THE OPTIMUM TAKEOFF ANGLE IN THE LONG JUMP

Nicholas P. Linthorne, Maurice S. Guzman and Lisa A. Bridgett
School of Exercise and Sport Science, The University of Sydney, Australia

This study showed that the optimum takeoff angle for a long jumper may be predicted by combining the equation for the range of a projectile in free flight with the relations between takeoff speed, takeoff height, and takeoff angle for the athlete. The prediction method was evaluated using measurements of three experienced male long jumpers who performed maximum-effort jumps over a wide range of take-off angles. The calculated optimum takeoff angles (about 23°) were in good agreement with the athletes' competition takeoff angles.

KEY WORDS: athletics, long jump, takeoff.

INTRODUCTION: The long jump is a 'projectile' event and so the distance achieved is strongly determined by the conditions at takeoff. It is generally recognised that a high takeoff speed is necessary for a good performance and that the jumper benefits from having a high position at takeoff. However, the optimum takeoff angle for the athlete is not well understood. The aim of this study was to identify the optimum takeoff angle and to explain the angle in terms of the mechanics of projectile motion.

Whilst in the air, a long jumper is essentially a projectile in free flight and so the horizontal range, R, of the athlete is given by (Hay, 1993)

$$R = \frac{v^2 \sin 2\theta}{2g} \left[1 + \left(1 + \frac{2gh}{v^2 \sin^2 \theta} \right)^{1/2} \right] \tag{1}$$

where v is the takeoff speed, θ is the takeoff angle, h is the relative takeoff height, and g is the acceleration due to gravity (Figure 1).
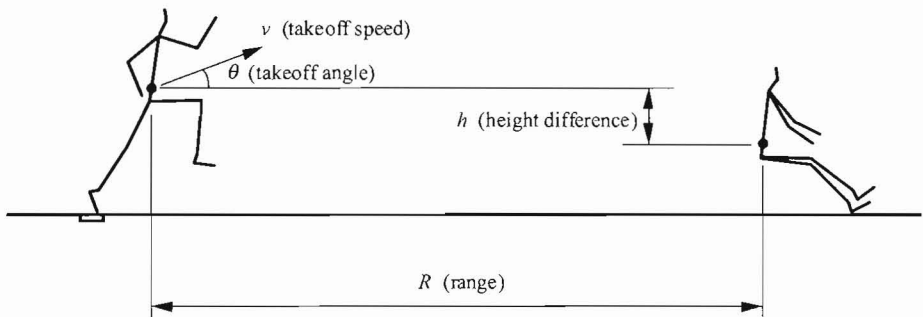

Figure 1. Diagram of an athlete performing a long jump. The takeoff variables that affect the horizontal range are shown.

The optimum takeoff angle is the angle at which the range, R, is a maximum. When using equation 1 to calculate the optimum takeoff angle, it is crucial to recognize that v, h, and θ are *not* independent variables. Both the takeoff speed and the relative takeoff height are functions of the takeoff angle. Therefore, before calculating the optimum takeoff angle, the athlete's expressions for $v(\theta)$ and $h(\theta)$ must be measured and substituted into the equation. This method was used by Red and Zogaib (1977) to calculate the optimum projection angle in the javelin throw, and by Linthorne (2001) to calculate the optimum projection angle in the shot put. In both studies the maximum projection speed the athletes could achieve decreased with increasing projection angle and so the calculated optimum projection angles

were considerably lower than the 45° expected for a projectile activity. The accuracy of the method was confirmed by the good agreement between the calculated optimum angles and the athlete's competition projection angles (35-38° for the javelin throw, and 31-36° for the shot put). In the present study, the relations between takeoff speed, takeoff height, and takeoff angle for three long jumpers were measured and used to calculate their optimum takeoff angles.

METHODS: Three experienced male long jumpers with personal best performances of 8.25 m, 7.94 m, and 7.58 m were recruited for the study. The athletes jumped several times using their normal competition takeoff angles, and then several more times using lower and higher takeoff angles. All jumps were performed with maximum physical effort, but the jumps at high takeoff angles were achieved by using a run-up that was shorter and slower than the competition run-up. A 2-D filming procedure that used a high-speed video camera operating at 100 Hz was used to record the jumps, and an Ariel Performance Analysis System was used to determine the takeoff speed, takeoff angle, and takeoff height for each jump.

RESULTS AND DISCUSSION: All three jumpers showed a substantial decrease in takeoff speed with increasing takeoff angle (Figure 2). The highest takeoff speeds were obtained when the jumper used a full speed run-up with very little jumping action at takeoff. The maximum takeoff angle that could be achieved when using a full speed run-up was about 25°. To achieve greater takeoff angles the jumper had to use a slower run-up speed and the takeoff speed was therefore less. With a near-vertical takeoff angle the run-up speed had to be reduced to walking pace and the takeoff speed was the lowest of all.
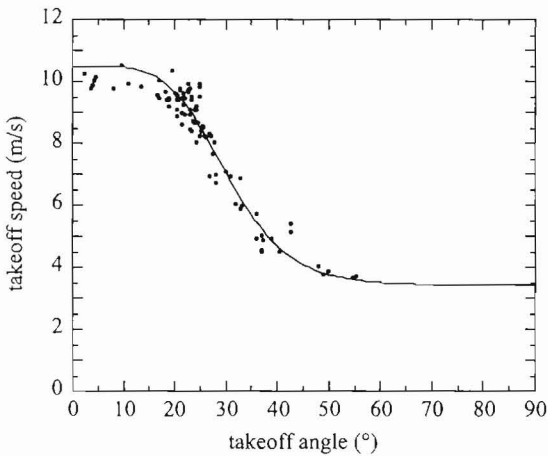

Figure 2. Decrease in takeoff speed with increasing takeoff angle in the long jump.

