

Biomechanics of the long jump

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Introduction

The basic technique used in long jumping has remained unchanged since the beginning of modern athletics in the mid-nineteenth century. The athlete sprints down a runway, jumps up from a wooden take-off board, and flies through the air before landing in a pit of sand. A successful long jumper must, therefore, be a fast sprinter, have strong legs for jumping, and be sufficiently coordinated to perform the moderately complex take-off, flight, and landing maneuvers. The best women long jumpers achieve distances of about 6.5–7.5 m, whereas the best men (who are faster and stronger) reach about 8.0–9.0 m.

The objectives in each phase of the jump are the same regardless of the athlete's gender or ability. To produce the greatest possible jump distance the athlete must reach the end of the run-up with a large horizontal velocity and with the take-off foot placed accurately on the take-off board. During take-off the athlete attempts to generate a large vertical velocity while minimizing any loss of horizontal velocity, and in the flight phase the athlete must control the forward rotation that is produced at take-off and place their body in a suitable position for landing. During the landing the athlete should pass forward of the mark made by their feet without sitting back or otherwise decreasing the distance of the jump.

This chapter presents a review of the most important biomechanical factors influencing technique and performance in the long jump. The biomechanical principles behind the successful execution of the run-up, take-off, flight, and landing phases of the jump are explained. The effects of changes in run-up velocity on the athlete's take-off technique are also examined, as are the design principles of long jump shoes and the techniques used by disabled athletes.

Typical values of selected long jump parameters are presented in Table 24.1. The values in this table are based on studies of elite long jumpers at major international championships (Arampatzis, Brüggemann, and Walsch, 1999; Hay, Miller, and Canterna, 1986; Lees, Fowler, and Derby, 1993; Lees, Graham-Smith, and Fowler, 1994; Nixdorf and Brüggemann, 1990). The table will be a useful reference while reading this chapter.

Table 24.1 Typical values of selected parameters for elite long jumpers

<i>Parameter</i>	<i>Men</i>	<i>Women</i>
Athlete's height (m)	1.82	1.75
Athlete's body mass (kg)	76	62
Jump distance (m)	8.00	6.80
Run-up length (m)	48	40
Horizontal velocity at touchdown (m/s)	10.6	9.5
Vertical velocity at touchdown (m/s)	-0.1	-0.1
Horizontal velocity at take-off (m/s)	8.8	8.0
Vertical velocity at take-off (m/s)	3.4	3.1
Take-off velocity (m/s)	9.4	8.6
Take-off angle (°)	21	21
Change in horizontal velocity during take-off (m/s)	-1.8	-1.5
Change in vertical velocity during take-off (m/s)	3.5	3.2
Leg angle at touchdown (°)	61	63
Knee angle at touchdown (°)	166	161
Take-off duration (s)	0.11	0.11
Touchdown height (m)	1.03	0.96
Take-off height (m)	1.29	1.20
Landing height (m)	0.65	0.60
Height difference between touchdown and take-off (m)	0.26	0.24
Height difference between take-off and landing (m)	-0.64	-0.60
Height at the peak of the jump (m)	1.88	1.69

Run-up

The run-up phase is crucial in long jumping; it is impossible to produce a good performance without a fast and accurate run-up. The three main tasks of the athlete during the run-up are: to accelerate to near-maximum speed, lower the body during the final few steps and bring it into position for take-off, and place the take-off foot accurately on the take-off board.

Run-up velocity

In long jumping, the distance achieved is strongly determined by the athlete's horizontal velocity at the end of the run-up. To produce a fast run-up, most long jumpers use 16–24 running strides performed over a distance of about 35–55 m. By the end of the run-up the athlete reaches about 95–99 per cent of their maximum sprinting speed. Long jumpers do not use a longer run-up length that gives 100 per cent sprinting speed because the advantage of a faster run-up speed is outweighed by the increased difficulty in accurately hitting the take-off board (Hay, 1986). Faster athletes tend to use a longer run-up because it takes them longer to build up to their maximum sprinting speed. Most long jumpers start their run from a standing position with one foot forward of the other. Some athletes prefer to take several walking strides onto a check mark before accelerating. However, this technique is believed to produce a less consistent velocity profile and hence a less accurate run-up.

