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CONSEQUENCES OF DEVIATION FROM THE CURVE RADIUS IN THE HIGH JUMP APPROACH

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The purpose of this study was to examine how well elite high jump athletes run the curved portion of the approach and how deviation from the curve affects parameters related to jump performance. The participants were elite men and women high jumpers competing in the 2012 USA Track & Field Olympic Trials. Based on reconstructed coordinates, constant radius curves were fitted to the approach of the jumpers and deviation from the curve on each step was analysed. All athletes demonstrated some degree of deviation from the curve, with the 8^{th} and penultimate steps being the most common sites of maximum deviation. There were significant beneficial relationships between maximum deviation from the curve and the height of the center of mass at plant and vertical velocity at takeoff. However, there were significant detrimental relationships between maximum curve deviation and change in inward lean during the takeoff and distance travelled down the bar. Overall, the results of this study suggest deviation from the curve radius may be mechanisms to help jumpers produce increased vertical velocity at takeoff but it comes at the price of negatively affecting bar clearance.

KEY WORDS: high jump, elite athletes, athletic performance.

INTRODUCTION: A high jump consists of three distinct phases: the approach run, the plant and takeoff, and the flight and bar clearance. Several studies have shown that conditions at the start of the takeoff phase have direct implications for jump performance (Dapena et al., 1990; Grieg and Yeadon, 2000). While the takeoff phase is clearly important, the approach phase may be even more important as actions during the approach largely determine conditions at the start of the takeoff phase. To date, most research on the approach phase examines the relationship between the curved nature of the approach and the development of angular momentum (Dapena, 1980a; Tan and Yeadon, 2005) or discusses how to layout the approach (Dapena, 1997). Thus, while there are solid theoretical foundations for what athletes should strive to do during the curved portion of the approach, there are currently no reports in the literature examining how well athletes actually execute the curved approach or how the quality of curve execution influences jump performance indicators. Therefore, the purpose of this study was to examine how well athletes run the curved portion of the high jump approach and how deviations from the curve affect key performance indicators.

METHODS: Data were recorded during the men's and women's high jump finals at the 2012 USA Track & Field Olympic Team Trials. Each jump was recorded with three video cameras (GC-PX10, JCV Corp) sampling at 60 frames per second. A volume encompassing the curved portion of the approach was calibrated using the multiphase calibration technique described by Challis (1995). Independent calibrations were performed for the right and left sides. Twenty individual body landmarks were manually digitized over the last 6 steps of the approach, takeoff, and flight. Cameras were synchronized based on the frames of foot contact and toe off (Dapena and Chung, 1988) and a DLT reconstruction was used to obtain 3D coordinates. The location of the whole body center of mass (COM) was calculated as the weighted sum of the individual segments based on Dempster's data (Winter, 2005). The following five dependent variables describing jump performance were then calculated:
Vertical velocity of the COM at takeoff (VvTO), horizontal velocity of the COM at plant (VhTD), height of the COM at plant (H_{COM}) expressed as a percentage of the athlete's standing height, change in inward lean during takeoff (ΔIL), measured from the ankle to the COM as described

by Ae et al. (2008), and bar travel distance (BTD), the distance travelled down the bar from takeoff until the athlete's hips were no longer over the bar (for makes) or the hips were clear of the plane of the bar (for misses).

Based on the 3D coordinates of the heel and toe on each step the location of the foot prints were plotted relative to the pit. On each step, actual foot position was identified as the midpoint between the heel and toe during midstance. The distance between the toe of the 5th step and the heel of the takeoff step (chord length) was used to fit a constant radius curve between these two points (Figure 1A). The time from toe off on the 5th step until touchdown of the takeoff step was normalized to 100% curve time. Based on the time between toe off on the 5th step and mid-stance on a given step, an appropriate arc was drawn, yielding an expected foot position along the constant radius curve for that step (Figure 1B). The magnitude of the vector joining the actual (heel-toe midpoint) and expected foot positions on a given step was used to calculate the deviation from the curve for each step. Average and maximal deviations across all four steps as well as the step on which maximal deviation occurred were also calculated. A series of regression analyses were used to examine relationships between curve deviation and the dependent variables.

