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# A simple method for measuring force, velocity and power output during squat jump

Pierre Samozino *, Jean-Benoît Morin, Frédérique Hintzy, Alain Belli

*Exercise Physiology Laboratory (EA 4338), University of Saint-Etienne, CHU Bellevue—Medecine du Sport et Myologie, 42055 Saint-Etienne Cedex 02, France*

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ABSTRACT

Our aim was to clarify the relationship between power output and the different mechanical parameters influencing it during squat jumps, and to further use this relationship in a new computation method to evaluate power output in field conditions. Based on fundamental laws of mechanics, computations were developed to express force, velocity and power generated during one squat jump. This computation method was validated on eleven physically active men performing two maximal squat jumps. During each trial, mean force, velocity and power were calculated during push-off from both force plate measurements and the proposed computations. Differences between the two methods were not significant and lower than 3% for force, velocity and power. The validity of the computation method was also highlighted by Bland and Altman analyses and linear regressions close to the identity line ($P<0.001$). The low coefficients of variation between two trials demonstrated the acceptable reliability of the proposed method. The proposed computations confirmed, from a biomechanical analysis, the positive relationship between power output, body mass and jump height, hitherto only shown by means of regression-based equations. Further, these computations pointed out that power also depends on push-off vertical distance. The accuracy and reliability of the proposed theoretical computations were in line with those observed when using laboratory ergometers such as force plates. Consequently, the proposed method, solely based on three simple parameters (body mass, jump height and push-off distance), allows to accurately evaluate force, velocity and power developed by lower limbs extensor muscles during squat jumps in field conditions.



## 1. Introduction

The ability to quickly accelerate the body from a resting position is considered to be particularly important for successful performance in many sport activities. Based on Hill's muscle mechanical model (Hill, 1938), this "explosive" ability is directly related to the mechanical characteristics of the muscle contractile component, and notably to maximal power output. Further, testing the maximal power output of lower limbs extensor muscles is a common practice in the assessment of human exercise performance. Maximal power output has been assessed from different leg movements, namely sprint running (Jaskolska et al., 1999; Jaskolski et al., 1996), sprint pedalling (Arsac et al., 1996; Seck et al., 1995; Vandewalle et al., 1987a) or vertical jumping (Davies and Young, 1984; Rahmani et al., 2000; Wilson et al., 1997). No matter what the type of leg movement analysed, power output may be computed as the product of force times velocity. Measuring force and velocity with accuracy requires specific and/or expensive devices, such as cycle ergometers (Arsac et al., 1996), force plates (Harman et al., 1991) or linear position transducers (Cormie et al., 2007a, b), which may be impractical for field use. Consequently, a convenient, simple and accurate method available for measuring power output could be essential for sport performance professionals.

Beyond being the most widely used movement because of its simplicity (Lara et al., 2006b; Vandewalle et al., 1987b), vertical jump can be considered one of the most "explosive" tests due to both its very short duration and the high intensity involved. Even being positively correlated to peak power output (Davies and Young, 1984), vertical jump height is only an alternative and indirect indicator of lower limbs explosive capacities, and has the dimension of mechanical work and not that of power (Vandewalle et al., 1987b). The late Carmelo Bosco test proposed a simple methodology for measuring mechanical power during repeated jumps (Bosco et al., 1983). Its different computations, based on contact and flight times, might also be applied to the drop jump exercise in order to obtain maximal power values. However, other muscle characteristics are also involved during this kind of jump, especially those related to stretch-shortening cycle (cf. Asmussen and Bonde-Petersen, 1974). Hence, Bosco's power test, but also drop and countermovement jump tests, cannot be used to evaluate only the explosive concentric capacities.

* Corresponding author. Tel.: +33 4 77 12 07 33; fax: +33 4 77 12 72 29.
*E-mail address:* pierre.samozino@univ-st-etienne.fr (P. Samozino).

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**Nomenclature**

| | |
|---|---|
| $W_T$ | total work done during squat jump (in J) |
| CM | body center of mass |
| $h_{PO}$ | vertical push-off distance (in m) |
| $h$ | jump height corresponding to the vertical distance covered by CM during aerial phase (in m) |
| $h_S$ | height of CM in starting position (in m) |
| $\bar{F}$ | mean vertical force (in N) |
| $\bar{v}$ | mean vertical velocity (in m s$^{-1}$) |
| $\bar{P}$ | mean vertical power (in W) |
| $\bar{F}_{FPM}$ | mean vertical force obtained with the force plate method (in N) |
| $\bar{v}_{FPM}$ | mean vertical velocity obtained with the force plate method (in m s$^{-1}$) |
| $\bar{P}_{FPM}$ | mean vertical power obtained with the force plate method (in W) |
| GRF | ground reaction force (in N) |
| $t_A$ | aerial time (in s) |
| $t_{PO}$ | push-off time (in s) |
| $v_{TO}$ | vertical velocity at takeoff (in m s$^{-1}$) |
| $a$ | vertical acceleration of the center of mass (in m s$^{-2}$) |
| $m$ | body mass (in kg) |
| $g$ | gravitational acceleration (9.81 m s$^{-2}$) |