Studies of competition jumps have consistently found high correlations between run-up velocity and jump distance. Figure 24.1 shows an example of this association (Hay, 1993). The data in the figure are from 306 jumps by men and women with a wide range of ability, from high school athletes through to elite athletes. However, one must recognize that the

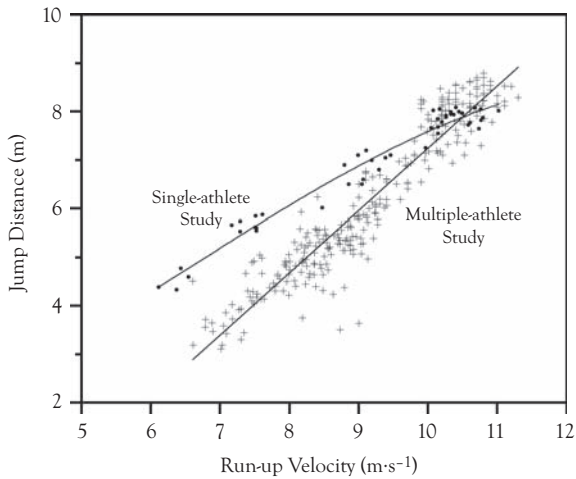


Figure 24.1 Increase in jump distance with run-up velocity in a multiple-athlete study (+) and in a single-athlete study (·). Data for the single-athlete study are for an elite male long jumper. Adapted with permission from Bridgett and Linthorne (2006).

slope of a regression line from a multiple-athlete study does not indicate the expected rate of improvement in jump distance for an individual athlete. The main cause of variations in jump distance among athletes is probably differences in muscular strength. The slope of the regression line in a multiple-athlete study therefore indicates how an individual's jump distance changes in response to a change in muscular strength, rather than how the jump distance changes with run-up velocity. For the individual athlete the relation between jump distance and run-up velocity is not quite linear (Bridgett and Linthorne, 2006). Figure 24.1 shows an example of the relation for an elite male long jumper.

Run-up accuracy

To produce the best possible jump distance, a long jumper must place their take-off foot close to, but not over, the take-off line that is marked by the front edge of the take-off board. The long jump run-up has two main phases; an acceleration phase during which the athlete produces a stereotyped stride pattern; and a 'zeroing-in' phase during which the athlete adjusts their stride pattern to eliminate the spatial errors that have accrued during the first phase (Hay, 1988). During the last few strides before take-off, the athlete uses their visual perception of how far away they are from the board as a basis for adjusting the length of their strides. Top long jumpers start using a visual control strategy at about five strides before the board and are able to perform the stride adjustments with only a small loss of horizontal velocity. Athletes of lesser ability tend to have a greater accumulated error and anticipate their stride adjustment later than highly-skilled jumpers. Many long jumpers use a check-mark at 4–6 strides before the board so that their coach can monitor the accumulated error in the first phase of the run-up.

Transition from run-up to take-off

Skilled long jumpers maintain their normal sprinting action up until about two to three strides before take-off (Hay and Nohara, 1990). The athlete then begins to lower their centre of mass (COM) in preparation for the take-off. A low position into the take-off is necessary to give a large vertical range of motion (ROM) over which to generate upwards velocity. The athlete lowers their COM to the required height and tries to keep a flat trajectory in the last stride before take-off. This ensures that the athlete's COM has minimal downward vertical velocity at the instant of touchdown and so the upwards vertical impulse exerted by the athlete during the take-off produces the highest possible vertical velocity at the instant of take-off. Most long jumpers spend a lot of time practicing to lower their COM while minimizing any reduction in run-up velocity.

The entry into the take-off is usually performed using a 'pawing' action, where the take-off leg is swept down and back towards the athlete (Koh and Hay, 1990). The take-off foot has a negative velocity relative to the athlete's COM, but the velocity of the foot relative to the ground is not quite reduced to zero (about 4–5 m/s). This 'active' landing technique is believed to reduce the braking force experienced by the athlete during the initial stages of the take-off.

Take-off

Although long jump performance is determined primarily by the athlete's ability to attain a fast horizontal velocity at the end of the run-up, the athlete must also use an appropriate take-off technique to make best use of this run-up velocity. Long jumpers place their take-off foot well ahead of their COM at touchdown to produce the necessary low position at the start of the take-off. The jumper's body then pivots up and over the take-off foot, during which time the take-off leg rapidly flexes and extends. Long jumping is essentially a projectile event, and the athlete wishes to maximize the flight distance of the human projectile by launching it at the optimum take-off velocity and take-off angle. In launching the body into the air, the athlete desires a large horizontal velocity at take-off to travel forward and a large vertical velocity to give time in the air before landing back on the ground. A fast run-up produces a large horizontal take-off velocity, but it also shortens the duration of the ground contact and hence the ability of the athlete to generate a vertical impulse (force integrated over time). To increase the duration of the foot contact, the athlete plants their foot ahead of the COM at touchdown. However, the resulting increase in vertical propulsive impulse is accompanied by an undesirable increase in horizontal braking impulse. Therefore, there is an optimum leg angle at touchdown which offers the best compromise between vertical propulsive impulse and horizontal braking impulse. In the long jump, the optimum take-off technique is to run up as fast as possible and plant the take-off leg at about 60–65° to the horizontal (Bridgett and Linthorne, 2006; Seyfarth, Blickhan, and Van Leeuwen, 2000).