The relative takeoff height (the difference between the takeoff height and the landing height) was insensitive to takeoff angle (Figure 3). The takeoff height was determined mainly by the athlete's size and amount of forward drive in the takeoff. In this study, the landing phase of the jump was not recorded. However, the landing phase in a long jump is similar to that in a *standing* long jump, and so a similar relation between landing height and takeoff angle was assumed for the athletes in the present study (Wakai and Linthorne, 2002). The landing technique used by a jumper is determined by the requirement to maintain balance during the landing. When jumping at low takeoff angles an athlete has a high horizontal speed at landing and so he can land with his feet far ahead of his body without the risk of falling backward after landing (Figure 1). When landing from a high takeoff angle the athlete has a

lower horizontal speed and so lands in a nearly upright position with the feet only slightly
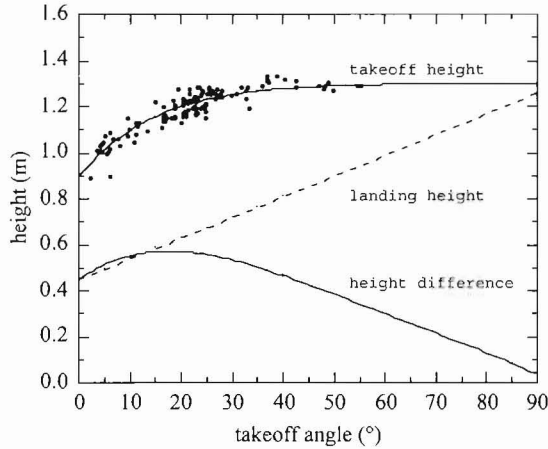ahead of the body.

Figure 3. Take-off height, landing height, and height difference for a long jumper.

The optimum takeoff angle for each of the three long jumpers was calculated by substituting
mathematical expressions for their measured takeoff speed, $v(\theta)$, and relative takeoff height,
$h(\theta)$, into equation 1, and then plotting range as a function of takeoff angle (Figure 4). The
optimum takeoff angle was not 42°, as would be expected if the takeoff speed were constant
for all takeoff angles (Lichtenberg and Wills, 1978). The calculated optimum takeoff angles
were about 23°, and were in good agreement with the angles used by the athletes in
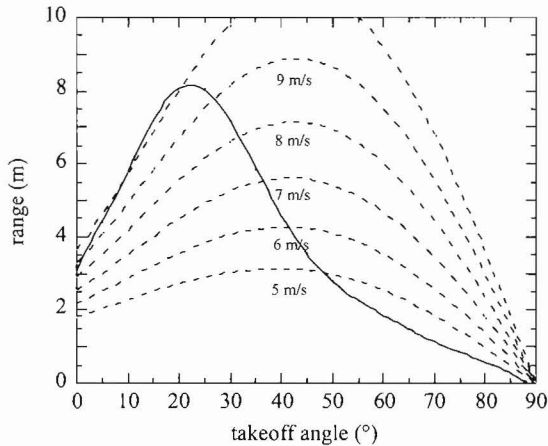competition (19-25°).

Figure 4. Calculated jump distance as a function of takeoff angle. The optimum takeoff angle is about
23°. The dashed lines are calculations that assume a constant takeoff speed.

The relation between takeoff speed and takeoff angle, $v(\theta)$, had a much larger effect on the
optimum angle than the relation between relative takeoff height and takeoff angle, $h(\theta)$. In

comparison to the shot put, the decrease in projection speed in the long jump is more rapid, and so the optimum projection angle is much lower (23° vs. 34°). In long jumping the optimum takeoff angle is a compromise between producing horizontal speed and producing vertical speed. For a well-trained male athlete the greatest *horizontal* speed possible is about 10-12 m/s in a flat out sprint (i.e. a takeoff angle of about 0°). The greatest *vertical* speed possible is about 3-4 m/s with a moderate run-up speed and a projection angle of about 50° (as in a running high jump). In long jumping it is better to attain a near-maximum horizontal speed, rather than a near-maximum vertical speed, and so the athlete jumps with a projection angle of about 23°. An important point for the coach to note is that the jump distance curve (Figure 4) is sharply peaked. This means that jumping performance is highly sensitive to selection of the takeoff angle. If the athlete uses a takeoff angle that is more than a few degrees from the optimum angle the athlete will suffer a substantial reduction in performance.

CONCLUSION: The optimum takeoff angle for a long jumper may be calculated by combining the equation for the range of a projectile in free flight with the relations between takeoff speed, takeoff height, and takeoff angle for the athlete.

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