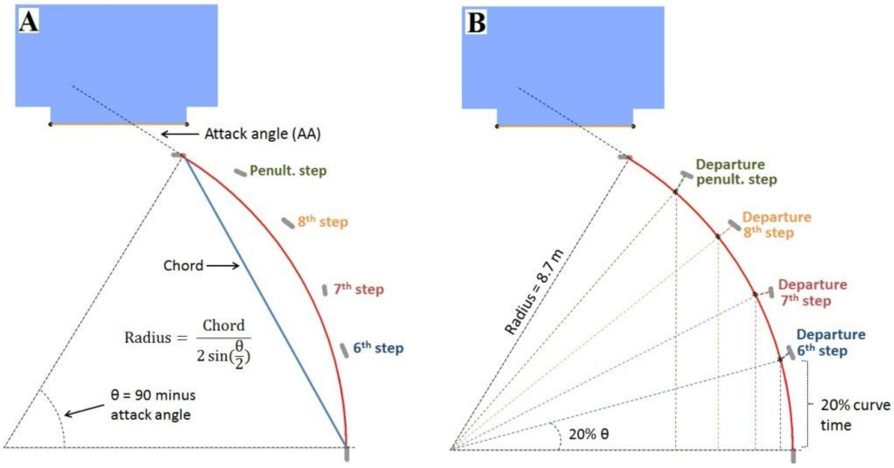

Figure 1: Illustration of how the constant radius curve was calculated (A), and then used to calculate deviation from this curve on each step of the approach (B).

RESULTS: Forty jumps have been analysed, 18 from women (12 makes, 6 misses; bar height: 1.91±0.09 m.) and 22 from men (13 makes, 9 misses; bar height: 2.25±0.06 m.). On all jumps, athletes demonstrated some deviations from the constant radius curve. Maximum curve deviation occurred most commonly on the 8th step for men and the penultimate step for women (Table 1).

Table 1
Average and Range of Deviations on Each Step, and Frequency with Which a Given Step Demonstrated Maximum Deviation from the Radius.

	Men			Women		
Variable	Mean	Range	Freq.	Mean	Range	Freq
6th step (m.)	0.23 (± 0.12)	0.05 – 0.43	25%	0.32 (± 0.19)	0.06 – 0.79	11.7%
7th step (m.)	0.49 (± 0.25)	0.08 – 0.82	15%	0.40 (± 0.31)	0.07 – 0.96	5.8%
8th step (m.)	0.51 (± 0.31)	0.03 – 0.97	55%	0.46 (± 0.28)	0.09 – 0.92	17.6%
Penultimate (m.)	0.50 (± 0.23)	0.15 – 0.90	5%	0.53 (± 0.27)	0.16 – 1.03	64.7%
Maximum (m.)	0.61 (± 0.19)	0.33 – 0.97	-	0.59 (± 0.25)	0.20 – 1.03	-

Curve deviation on the 7th step predicted curve deviation on the 8th step (R2 = 0.884, $p < .001$) and on the penultimate step (R2 = 0.609, $p < .001$). Similarly, deviation on the 8th step predicted deviation on the penultimate step (R2 = 0.739, $p < .001$). Deviation on the 6th step did not predict deviation on any subsequent steps. Significant relationships were observed between max deviation on the curve and HCOM, VvTO, ΔIL, and BTD (Figure 2).

On jumps with a greater deviation from the curve athletes tended to have a lower H_{COM} and generate more VvTO. However, on these jumps the athletes also experienced less ΔIL and greater amounts of BTD. Jumps with greater maximum deviation trended towards having greater VhTD however, this was not statistically significant (R^2 = .075, p = .087).