Take-off mechanism

Just before touchdown the athlete pre-tenses the muscles of the take-off leg. The subsequent bending of the leg during the take-off is due to the force of landing, and is not a deliberate yielding of the ankle, knee, and hip joints. Flexion of the take-off leg is unavoidable and is limited by the eccentric strength of the athlete's leg muscles. Maximally activating the muscles of the take-off leg keeps the leg as straight as possible during the take-off. This enables

the athlete's COM to pivot up over the foot, generating vertical velocity via a purely mechanical mechanism. Over 60 per cent of the athlete's final vertical velocity is achieved by the instant of maximum knee flexion, which indicates that the pivot mechanism is the single most important mechanism acting to create vertical velocity during the take-off (Lees, Fowler, and Derby, 1993; Lees, Graham-Smith, and Fowler, 1994). The knee extension phase makes only a minor contribution to the generation of vertical velocity, and the rapid plantar flexion of the ankle joint towards the end of the take-off contributes very little to upward velocity. Long jumpers spend a lot of time on exercises to strengthen the muscles of their take-off leg. Greater eccentric muscular leg strength gives the athlete a greater ability to resist flexion of the take-off leg, which enhances the mechanical pivot mechanism during the take-off and hence produces a greater take-off velocity.

The stretch-shorten cycle, where the concentric phase of a muscle contraction is facilitated by a rapid eccentric phase, does not play a significant role in the long jump take-off (Hay, Thorson, and Kippenhan, 1999). Rather, fast eccentric actions early in the take-off enable the muscles to exert large forces and thus generate large gains in vertical velocity. In the long jump take-off the instant of maximum knee flexion is a poor indicator of when the extensor muscles of the take-off leg change from eccentric activity to concentric activity. In long jumping, the *gluteus maximus* is active isometrically at first and then concentrically; the hamstrings are active concentrically throughout the take-off; rectus femoris acts either isometrically at first then eccentrically or eccentrically throughout the take-off; and the vasti, soleus, and gastrocnemius act eccentrically at first and then concentrically.

The explosive extension of the hip, knee, and ankle joints during the last half of the take-off is accompanied by a vigorous swinging of the arms and free leg. These actions place the athlete's COM higher and farther ahead of the take-off line at the instant of take-off, and are also believed to enhance the athlete's take-off velocity. Some athletes use a double-arm swing to increase the take-off velocity, but it is difficult to switch smoothly without loss of running velocity from a normal asynchronous sprint arm action during the run-up to a double-arm swing at take-off.

Take-off angle

It is well known that take-off angles in the long jump are substantially less than the 45° angle that is usually proposed as the optimum for a projectile in free flight. Video measurements of world-class long jumpers consistently give take-off angles of around 21°. The notion that the optimum take-off angle is 45° is based on the assumption that the take-off velocity is constant for all choices of take-off angle. However, in the long jump, as in most other sports projectile events, this assumption is not valid. The take-off velocity that a long jumper is able to generate is substantially greater at low take-off angles than at high take-off angles and so the optimum take-off angle is shifted to below 45° (Linthorne, Guzman, and Bridgett, 2005).

From a mathematical perspective the athlete's take-off velocity is the vector sum of the horizontal and vertical component velocities, and the take-off angle is calculated from the ratio of the component velocities. A take-off angle of 45° requires that the horizontal and vertical take-off velocities are equal in magnitude. The maximum vertical velocity an athlete can produce is about 3–4 m/s (when performing a running high jump), but an athlete can produce a horizontal take-off velocity of about 8–10 m/s through using a fast run-up. By deciding to jump from a fast run-up, the athlete produces a high take-off velocity at a low take-off angle. In long jumping, generating a higher take-off velocity gives a much greater performance advantage than jumping at closer to 45°.

