

A FORMULA FOR MEASUREMENT OF LEG POWER IN THE VERTICAL JUMP

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INTRODUCTION

The measurement of leg power through the execution of a standing vertical jump seems to be an on-going challenge to biomechanists. The problem is that the height of a jump is produced by the instantaneous velocity of the jumper at the moment of release from the supporting surface and neither the height of the jump nor the release velocity are measures of leg power. Thus, the challenge seems to be to develop a model through which leg power can be measured through height measures obtained from a standing vertical jump.

The purpose of this paper is to present a model for the calculation of leg power based on the height of the center of mass at three positions. These positions are Y_1 , the lowest crouched position; Y_2 , the extended position just as the body releases from the floor; and Y_3 , the highest part of of the jump. A simple analysis based on these three heights may be used to obtain the work done in jumping, the release velocity from the floor, and an "average" vertical force exerted during the jump. From the release velocity and average vertical force, an approximate average power can be calculated.

CALCULATION OF WORK, FORCE, AND VELOCITY FROM HEIGHT DATA

The work-energy theorem states that the net work on an object moving from position A to positions B will be equal to the difference in kinetic energy of the object at point B compared to point A. If we assume the jumper has zero velocity at the initial crouched position and at the maximum height of the jump, the net work between those two points would be zero. The assumption of zero velocity is not valid if the jumper is allowed to drop into and through the lowest crouch using a vigorous arm pump. For the assumption and resultant analysis to be valid, no arm movement should be used and the jumper's internal kinetic energy associated with limb motion and external kinetic energy associated with velocity of the (com) must be zero at the lowest height.

The net work will consist of the positive work by the ground reaction force while the (com) rises from Y_1 to Y_2 , and the negative work of the gravitational force while the (com) rises from Y_1 to Y_3 . The ground reaction force would not be constant, but there would be a spatial average value, F , for the motion from Y_1 to Y_2 . The gravitational force, or weight of the jumper is given by the product of mass, m , and gravitational acceleration, g . The resulting statement from application of the work-energy theorem is:

$$F(Y_2 - Y_1) - mg(Y_3 - Y_1) = 0. \quad (\text{eg. 1})$$

Therefore, the work done by the ground reaction force, W , and thus by the jumper would be:

$$W = F (Y_2 - Y_1) = mg (Y_3 - Y_1). \quad (\text{eq. 2})$$

Likewise, the spatial average of the ground reaction force, and thus the jumper's exerted force would be:

$$F = mg (Y_3 - Y_1) / (Y_2 - Y_1). \quad (\text{eq. 3})$$

During the airborne phase, the jumper can be assumed to be in free-fall, thus his kinetic energy at release, given by $mV_r^2/2$ where V_r is the velocity at release, will be equal to the gain in potential energy when at maximum height, i.e., $mg (Y_3 - Y_2)$. This implies:

$$V_r = \sqrt{2g (Y_3 - Y_2)} \quad (\text{eq. 4})$$

APPROXIMATE POWER FROM HEIGHT DATA

Two simplifying assumptions must be made in order to calculate an average power from the above analysis. Neither of these assumptions are completely valid, and thus the average power calculated will be an approximation at best.

The first assumption will be that the average velocity of the (com) while accelerating from zero velocity at Y_1 to a velocity of V_r at Y_2 is given by:

$$V = V_r / 2. \quad (\text{eq. 5})$$

This assumption would be valid if the ground reaction force, and therefore the acceleration, was constant during the jump. However, the ground reaction forces are not constant, and eq. 5 is an approximation at best.

The second assumption is that the average power can be obtained by multiplying an average force by an average velocity. This assumption is not valid for most cases. For example, note that the average of the deviation from the mean for a set of numbers is zero, and therefore the product of the average deviations with itself is zero. But the average of the square of the deviations is not zero. In general

$$\langle X \cdot Y \rangle \neq \langle X \rangle \cdot \langle Y \rangle. \quad (\text{eq. 6})$$

So calculating an average power by

$$P = F (V_r / 2) \quad (\text{eq. 7})$$

would be a rough approximation at best.