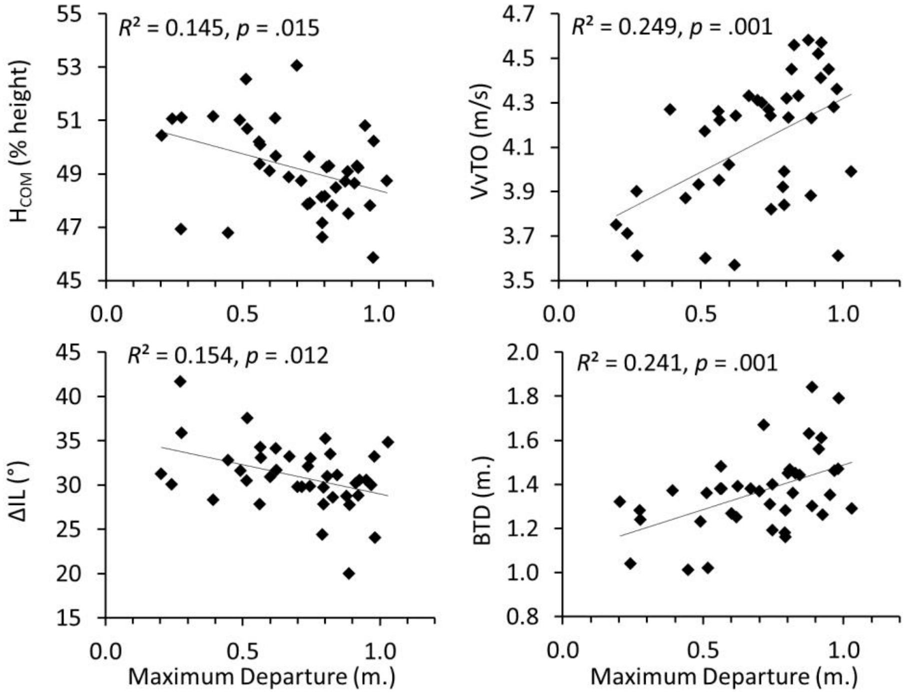

Figure 2: Relationships Between Maximal Curve Deviation and H_{COM}, VvTO, ΔIL, and BTD

DISCUSSION: All the jumpers in this study demonstrated some degree of deviation from the constant radius curve, suggesting this is common among elite high jumpers. However, it also appears to have direct implications for jump performance. On jumps with larger maximum curve deviation, jumpers tended to have a lower H_{COM}. Having a lower H_{COM} allows for greater displacement of the COM during the takeoff, thereby generating greater VvTO (Dapena, 1980b; Dapena et al., 1990). Once the jumper leaves the ground their COM will follow a parabolic path. Thus, VvTO is a critical factor in determining how high their COM will rise after takeoff.

However, the winner of a high jump competition is decided by which athlete clears the highest bar, not by which athlete produces the highest COM height. The jumps with greater deviation from the curve also demonstrated smaller ΔIL values. ΔIL during the takeoff contributes to the development of lateral somersaulting angular momentum (Dapena, 1980a; Tan & Yeadon, 2005), which helps the athlete rotate around the axis of the bar. Therefore, without enough ΔIL the athlete will tend to have problems with bar clearance (Dapena, 1995). One way bar clearance problems could manifest would be that the athlete getting on top of the bar but, since they are not rotating, travelling down the bar and either hit the bar on the way down or pull it off as their legs pass through. In this study it was observed that greater deviation from the curve was associated with greater BTD, suggesting either of these could be possible outcomes of reduced ΔIL.

Deviation on the 7th step predicted curve deviation on subsequent steps, suggesting that once present, deviations from the curve continue to grow throughout the approach. This has two important implications for high jump coaches. First, given the number of jumps taken throughout their careers, elite jumpers likely intuitively know where they need to be in order to execute the jump. Thus, if they deviate from the radius, especially late in the approach, at some point they will need to make a correction to reorient to their desired takeoff location. Such corrections, and the postural breakdowns which accompany them, are likely easily observed in video and as such may serve as qualitative indicators to coaches that the athletes are not maintaining a curve.

Second, the relationship between deviation on the 7th step and subsequent steps suggests that if an athlete wishes to run an approach with minimal deviation from the curve, they must focus on executing the 5th or 6th step in such a way as to minimize deviation coming onto the 7th step. These are the steps where most athletes transition from the straight portion of the approach to the curved portion. While this transition has been addressed in the coaching literature (Schexnayder, 1994), it has been largely ignored in the scientific literature. Future studies should examine kinematic, kinetic, or postural markers indicative of successful execution of this transition.

It is possible elite high jumpers do not use a constant radius curve, as assumed in this study. However, it is also possible that the athletes may simply lack the skill to run a constant radius at speed. Running fast around a constant radius requires significantly more laterally directed force than does running a straight line (Chang & Kram, 2007). Thus, if athletes do not appropriately adjust their force application as they enter the curve, they may begin drifting off the radius. Additionally, while athletes should generate as much VhTD as they can safely handle since VhTD strongly predicts VvTO (Dapena et al., 1990; Grieg & Yeadon, 2000), there is currently no research documenting when during the approach horizontal velocity should be developed. Theoretically, if athletes have not developed sufficient horizontal velocity prior to entering the curve they may try to accelerate while running the curve. However, the mechanics and postures involved in acceleration are markedly different than those desired while running the curved portion of the approach and these may contribute to the athlete deviating from the radius. Future studies should consider these questions as they investigate why athletes may deviate from the curve during the high jump approach.

CONCLUSION: The results of this study suggest deviation from a constant radius curve is common among elite high jumpers. While these deviations may help athletes get on top of bars through the production of greater vertical velocities at takeoff, it is likely that, through decreased rotation during takeoff and increased bar travel, they impair and athlete’s ability to cleanly negotiate the bar. These results suggest coaches and athletes must find an appropriate balance between vertical velocity production and rotation. These results also suggest coaches and athletes should be especially mindful of the transition from the straight portion of the approach to the curved portion, as the quality of its execution will have strong ramifications for the remainder of the approach.

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