained from the first filming, and on the information available in the coaching and research literature, particularly the phase ratio data (Table 1), specific technique changes were recommended. Both the subject and the coaches has access to the film and to the results of the film analysis.

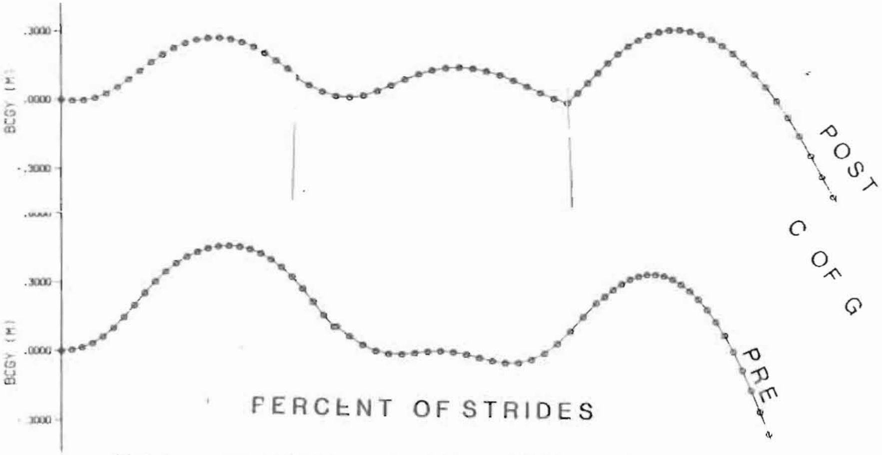

Figure 1. Trajectory of the body center of gravity (C of G) throughout the three phases of the triple jump.

TABLE 1
Recommended Phase Ratios of the Triple Jump

	Hop	Step	Jump
Fukashiro et al. (1981)	36.9%	29.1%	34.0%
Hay et al. (1985)			
Mean of 7 subjects 36.4%	29.5%	34.2%	
Mean of 5 subjects 34.4%	29.3%	36.3%	
McNab (1968)			
Russian Technique 39%	30%	31%	
Polish Technique 35%	29%	36%	
Nett (1970)	35%	30%	35%
Smith et al. (1980)			
3 Best	34%	29%	37%
12 Lowest	32%	31%	37%

In addition, plyometric jumping exercises were stressed throughout the subject's training regimen. Her best performance in competition during the 1984-85 season was 12.78 m. Her best performance during the 1985-86 season was 12.75. The subject was filmed for a second time in April, 1985 to determine which of the selected kinematic characteristics changed and which appeared to be related to the 1.65 m improvement in the distance of her jump. At various times over the six month period of this study, this jumper's indoor record ranked between second and fifth in the world. At the 1986 Big Ten Track and Field Championships, the subject took first place with a jump of 12.60 m.

FILMING PROTOCOL

For the first two filming sessions, one Milliken 16mm camera, Model DBM 55, with a 72 degree shutter and a 25mm lens was used. The film speed was set at 80 fps and verified by an internal pulse generator set at 10 hz. A board, one meter in length was filmed in the plane of the jumper's run-up path in order to convert the film distances to actual linear distances. In order to overcome the problem of a small image size which would result by filming the three-phase sequence in it's entirety, three trials were required. The camera was positioned perpendicular to the plane of the motion at a distance of 19.2 m. With this arrangement, a photographic area of approximately 6 m included the takeoff and touchdown of each phase. To account for possible technique differences in the trials, the total distance of each jump was recorded. The total distances for each jump for the first two filming sessions are given in Table 2. Because of small trial to trial differences in the total distance jumped, it was assumed that the subject's technique for each phase among the three trials was relatively consistant.

