Jump Height Determination with Force Plate for Continuous Jumps

C. Calame¹, M. S. Kuster²

¹ Kistler Instrumente AG Winterthur, CH-8408 Winterthur, Switzerland
² Klinik fuer Orthopaedische Chirurgie, Kantonsspital, CH 9007 St. Gallen, Switzerland

Introduction
Using a force plate for jump performance analysis is a well accepted and proven method (1). One of the most often used parameters is the jump height s which is calculated using a "traditional" double integration of the vertical force F:

\[ a(t) = \frac{F(t)}{m} \]
\[ v(t) = \int (a(t) - a_0) \, dt \]
\[ s(t) = \int (v(t) - v_0) \, dt \]

The initial conditions for acceleration (a₀) and velocity (v₀) have to be determined carefully to prevent the integrations from "drifting".

A common method for single jumps is that the subject has to stand still and in the same position at the beginning and at the end of the jump. The initial conditions a₀ and v₀ are then adjusted so that velocity (v) and jump height (s) are zero at the beginning and at the end of the trial.

This "traditional" method works well for double integration over a short period of time (few seconds) such as single jumps (countermovement jump, squat jump).

However it does not produce satisfactory results for continuous jump (rebound jump) over a longer period of time. The reason is that small measurement and A/D errors add up sample by sample creating drift and fluctuations of the double integrations.

This paper describes a new jump-to-jump method to determine velocity, jump height and related parameters even for long duration continuous jumping. The method is implemented with good results in the software of Quattro Jump, a force plate system for routine jump performance analysis.

Materials and Methods
Subjects
For all jump tests the same healthy male subject was used (age: 32; weight: 62 kg; height: 1.72m). The subject was well instructed and trained to perform the jumps correctly.

Experimental Setup and Procedure
Several different Kistler force plates (types: 9281CA, 9286AA and Quattro Jump) have been used which were all calibrated in a certified calibration laboratory less than 12 months ago. The data acquisition was performed through a 16 bit A/D board (Computerboards Inc., DAS1602/16) at 500Hz per channel into the Kistler...
BioWare software. The continuous jumps were acquired (500Hz; 14bit) and analyzed with the Kistler Quattro Jump software.

Great care was taken that the subject stood still on the force plate at the beginning and at the end of the measurement.

Data Analysis

The integrations were performed within the BioWare and the Quattro Jump software using the Simpson's method (2).

The initial conditions for \( a_0 \) and \( v_0 \) were determined
1. in BioWare: automatically (using the "traditional" integration method).
2. in Quattro Jump:
   a) single jumps: automatically using the "traditional" integration method.
   b) continuous jump: using the described jump-to-jump algorithm.

Jump-to-Jump Integration of Continuous Jumps

Continuous jumps were integrated one by one, using the following assumptions to determine the initial conditions for \( a_0 \) and \( v_0 \) (see figure 5):

A. Velocity at mid-flight time is zero
   \( v(\text{mid-flight}) = 0 \).

B. Jump height at take-off is always the same value: an "anthropometric" constant \( h_a \) (ankle height)
   \( s(\text{take-off}) = h_a \)

Jump-to-jump double integration

For the velocity \( v \) the following formula was used:

\[
\begin{align*}
\text{interval} & \quad \text{mid-flight to mid-flight} \\
\text{acceleration} & \quad a(t) = \frac{F(t)}{m} \\
\text{velocity} & \quad v(t) = \int (a(t) - a_0) \, dt \\
& \quad a_0 = \text{avg}(a(t))
\end{align*}
\]

For the jump height \( s \) the following formula was used:

\[
\begin{align*}
\text{interval} & \quad \text{take-off to take-off} \\
\text{jump height} & \quad s(t) = \int (v(t) - v_0) \, dt + h_a \\
& \quad v_0 = \text{avg}(v(t))
\end{align*}
\]

For the first and the last jump the algorithm was slightly modified because there is a standing-still condition before the first and sometimes after the last jump.

Ankle height \( h_a \)

For reasons of simplicity the parameter \( h_a \) was implemented as a function of body height.

<table>
<thead>
<tr>
<th>Body Height</th>
<th>( h_a ) (Ankle Height)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1.60 m</td>
<td>0.09 m</td>
</tr>
<tr>
<td>1.60...&lt; 1.70 m</td>
<td>0.10 m</td>
</tr>
<tr>
<td>1.70...&lt; 1.80 m</td>
<td>0.12 m</td>
</tr>
<tr>
<td>≥ 1.80 m</td>
<td>0.14 m</td>
</tr>
</tbody>
</table>

Table 1 – Parameter \( h_a \) (ankle height) used as a function of body height.
Results
The results are demonstrated with 20 s continuous jumps:
• Figure 4 shows the jump height calculated with the "traditional" double integration method. The fluctuations due to the effects explained in the introduction are obvious.
• Figure 5 shows the jump height (all jumps overlaid) calculated with the described jump-to-jump method.

Validation
The described method was validated against a different method for jump height measurement with a rubber band goniometer attached to the belt buckle. The rubber band systematically measured the average jump height 6.3% higher and the squat position 31.4% lower for the single jumps. Systematic differences were expected. For the continuous jumps the results were very consistent, average 0.1% too high. A comparison of 33 jumps is shown in figure 6.

Discussion
The jump-to-jump method is a practical way to overcome the problems of "traditional" double integration over a series of continuous jumps. The method produces consistent velocity and jump height curves which connect smoothly from jump to jump (no discontinuities). It is based on easy to understand assumptions.

Nevertheless the jump-to-jump method is a compromise for the following reasons:
1. At mid flight time the velocity is not necessarily zero: A typical error occurs when the subject takes off with straight legs and lands with bent legs.
2. The jump height at takeoff (ha, ankle height) is not constant as assumed because:
   a) ha depends on the jump type
   b) ha has a jump-to-jump variability
   c) ha is has a inter- and intra-subject variability (jump type, fatigue, coordination, shoe size etc.)
To minimize the above described errors it is suggested that the method is used only for intra-subject comparison and only within the same jump type. The table for ha as a function of body height has to be verified and improved in an additional study. With this limitation it still enables the analysis of fatigue parameters and gives a good insight into the concentric/eccentric phase.

References