Take-off forces

During the take-off the athlete experiences a ground reaction force (GRF) that tends to change the speed and direction of the athlete's COM. The horizontal force during the take-off is predominantly a backwards braking force, and only for a very short time at the end of the take-off does it switch over to become a forwards propulsive force. Because the braking impulse is much greater than the propulsive impulse, the athlete's forward horizontal velocity is reduced during the take-off (by about 1–3 m/s). The vertical GRF exerted on the athlete produces the athlete's vertical take-off velocity. The vertical force initially acts to reverse the downward velocity possessed by the athlete at touchdown, and then accelerates the athlete upwards. The athlete always experiences a slight reduction in upwards velocity in the last instants before take-off. This decrease occurs because the vertical force must drop down to zero at the instant of take-off. For a short time before take-off the vertical GRF is less than body weight and is therefore not enough to overcome the gravitational force on the athlete. Both the horizontal and vertical components of the GRF display a sharp impact peak at touchdown when the take-off leg strikes the ground and is rapidly reduced to near zero velocity.

As well as changing the speed and direction of the athlete's COM, the GRF tends to produce angular acceleration of the athlete's body about its somersaulting axis. The GRF produces a forward or backward torque about the athlete's COM depending on whether the line of action of the force passes behind or ahead of the COM (Hay, 1993). In the initial stages of the take-off the torque acts to produce backwards acceleration, but it soon changes to produce forwards acceleration. Overall, the athlete experiences a large forwards rotational impulse, and so the athlete leaves the take-off board with a large amount of forward-somersaulting angular momentum. Forward angular momentum is consistently a source of difficulty for the athlete. Unless the jumper takes appropriate steps to control the angular momentum during the flight, excessive rotation of the body will reduce the distance of the jump by producing a landing with the feet beneath the body rather than extended well in front of the body.

Flight and landing

During the flight phase, most long jumpers either adopt a 'hang' position or perform a 'hitch-kick' movement (a modified running-in-the-air action). In both techniques the athlete's actions are designed to control the forward rotation that is imparted to the body at take-off and hence allow the athlete to attain an effective landing position (Hay, 1993). The hang and hitch-kick techniques deal with the angular momentum during the flight phase in different ways. In the hang technique the athlete attempts to minimize the forward rotation of the body, whereas in the hitch-kick technique the athlete performs movements that actively counter the forward rotation.

In the hang technique the athlete reaches up with their arms and extends their legs downwards just after take-off. This extended body position gives the athlete a large moment of inertia (MOI) about their somersaulting axis and hence reduces the athlete's forward angular velocity. The athlete maintains the hang position for as long as possible during the flight so as to minimize the amount of forward rotation.

The hitch-kick technique involves using the motions of the arms and legs to evoke a contrary reaction of the trunk, thereby maintaining the athlete's upright posture in the air. The athlete rotates their arms and legs forward in a movement that is similar to running.

Because the athlete is in free flight the athlete's total angular momentum must be conserved. The forward angular momentum generated by circling the arms and legs forward is, therefore, countered by an equal backwards angular momentum in the trunk. The athlete is thus able to counter the forward rotation of the body that was developed in the take-off.

Long jumpers choose their flight technique according to the amount of angular momentum they generate during the take-off and the time they have available before landing. Many coaches recommend the hang technique for athletes of lesser ability, who usually generate a lower angular momentum during the take-off and spend less time in the air. The hitch-kick is recommended for better athletes, who usually generate a higher angular momentum during the take-off and have a longer flight time. The hitch-kick technique has two main variants, '2½-step' and '3½-step', named according to the number of steps the athlete executes during the flight. Contrary to what is sometimes thought, the long jumper's forward circling actions in the air do not increase the distance of the jump by propelling the athlete through the air.

Towards the end of the flight phase the athlete prepares for landing by lifting their legs up and extending them in front of the body. The goal of the landing is to create the greatest possible horizontal distance between the take-off line and the mark made by the heels in the sand. The landing technique should not result in the athlete falling backwards into the pit or otherwise producing a mark that is closer to the take-off board than that made by the heels. There are several basic variations on landing technique, including the 'orthodox', 'slide-out' and 'swivel-out' techniques, but there is currently no consensus on the optimum technique that produces the longest jump distance (Hay, 1986).

Flight distance equation

The athlete's jump distance is measured from the take-off line to the nearest mark made by the athlete in the landing area. Jump distance may be considered as the sum of the take-off distance, the flight distance, and the landing distance (Figure 24.2):

$$d_{\text{jump}} = d_{\text{take-off}} + d_{\text{flight}} + d_{\text{landing}}.$$

In most jumps the flight distance is about 90 per cent of the total jump distance. Therefore, the biomechanical factors that determine the athlete's flight distance are very important in long jumping.