TABLE 2
Total Distances jumped for Three trials at Pre and Post Season Filming Sessions

Trial No.	Phase Filmed	Total Distance Pre Test	Total Distance Post Test
1	Hop	11.15 m	12.07 m
2	Step	10.90 m	12.42 m
3	Jump	11.05 m	12.17 m
Mean		11.03 m	12.22 m

For the third filming session, two Milliken 16mm cameras were run simultaneously at 80 fps. The cameras were positioned 107 feet from the center of the fun-up path. A two meter standard was used in this situation for converting the film measurements. For one camera, the field of view included the hop and the step phases. The visual field of the other camera included the touch down of the step and the jump phase.

FILM ANALYSIS

The film was sampled each .0246 s (every other frame). For each frame, nineteen pairs of x and y coordinates defining the body segments were digitized using a Lafayette Analysis 16 mm projector and a Numonics Model 224 digitizer interfaced with Purdue's CDC 65-6500 computer. A FORTRAN program was written to obtain selected kinematic characteristics of each phase of the jump. Through harmonic analysis carried out on a prior pilot study, it was determined that the data could be represented by the first four harmonics. A second-order Butterworth recursive digital filter was used to model the raw data (Hamming, 1977). The appropriate filter coefficients were selected based on the sample rate to harmonic level. The center of gravity of the body was calculated using segmental characteristics as determined by Dempster (1955). The initial angle and initial velocity of the body's center of gravity at takeoff were computed for each phase of the jump. The average initial angle and initial velocity were based on the take-off frame plus five additional frames using the following projectile equations:

$$Xcg = V_o t \cos\theta$$
$$Ycg = V_o t \sin\theta - 1/2\, gt^2$$

where:

Xcg and Ycg are the coordinates of the body's center of gravity relative to an origin

V_o is the initial velocity of the body's c of g

θ^o is the initial angle of projection of the body's c of g

t is the time to Xcg, Ycg

To solve for the initial horizontal and vertical components:

$$VELx = V_0 \cos\theta$$
$$VELy = V_0 \sin\theta$$

All other velocity measurements were calculated using a first central finite difference equation where:

$$VELx = (X(I-1) - X(I+1))/2(dt)$$
$$VELy = (Y(I+1) - Y(I-1))/2(dt)$$
$$\text{Resultant Velocity} = \sqrt{Velx^2 + VELy^2}$$

The analysis related to the third filming session was limited to the determination of only the percentage of each phase to the total distance jumped. Interference during the filming by spectators, athletes and officials blocked out the subject for various frames during the performance and thus prevented obtaining body coordinates for a detailed kinematic analysis.

RESULTS AND DISCUSSION OF THE FIRST TWO FILMING SESSIONS

The pre season film records were analyzed and the results were shared with the subject and coaches. Training regimens focused on those factors which appeared to be discrepant with data available in the existing coaching and research literature. Since no studies were found on women triple jumpers, judgments concerning performance characteristics were based on data from male triple jumpers.

The ratios of each phase to the total distance jumped were used as the best criteria for judging the effect of the selected kinematic variables on performance. While the literature is not in precise agreement in these ratios (Table 1), none was found which attributed less than 29% to the step phase. In a comparison of this jumper's pre season phase ratios (39.5%: 19.7%: 40.8%:) with the phase ratios reported in the literature, the most obvious discrepancy appeared to be in the length of the step phase. Thus, the focus of this athlete's training program was on modifying any part of the jumper's technique which would possibly contribute to lengthening the step phase.

On the basis of the results of the analysis of the pre season film several kinematic variables appeared to be affecting the length of the step. It appeared that the initial angle of the hop was unreasonably high and the vertical velocity of the hop was larger than desirable. These factors were causing the body to rise higher than optimal during flight following the takeoff from the hop. Coaching suggestions made during the 1984-85 season for lengthening the step were directed primarily toward modifying those two particular kinematic characteristics of the hop.

The post season film records were analyzed and the phase ratios and selected kinematic characteristics were compared with the pre season results. The results of the pre and post season analyses are given in Table 3.

