Power measurement in maximum height jump

F Crenna¹, A Palazzo and G B Rossi  
Measurement Laboratory, DIME, Dept. of Mechanical Engineering,  
University of Genova Via Opera Pia 15A 16145 Genova, ITALY  
E-mail: francesco.crenna@unige.it

Abstract. Athletes performance can be evaluated through different tests generally specifically designed to consider a specific quality. When dealing with explosive power, maximum height jump is widely used. Athlete’s performance may be evaluated through different parameters such as elevation differential, excursion of the center of mass in vertical direction, or in more detailed way, through a power measurement. A few methods can be considered for this purpose and the aim of this paper is to compare them, providing guidelines for their application and for measurement-uncertainty evaluation, as far as possible for such a gesture, considering the complexity of the measurement.

1. Introduction

Athletes performance can be evaluated through specific tests, according to the athletic qualities to be considered. When the focus is on explosive power the jump at maximum height without the help of a run-up is a widely used gesture [1]. Sports mainly involved are the ones requiring jumps at maximum height with limited or absent run up preparation, such as volley and basketball [2, 3, 4]. It is also widely used in athletics to evaluate overall physical condition and training progression in sprint, high and long jump athletes [5]. Besides that, high jump test is used to select young athletes for a specific sport in schools, or to establish team composition by selecting most performant subjects. Unfortunately, in spite of its wide use, there is no recognised standardization neither for the test protocol itself, nor for required measurement system and measurement method, and for signal processing [6].

A few jumping techniques may be considered, as well as measurement methods with different complexity and possibly reliability. One possibility is to perform a high jump from a standing position and the measurement of the maximal height the subject is able to reach by extending his arms [7]. In this case performance is evaluated by the differential between the maximum height reached and the height with subject standing on the floor. Comparing test results from different training periods or different subjects a very basic performance evaluation can be carried out, to determine training-period effects or to select athletes in better conditions or most suitable for a specific sport. In this simple case usually the height is measured by the subjects touching a reference scale on the wall with the hand covered by chalk. More sophisticated measurement systems include video recording, throw wire encoders and similar devices. Moreover, a complete characterisation requires a subject instrumented with proper markers placed on specific anatomical landmarks which displacement is recorded while

¹ To whom any correspondence should be addressed.
the subject executes the test on a force platform. Such a system enables a complete characterization of
the biomechanical kinetics, by measuring the forces exchange with the ground, and kinematics in two
or even three dimensional space, if more than one video camera is used [8,9].
Different test modalities are reported in the literature. Traditional squat jump starts from a static
position with knee and hip flexed and the jump takes place by a fast whole body elongation including
arms. Another possibility is a dynamic pre-activation by a countermovement requiring muscles
eelongation, followed by a fast contraction. It has been found that such a condition increases power
output, probably due to muscle and tendons elastic properties [10]. Time history of the measured
quantities, such as reaction force or joint angles or even power output can give useful information if
correlated with surface electromyography muscle activity measurements [11]. In this paper we focus
specifically on power measurement comparing alternative methods to measure mechanical power
exchanged by the athlete with surroundings [12]. In section 2 we introduce power measurement issues,
while in 3 a description of the experimental set up is given. In section 4 we present and discuss first
experimental results for both squat and countermovement jumps.

Table 1. Power measurement approaches

| Method       | Description                                                                 |
|--------------|-----------------------------------------------------------------------------|
| Pure GRF     | Only GRF measurement                                                        |
| Mixed 1      | GRF and iliac crest kinematic measurements – rigid body CoM                 |
| Mixed 2      | GRF and kinematic measurements - multi segment body model CoM               |
| Pure kinematics | Only Kinematic measurements                                                 |

2. Power measurement
Instantaneous mechanical power output from a jump test is defined as the scalar product

\[ P(t) = F(t) \cdot v(t) \]  