During the flight phase of the jump the effects of gravity are much greater than those of aerodynamic forces and so the jumper may be considered as a projectile in free flight. The trajectory of the athlete's COM is determined by the conditions at take-off, and the flight distance is given by

$$d_{\text{flight}} = \frac{v^2 \sin 2\theta}{2g} \left[1 + \left(1 + \frac{2gh}{v^2 \sin^2 \theta} \right)^{1/2} \right], \quad (1)$$

where v is the take-off velocity, θ is the take-off angle, and g is the acceleration due to gravity. Here, the relative take-off height, h , is given by:

$$h = h_{\text{take-off}} - h_{\text{landing}},$$

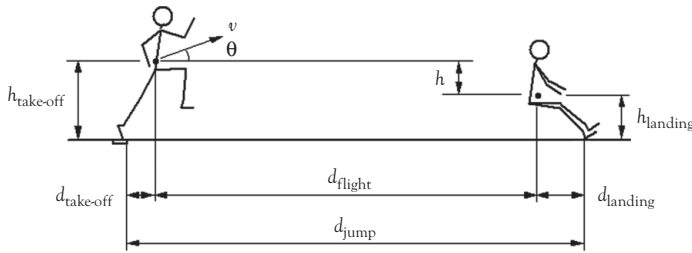


Figure 24.2 The total jump distance is the sum of the take-off, flight, and landing distances. The flight distance is determined by the take-off velocity (v), the take-off angle (θ), and the relative height difference between take-off and landing (h). Adapted with permission from Linthorne, Guzman, and Bridgett (2005).

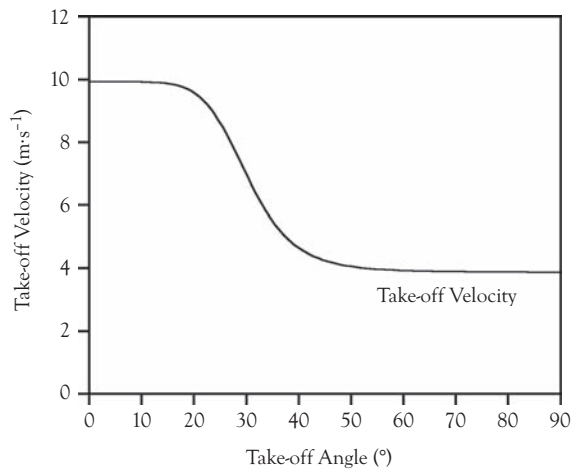
where $h_{\text{take-off}}$ is the take-off height and h_{landing} is the landing height (Figure 24.2). When $h = 0$, equation (1) reduces to the familiar expression for the range of a projectile launched from ground level over a horizontal plane, $d_{\text{flight}} = (v^2 \sin 2\theta)/g$.

An examination of equation (1) reveals how the athlete can maximize the flight distance of the jump. By far the most important variable is the take-off velocity. The flight distance is proportional to the square of the take-off velocity, and, therefore, the athlete should strive for a high velocity at take-off. The athlete should also aim to maximize the height difference between take-off and landing by having a high body position at take-off and a low body position at landing. However, any actions to achieve a large height difference should not come at the expense of a fast take-off velocity. At first glance, equation (1) suggests that the athlete should jump with a take-off angle of about 45° so as to maximize the 'sin 2θ ' term. However, it is important to recognize that the take-off velocity (v) and relative take-off height (h) are not constants, but are functions of the take-off angle (θ). These relations must be determined and inserted into equation (1) in order to determine the athlete's optimum take-off angle.

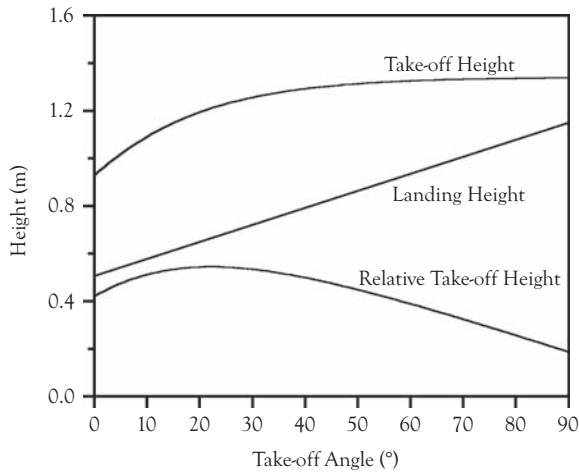
Optimum take-off angle

A long jumper's optimum take-off angle may be determined by using high-speed video to measure the athlete's relations between take-off velocity and take-off angle, $v(\theta)$, and between relative take-off height and take-off angle, $h(\theta)$ (Linthorne, Guzman, and Bridgett, 2005). To obtain reliable measures of these relations the athlete must jump many times using a wide range of take-off angles (0 – 90°). The highest take-off velocities are obtained when the jumper uses a fast run-up and then attempts to jump up as much as possible. However, long jumpers cannot attain take-off angles greater than about 25° using this technique (Figure 24.3a). To achieve greater take-off angles the athlete must use a slower run-up and so the take-off velocity is reduced. In the extreme case of a near-vertical take-off angle, the run-up velocity must be reduced to walking pace and so the take-off velocity is at its lowest. The take-off height and landing height are determined by the athlete's body configuration. Although the take-off and landing heights both increase with increasing take-off angle, the height difference between the two remains approximately constant (Figure 24.3b).