Nett (1970) suggested that the optimal contribution of the hop phase should be between 35% and 37%. He stated that when the contribution of the hop was greater than 38%, the horizontal velocity decreased considerably. When the contribution was between 20% and 30% there was no apparent decrease in the horizontal velocity, but the athlete could not jump as long a distance. According to Nett's theory, this jumper's pre season ratio for the hop was slightly too large but an overcorrection made during the time between filming sessions resulted in a ratio lower than Nett's suggested optimal value. The post season hop ratio of 31.7% is lower than the percentage found for the elite jumpers listed in Table 1, even for those who might be considered as using the "Polish technique." While an increase in the step phase was achieved for the subject of this study, it was at the expense of the hop.

TABLE 3

Pre and post season kinematic variables of an elite female triple jumper

Variable	Pre Season	Post Season
Phase Distance (m):		
Hop	4.40	4.05
Step	2.20	3.46
Jump	4.55	5.27
Position of CG at Touchdown Relative to Support Foot (m):		
X Last Step	-0.36	-0.39
Y Last Step	0.99	0.90
X Hop	-0.27	-0.41
Y Hop	1.05	0.99
X Step	-0.34	-0.43
Y Step	0.98	0.85
Position of CG at Takeoff Relative to Support Foot (m):		
X Hop	0.32	0.36
Y Hop	1.18	1.05
X Step	0.61	0.52
Y Step	0.99	1.00
X Jump	0.42	0.34
Y Jump	1.15	1.10
Horizontal Vel. of CG at Touchdown (m/s/:		
Into the Hop	5.81	6.73
Into the Step	6.05	6.72
Into the Jump	5.03	5.27
Vertical Vel. of CG at Touchdown (m/s):		
Last step	0.27	1.01
Hop	-1.24	-1.32
Step	-0.73	-1.14
Resultant Vel. of CG at Touchdown (m/s)		
Last Step	5.85	6.80
Hop	6.18	6.85
Step	5.69	5.39
Initial Vel. of CG at Takeoff (m/s):		
Hop	7.15	8.28
Step	7.06	7.53
Jump	6.44	6.92
Horizontal Component at Takeoff (m/s):		
Hop	6.87	8.14
Step	7.05	7.46
Jump	5.27	6.76
Vertical Component at Takeoff (m/s):		
Hop	1.96	1.54
Step	-1.16	1.02
Jump	1.41	1.51
Initial Angle of CG at Takeoff (deg.)		
Hop	15.9	10.7
Step	-1.3	7.8
Jump	12.8	12.5
Upper Extremity Velocities of CG at Takeoff of Step Phase (m/s):		
X Hand	5.5	10.4
Y Hand	1.1	3.9
X Forearm	5.5	11.0
Y Forearm	1.0	2.6
X Upperarm	5.7	11.7
Y Upperarm	0.61	1.8
Support Time - Touchdown to takeoff (s):		
Hop	0.12	0.12
Step	0.15	0.15
Jump	0.15	0.15
Maximum Height of CG During Flight Phase (m):		
Hop	1.46	1.31
Step	0.84	1.03
Jump	1.37	1.30

The high contribution of the jump phase for this athlete at the time of both filming sessions may be a reflection of her past experience. Her extensive training as a long jumper might actually have interfered with her ability to achieve the higher hop and step ratios reported in the literature.

While some distance was lost in the hop phase, the step and the jump phase gained. Even though the percent contribution of the step phase did not reach the minimum 29% reported in the literature, the increase from 19.7% to 27.1% was a significant improvement.

Some differences found between the pre and post season kinematic characteristics would appear to provide a mechanical explanation for the improvment in the length of the step as well as for an increase in overall jump distance from 11.15 m to 12.78 m. In taking off from the hop, the center of gravity of the body was shifted slightly lower and slightly farther forward of the support foot. This provided for a greater contribution of horizontal motion during the hop phase. In taking off from the step, the center of gravity was slightly higher and closer to the support foot. This made a significant improvement in the angle of takeoff from the step. Not only was there an increase in the vertical velocity of the body at take off from the step but the jumper was able to increase the horizontal velocity component as well. At takeoff for the jump, the subject increased both the horizontal and vertical components of velocity. This may be due to a more efficient utilization of velocity in the two prior phases of the jump. The changes that occurred in the takeoff angles and velocities of the hop and step resulted in a lower trajectory of the body during the hop phase and a higher trajectory of the body during the step phase. The jump phase trajectory remained about the same.