The measurement of heights during a standing jump then gives a measure of work and average force, but only crudely measures power (unless time as well as height is measured).

CALCULATION OF VELOCITY, POWER, AND WORK FROM FORCE VS TIME DATA

The validation of the formulas described above for the calculation of work, force, velocity, and power from height data requires that their results be compared with those obtained through the use of electronically measured force vs time data. Thus, the following protocol was developed for the use in Anand Shetty's validation study described elsewhere in these proceedings. (*)

A Kistler force-platform utilizing piezo-electric crystals was used in Shetty's study to obtain force vs time data for the standing jump. The amplified analog signal from the Kistler platform was converted to 12 bit digital data and stored via interface circuitry on an Apple IIe computer. The computer was then used to perform the required numerical analysis described below.

Since the computerized force-platform system yielded ground reaction forces as a function of time, $F(t)$, during the jump and since the jumper's mass, m , is known, the velocity as a function of time, $V(t)$, and the power as a function of time, $P(t)$, can be calculated. The algorithms for these calculations are:

If the ground reaction forces are known as a function of time, $F(t)$, during the jump and the jumper's mass, m , is known, the velocity as a function of time, $V(t)$, and the power as a function of time, $P(t)$, can be calculated.

The momentum-impulse relation can be expressed by

$$mV(t) - mV(t_0) = \int_{t_0}^t F_{\text{net}}(t') dt' \quad (\text{eq. 8})$$

If the jump is initiated at $t_0 = 0$ and $V(t_0) = 0$, then

$$V(t) = 1/m \int_0^t [F(t') - mg] dt' \quad (\text{eq. 9})$$

where $F(t') - mg$ is the net force acting on the jumper. The power exerted by the jumper is given by

$$\begin{aligned} P(t) &= F(t) \cdot v(t) \\ &= F(t) \cdot \int_0^t [F(t')/m - g] dt' \end{aligned} \quad (\text{eq. 10})$$

That is, the power at time t is the force at time t multiplied by the impulse from $t = 0$ to time t divided by the mass.

The time of release from the floor can be determined by when the ground reaction force data goes to zero. This time, t_r , can be used in eq. 9 to evaluate V_r . Also, the work done by the jumper would be given by

$$W = \int_0^{t_r} P(t') dt' \quad (\text{eq. 11})$$

where t_r would be used for the upper limit of integration. The average power could then be obtained by dividing the work by t_r , i.e.

$$\langle P \rangle = W/t_r \quad (\text{eq. 12})$$

In Shetty's study height measurements were made cinematographically to compare with the force platform data. In addition, the time-of-flight, T , was obtained from the force platform data, and used in the free fall equation for vertical projection

$$v_r = gT/2 \quad (\text{eq. 13})$$

as a third method of determining the release velocity.

VALIDATION OF LIGHTSEY LEG POWER FORMULA

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The purpose of this study was to compare the results obtained through Lightsey's formula for the calculation of approximate leg power from height data measured from filmed standing vertical jump performances with those obtained from precise force-platform measures of the same performances.

A Kistler force-platform utilizing piezo-electric crystals was used to obtain force vs time data for the standing vertical jump. Eleven male college students performed two maximum standing vertical jumps from the surface of the platform without using their arms. Force vs time data were obtained from the platform at a frequency of 100 hz in the form of amplified analog signals which were converted to 12 bit digital data and stored via interface circuitry on an Apple IIe computer. Lightsey's protocol for the measurement of velocity, power, and work from force vs time data was used by Kevin Spooner and Paul Lightsey to write a computer program for the calculation of these quantities on the Apple IIe.

The two jumps performed by each of the eleven subjects were filmed at 24 frames per second with a Photo-Sonics camera. The film was digitized on a Vanguard Motion Analyzer. The centers of mass (com) locations of the subjects were estimated at three positions during their jumps. The three (com) positions were: (com1) when the subjects were at their lowest crouched positions; (com2) when the subjects were in an extended position just before their release from the floor; and (com3) when the subjects were at the highest