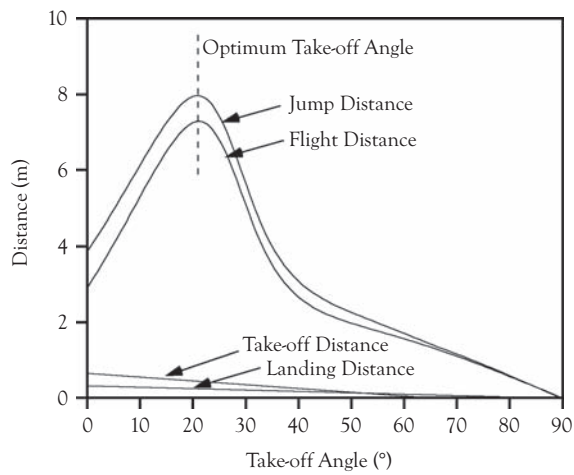
To find the athlete's optimum take-off angle, the mathematical expressions for $v(\theta)$ and $h(\theta)$ are inserted into the equation for the flight distance (equation 1). The flight distance is then



(a)



(b)



(c)

Figure 24.3 Calculation of an athlete's optimum take-off angle: (a) relation between take-off velocity and take-off angle; (b) relation between relative take-off height and take-off angle; and (c) component distances and total jump distance. Curves are for an elite male long jumper, and the optimum take-off angle is about 21°. Adapted with permission from Linthorne, Guzman, and Bridgett (2005).

plotted as a function of the take-off angle, and the optimum take-off angle is the point on the curve at which the flight distance is greatest (Figure 24.3c). In the long jump, $v(\theta)$ has a strong influence on the optimum take-off angle, whereas $h(\theta)$ is relatively unimportant. In long jumping, the total jump distance is slightly more than the flight distance (Figure 24.2). However, the take-off and landing distances make relatively small contributions to the total jump distance and have little effect on the optimum take-off angle (Figure 24.3c). Launching the body at close to the optimum take-off angle is essential for a successful long jump. The distance achieved by the jumper is sensitive to take-off angle, and so large deviations from the optimum take-off angle cannot be tolerated (Figure 24.3c).

Run-up velocity and take-off technique

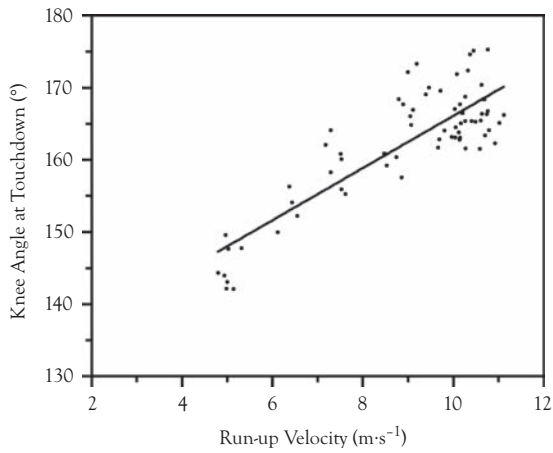
The most important determinant of success in long jumping is the athlete's ability to produce a fast run-up velocity and hence a fast take-off velocity. Long jumpers, therefore, spend a lot of time developing their maximum sprint speed and improving their ability to get close to this maximum speed in the last stride before take-off. However, an athlete must make adjustments to their take-off technique in order to benefit from a faster run-up velocity. Bridgett and Linthorne (2006) determined the relations between run-up velocity and take-off technique by manipulating the run-up length used by an elite male long jumper. The improvement in jump distance with increasing run-up velocity is shown in Figure 24.1, and the effects of run-up velocity on the athlete's take-off technique are shown in Figure 24.4.