Furthermore, different formulae have been proposed to estimate power output from vertical jump height and body mass. Some of them are derived from fundamental laws of mechanics (Gray et al., 1962; Lewis cited in Fox and Mathews, 1974), but the underlying biomechanical models from which they were developed have been challenged. Indeed, it has been argued that Lewis's formula divides the change in potential energy by the aerial ascending phase duration instead of that of the push-off, and does not take into account the change in potential energy during push-off (Harman et al., 1991; Vandewalle et al., 1987b). Gray's formula assumes that the vertical acceleration of the center of mass (CM) is constant during push-off, which is in contradiction to some experimental results frequently presented in the literature (Cormie et al., 2007a, b; Harman et al., 1991). Other formulae arose from experimental regression equations obtained between power and biomechanical parameters, which statistically showed that maximal power output was highly dependent on vertical jump height and body mass (Canavan and Vescovi, 2004; Harman et al., 1991; Johnson and Bahamonde, 1996; Sayers et al., 1999; Lara et al., 2006a, b). The first limitation of such predictive equations is the lack of theoretical rationale explaining the link between power and these two parameters, there remaining the doubt if all athletes with the same body mass and reaching the same jump height develop the same power output, as well as if push-off time should not be taken into account. The other limitation of such equations is the population-dependence of the proposed regressions, which may lead to a lower accuracy for estimating power (Canavan and Vescovi, 2004; Hertogh and Hue, 2002; Lara et al., 2006a, b).

If these different studies did not propose an accurate method for measuring power output in field conditions, the fact remains that they showed (i) the strong influence of body mass and vertical jump height on maximal power developed, and (ii) the enduring interest observed throughout the literature (at least from 1962 to 2006) towards evaluating maximal power output from simple parameters during vertical jumps. Therefore, the aim of this study was to clarify the relationship between power output and the different mechanical parameters influencing it during squat jumps by the sole use of the fundamental laws of mechanics, and to further use this relationship to elaborate a new computation method for power output evaluation in field conditions.

## 2. Methods

### 2.1. Theoretical background and development of formulae

During a squat jump, the lower limbs produce mechanical work to elevate the CM from its initial vertical position to that of maximal height. The vertical velocity (and hence kinetic energy) being null at these two instants, the total work done ($W_T$) is equal to the potential-energy change between these two positions:

$$W_T = mg(h_{PO} + h + h_S) - mgh_S \tag{1}$$

$$W_T = mg(h_{PO} + h) \tag{2}$$

with $m$ the body mass, $g$ the gravitational acceleration, $h_{PO}$ the vertical push-off distance, $h$ the jump height and $h_S$ the height of CM in the starting position (Fig. 1).

Furthermore, $W_T$, developed by the lower limbs during push-off, is also equal to the product of $h_{PO}$ times the mean vertical force ($\bar{F}$) generated by lower limbs. Consequently

$$\bar{F} = \frac{W_T}{h_{PO}} \tag{3}$$

Substituting (2) in this equation gives

$$\bar{F} = mg\left(\frac{h}{h_{PO}} + 1\right) \tag{4}$$

The mean vertical velocity of the CM during push-off ($\bar{v}$) was computed as

$$\bar{v} = \frac{h_{PO}}{t_{PO}} \tag{5}$$

with $t_{PO}$, the push-off phase duration, obtained from the impulse–momentum relationship. Applying it to squat jump with null starting velocity, the following equation is obtained:

$$t_{PO} = \frac{mv_{TO}}{(\bar{F} - mg)} \tag{6}$$

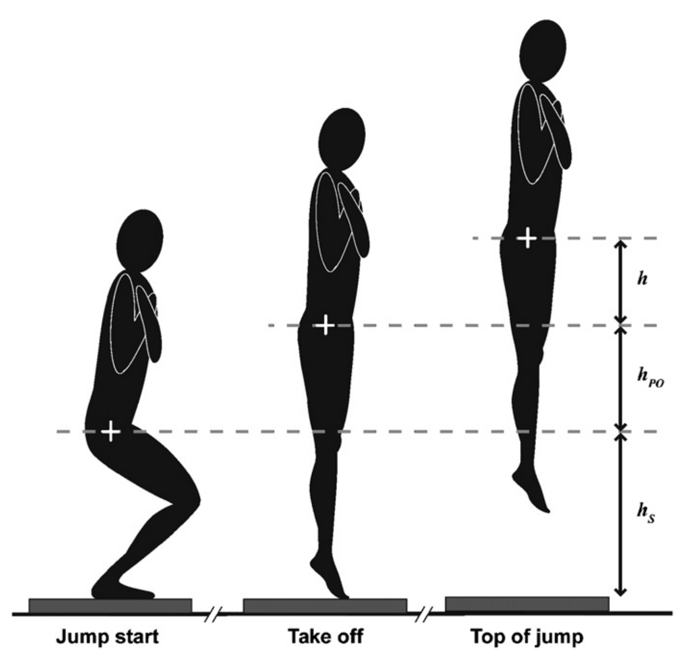


**Fig. 1.** The three key positions during a vertical squat jump and the three distances used in the proposed computations.