The horizontal velocity component of the body's center of gravity showed an increase from pre to post season at the time of touchdown and takeoff for each phase of the jump. While the pre season results show an increase from hop to step and a decrease from step to jump, the post season results show a gradual decrease from the hop through the jump. This indicates a more efficient conservation of the horizontal velocity throughout the jump.

While there is no mention of arm velocities in the current literature, it seemed to be an important factor for this jumper. An increase in arm segment velocities found in the post season analysis indicated that the jumper was using her arms more vigorously, particularly at the time of takeoff for the step phase.

The fact that no change in support time was found was attributed to the fact that the film speed of 80 fps was inadequate to record the instants of touchdown and takeoff.

In general, the kinematic characteristics selected for analysis appeared to indicate a positive trend in conserving the horizontal velocity throughout the three phases and, particularly in improving the length of the step.

RESULTS AND DISCUSSION OF THE THIRD FILMING SESSION

Since the ratios of each phase to the total distance jumped were used as the best criterion for judging the variables affecting performance, this third analysis dealt exclusively with the relative contribution of each phase. The results were compared with those of the first two sessions. The phase ratios of the three filming sessions are shown in Table 4. It appears that the subject's technique is still fluctuating during the hop phase. There was no noticeable change in the step phase from the second to the third filming. This phase still fails to reach the minimum (29%) reported in the literature. The consistency of the ratios for the step phase might possibly be due to unique body segment lengths of female athletes.

Phase	Analysis #1 %	Analysis #2 %	Analysis #3 %
Hop	39.5	31.7	39.9
Step	19.2	27.1	25.6
Jump	40.8	41.2	39.3

TABLE 4
Phase Ratios

According to Nett (1970), a long hop phase affects the ability to conserve horizontal motion. It might be assumed that the jump phase for this subject was not executed well (1.38 m) because of the loss of horizontal motion. Failure of the subject to show an improvement in performance might be explained by the subject's involvement in practicing for several events and to an ankle injury which she suffered during 1986.

A female triple jumper was filmed prior to and at the end of the 1984-85 track season and again during a competition in 1986. During 1984-85, the subject improved her competitive triple jump record from 11.15 mto 12.78 m. This improvement was believed to be due primarily to an increase in the horizontal velocity component during the hop phase which resulted in an increase in step length. Her best competitive jump in 1985 of 12.75 failed to surpass her prior p.r. This could be attributed primarily to an ankle injury which interrupted training.

The phase ratio data in the literature were considered as the best criteria for evaluating the level of skillfulness of this subject's triple jump pattern. Since there is no reason to believe that these ratios, which currently pertain to male jumpers, ought to be different for women, the results of the second and third analyses suggest that the subject's phase ratios are approaching the range of ratios found for elite male jumpers.

The reason for the improvement in the phase ratios for this jumper appeared to be primarily as a result of an increase in the horizontal velocity component at touchdown from the hop. The more a jumper is able to conserve the horizontal velocity while maintaining an optimal vertical velocity at takeoff of each phase, the greater will be the distance jumped. To do this, the jumper must get the center of gravity of the body in the desirable position in front of and above the support foot at takeoff. Since absolute values for this position are useless when dealing with athletes of differing stature, the norms for optimal takeoff positions need to be developed based on relative heights of jumpers. This would extend the opportunity for making judgements concerning the optimization of a jumper's performance in the same way that is possible now with the phase ratio data.

When an athlete is being coached to change some aspect of his or her technique, overcorrection is always a possibility. It would seem to be advisable, therefore, to conduct frequent detailed analyses and to provide the athlete with specific feedback relative to the results of those analyses.

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