A long jumper must use a straighter knee at touchdown in order to benefit from a faster run-up velocity (Figure 24.4a). A straighter take-off leg has a smaller moment arm about the knee for the GRF and is, therefore, more resistant to flexion. By preventing excessive flexion, less energy is dissipated by the leg muscles in eccentric contraction. A faster run-up speed also requires the athlete to use a slightly lower leg angle at touchdown (Figure 24.4b). The lower leg angle arises because a faster run-up velocity requires the athlete to increase the duration of the foot contact in order to maintain a high vertical take-off velocity. The athlete therefore plants the foot farther ahead of the COM at touchdown and hence has a lower leg angle.

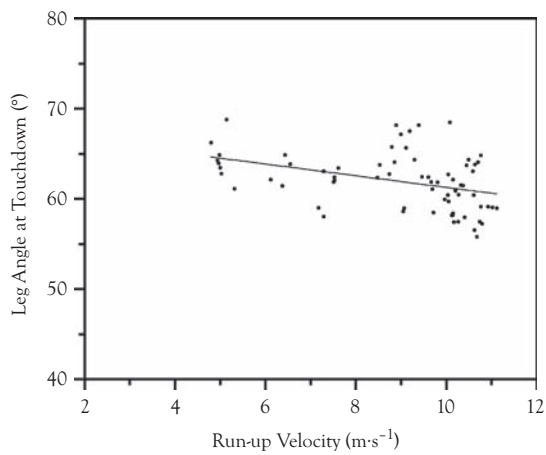
Even though a long jumper performs actions during the take-off that are aimed at generating vertical velocity, the athlete is still able to transfer much of his run-up velocity through to horizontal take-off velocity. The resultant take-off velocity therefore steadily increases with increasing run-up velocity (Figure 24.4c). In the long jump, the jumping action results in a reduction in horizontal velocity, and this loss becomes greater as the run-up velocity is increased.

A long jumper produces a lower take-off angle at faster run-up velocities (Figure 24.4d). The take-off angle is determined by the ratio of the vertical velocity and the horizontal velocity. At all run-up velocities the optimum take-off strategy that produces the greatest jump distance is to generate close to the maximum possible vertical velocity. Changes in the take-off angle are therefore determined by changes in the horizontal velocity. Because the athlete's horizontal take-off velocity increases with increasing run-up velocity, the angle of the take-off velocity vector to the horizontal steadily decreases.

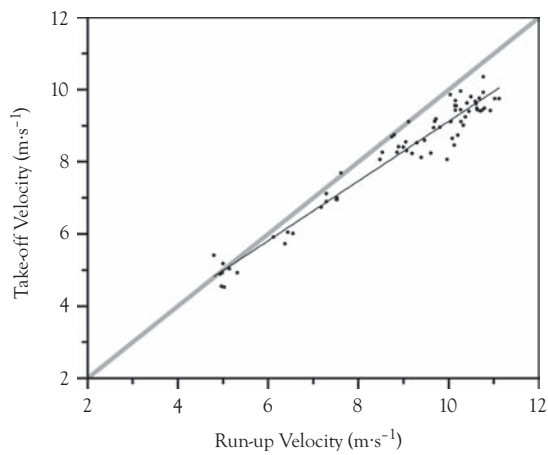
In jumps from a full-speed run-up the take-off foot is in contact with the ground for about 0.12 s. The duration of the take-off decreases in proportion to $1/v^{0.6}$, where v is the run-up velocity (Figure 24.4d). A simplistic model of the long jump take-off, in which the rotational ROM of the take-off leg is the same at all run-up velocities, suggests that the take-off



(a)

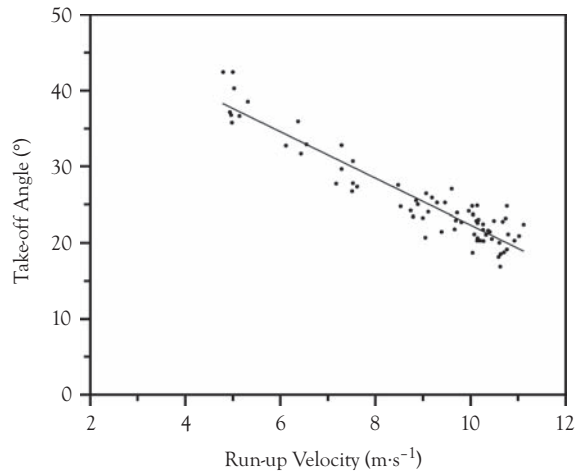


(b)