(1)

where \( F(t) \) is the force applied to the body Centre of Mass (CoM) and \( v(t) \) is its velocity. Since the
gesture develops above all in the vertical direction, we can consider only power contributions from
vertical force and velocity. So we can define power output as:

\[ P(t) \cong F_y(t) \cdot v_y(t) \]  

(2)

Such power can be measured according to a few methods on the basis of the raw measurement data
available. Let’s consider the first method based on force data only. The ground reaction force vertical
component can be directly measured by the force platform, while vertical CoM velocity can be
obtained through the integration of acceleration obtained from the same GRF data:

\[ P_f(t) \approx \left( F_y(t) - mg \right) \int_0^t \frac{F_y(t') - mg}{m} dt' \]  

(3)

where \( F_y(t) \) is the vertical force component as measured by the force platform, \( m \) subject’s mass, \( g \)
gravity. Note that we have considered only the dynamic contribution to GRF, by subtracting the force
due to subject’s weight. Of course if we can measure the CoM vertical velocity a mixed method might
be considered. In this case we have two possibilities: approximating the CoM vertical position with the
standard anatomic position on the iliac crest, or computing the CoM vertical position according to the
vertical positions of the CoM of segments constituting the body. In the former case we are considering
subject’s body as rigid, while in the latter this second case we take into account CoM movements due
to the different body configurations during test executions.

\[ P_m(t) \approx \left( F_y(t) - mg \right) \cdot \dot{y}_{CoM} \]  

(4)
Lastly, if we have only kinematic measurements without force platform data, it is possible to obtain CoM acceleration and velocity from position through proper differentiation procedures \[13\].

\[
P_k(t) = m \cdot \ddot{y}_{CoM}(t) \cdot \dot{y}_{CoM}(t)
\]  

In the following we will consider in particular pure force and the two approaches to the mixed method, while the last, pure kinematic, method will be investigated in future.

3. Measurement system set up

The experimental set up we are using includes a force platform based on four load cells, a motion capture system based on a set of active markers and a camera, and a personal computer with a data acquisition board and dedicated software.

Since gesture we are considering is mainly planar a single camera set up is used. Camera alignment is preliminary verified to have the image plane parallel to the sagittal plane of motion. Calibration is carried out to obtain sensitivity parameters relative to markers plane of motion.

Markers are high intensity white led, and are placed on main anatomical landmarks of subject’s right side: shoulder, iliac crest (or approximate body CoM), hip, malleolus, heel, metatarsus and foot tip. Camera exposure is minimal to obtain dark images with white spots representing markers. A film is recorded at maximum frame rate maintaining full camera resolution and no compression. In this first investigation we are using a VGA resolution camera at 50Hz frame rate. Further improvements will include higher resolutions and frame rates. Ground reaction force vertical component is measured by a custom force platform, based of 4 calibrated load cells with an overall measurement range of 10 kN and a bandwidth of approximately 100 Hz. Acquisition takes place at 5kHz and it is synchronised with the video system.

4. Preliminary results

We present here some preliminary results extracted for a set of tests sessions carried out by two subjects. A tests session was arranged to have a sequence of four jumps: squat jump, with and without upper limbs contribution; countermovement jump with and without upper limb contribution.

![Figure 1](image1.png)

**Figure 1.** Force platform measurements for squat (a) and countermovement jump (b)

Force time history is presented in figure 1, while figure 2 presents power output measurements. The three methods present good consistency both in the time history development and in the maximum value. Since a reference method is not available, an energy balance validation procedure could be of help for power measurements metrological characterisation. We are going to introduce such approach in future.
Figure 2. Power output measured by force and mixed mode methods for squat(a) and countermovement jump (b)

5. Conclusions
In this paper we have compared different approaches in power measurement during a maximum height jump. Power-measurement methods we have considered give a maximum peak value very similar and a comparable time behaviour. In future we plan to introduce some energy balance considerations to further validate results.

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