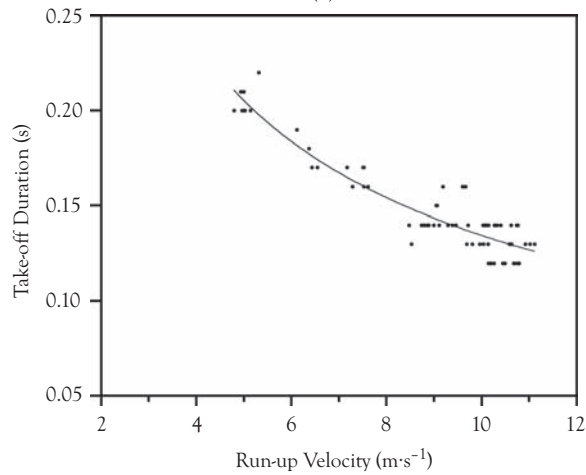


(c)

Figure 24.4 Relations between run-up velocity and take-off technique for an elite male long jumper: (a) knee angle at touchdown; (b) leg angle at touchdown; (c) take-off velocity; (d) take-off angle; and (e) take-off duration. Adapted with permission from Bridgett and Linthorne (2006).



(d)



(e)

Figure 24.4—Cont'd

duration should vary in proportion to $1/v$. However, long jumpers tend to use a greater rotational ROM of their take-off leg at faster run-up velocities.

Long jump shoes

Long jumpers use shoes that are designed specifically for the event. The shoes have several spikes positioned under the ball of the foot to give a firm grip on the board at take-off, and a beveled toe to help reduce the chances of marking the plasticine indicator board at take-off. Some companies manufacture long jump shoes with stiff soles under the balls of the feet. Studies of the foot during the stance phase of running and jumping have shown that the

metatarsophalangeal joint flexes as the athlete rolls onto the forefoot and does not extend until after take-off. The metatarsophalangeal joint is, therefore, believed to be a large energy absorber (Stefanyshyn and Nigg, 1998). In shoes with stiff soles, the energy that is normally dissipated during the bending of the metatarsophalangeal joints at touchdown is stored in the sole and returned to the athlete during the take-off phase of the stride.

Shoes with stiff soles are expected to benefit the athlete in both the run-up and take-off phases of the jump. Experiments on sprinters with stiffening plates in their shoes showed an improvement in sprinting speed of just over 1 per cent (Stefanyshyn and Fusco, 2004). In the long jump, a 1 per cent increase in run-up velocity produces a 6 cm increase in jump distance (Bridgett and Linthorne, 2006). About 60–100 J is believed to be absorbed in the metatarsophalangeal joint during a long jump take-off. A sole that stores and returns a large fraction of this energy to the athlete (say, 40 J) will increase the jump distance by about 10 cm.

Some shoe companies manufacture long jump shoes that have a tapered sole. The sole is thickest under the ball of the foot (13 mm; the maximum allowed by the rules) and thinnest under the heel. These shoes give the athlete an effectively longer leg during the take-off. The advantage is maximized by making the difference between the length of the leg at touchdown (with the landing on the heel) and at the instant of take-off (on the ball of the foot) as great as possible. A longer take-off leg may give a biomechanical advantage by allowing the athlete to generate a greater take-off velocity, and hence produce a longer jump.

Disabled athletes

Disabled athletes are classified according to their functional ability, and for lower limb amputee athletes the relevant classifications are 'below-knee amputee' and 'above-knee amputee'. Most single-leg amputee athletes jump from their intact leg and use the same basic jumping technique as able-bodied athletes (Nolan, Patrilli, and Simpson, 2006). The jump distances achieved by able-bodied athletes are usually greater than those achieved by amputee athletes, and below-knee amputees generally jump farther than above-knee amputees.

Performances achieved by amputee athletes are limited by their asymmetrical gait and its detrimental effect on the run-up velocity that the athlete can attain. Amputee athletes spend longer in stance and have a shorter swing phase on their intact limb than on their prosthetic limb. They also spend longer stepping into their prosthetic limb than into their intact limb. These differences probably arise because of the lower mass and different inertial characteristics of the prosthetic limb.

Even at equal run-up velocities, amputee athletes do not produce jump distances as great as those produced by able-bodied athletes because they find it more difficult to get into the correct position at touchdown. Amputee athletes have difficulty in lowering their COM during the support phase of the last stride before take-off because their prosthetic knee needs to be locked to support their body weight during stance. Amputee athletes therefore have a greater downward vertical velocity into the take-off stride than able-bodied athletes, and so are less effective at generating upwards vertical velocity. Above-knee amputee athletes are less able than below-knee amputees to lower their COM into the take-off. Their jump distances are therefore usually not as great as those by below-knee amputees. Both above-knee and below-knee amputees attempt to compensate for the partial loss of a lower limb by using a greater ROM at the hip joint of the intact limb during the take-off.

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