B10-1 ID30

ACCURACY AND PRECISION OF THE KINETIC ANALYSIS OF COUNTER MOVEMENT JUMP PERFORMANCE

Dino A. Palazzi, Benjamin K. Williams and Pitre C. Bourdon

Aspire Academy, Doha, Qatar

The purpose of this study was to quantify the accuracy and precision of measuring counter movement jump (CMJ) performance kinetically (i.e. measuring impulse using a force plate). A 14-camera 3D motion analysis system and a force plate were used simultaneously to obtain vertical trajectories of centre of mass (CM) for comparison. Fifty-eight CMJs were analyzed from eleven physically active males. Jump height differences were trivial, and small bias was obtained thereby showing good accuracy as well as small typical errors for performance. Our study indicates that force plates can be used confidently for CMJ analysis.

KEY WORDS: CMJ, force plate, biomechanics, centre of mass, impulse, plyometrics

INTRODUCTION: CMJ height is often measured in studies of human power and muscle mechanics (Street, McMillan, Board, Rasmussen & Heneghan, 2001). The resultant jump height is also a popular way of field testing physical performance. CMJs are also often used in plyometric training sessions designed to prepare athletes for explosive activities. The use of force plates with appropriate software to analyze the mechanical performance of these jumps can provide instant feedback to coaches. Nevertheless, jump height calculations have been reported to lack accuracy and precision (Street, McMillan, Board, Rasmussen & Heneghan, 2001). The aim of this study was to quantify the accuracy and precision of the CMJ performance using a force plate, by comparing the differences in the vertical displacement of the trajectory of the CM obtained simultaneously by kinetic and kinematic methods. In this study, the kinematic method was used as the reference measurement.

METHODS: Eleven healthy, physically active men, (body mass (BM) = 80.6 ± 8.1 kg, age = 31.39 ± 5.27 years, height = 183.6 ± 5.8 cm) who were familiar with CMJ techniques volunteered for the study.
Subjects performed six CMJs for maximum height. For each trial, two vertical CM trajectories were obtained (kinetic and kinematic) from which performance was calculated at five different time points (see Table 1). Comparisons were then performed between the five events.

Table 1: CMJ events in chronological order

Event	Comment	Symbol
Start	Start of the movement, manually picked	Start
Reverse	Lowest point of CMz before TO	Rev
Take-Off	First point below threshold	TO
Apex	Maximum Jump Height	Apex
Touch-Down	First point above threshold	TD

Of these points, the Apex of the airborne parabola was identified as the most important performance measure.
Kinematic variables were measured using a 14-camera Vicon 3D motion analysis system sampling at 500 Hz. (MX-13, OMG, England). Passive reflective markers were placed according to the 39-marker full-body Plug-in Gait model and the kinematic data recorded was used to calculate the CM displacement. Kinetic variables were measured using a 60 x 90 cm multi component force plate (Kistler type 9287, Switzerland) sampling at 500 Hz, which was covered with a competition quality rubber mat (Mondo, Italy). The force plate was zeroed before every trial. The synchronization between the kinematic and kinetic data was performed

by the MX system (Vicon, OMG, England). Subjects performed a self-selected warm-up before the trials, which included a number of practice CMJs. CMJs were performed from a stationary position with the subjects feet set at about shoulder width apart. All trials were performed with the subjects' hands remaining on their hips throughout the whole movement. A trial was considered successful when both feet clearly landed wholly on the surface of the force plate. The measurements started while the subject was waiting for the testers command maintaining a stationary position on the FP for at least a second before jumping; this was to ensure accurate body weight (BW) data and initial CM height, as well as providing the start of the calculations with a reliable initial vertical velocity of 0 m/s. The vertical component of the ground reaction force (GRF) from the force plate (F_Z) and CM_Z (vertical coordinate of the kinematically calculated CM displacement) were used for analysis. The F_Z data of the airborne phases was defined as the data below a threshold set to 20 N, which was replaced by zeroes. The curves were smoothed using a zero-lag, 4th order Butterworth low-pass filter (Winter, 2009), with a cut-off frequency of 24 Hz (Yu, 1996; 1999). The CM_Z trajectory was then calculated by double integration, using the following impulse equation from mechanics:

$$CM_{Z(t)}\,[m] = CM_{Z0} + \frac{1}{BM}\iint [F_Z(t) - BW]\,dt = CM_{Z0} + \int V_Z(t)\,dt$$

where

$V_{Z0} = 0$ due to the motionless state before jumping

$and\ CM_{Z0}\ was\ set\ to\ 0$ to normalize different individual's CM heights

while

$$BM\,[kg] = \frac{BW}{g} \quad \text{and} \quad BW[N] = \frac{1}{b-a}\int_a^b F_z(t)\,dt$$

The integration interval (a,b) was manually selected in each trial before the jumping movement started, aiming to get the largest portion of the stationary vertical force readings prior to the jump. The acceleration due to gravity (g) was set to 9.81 $[m/s^2]$.

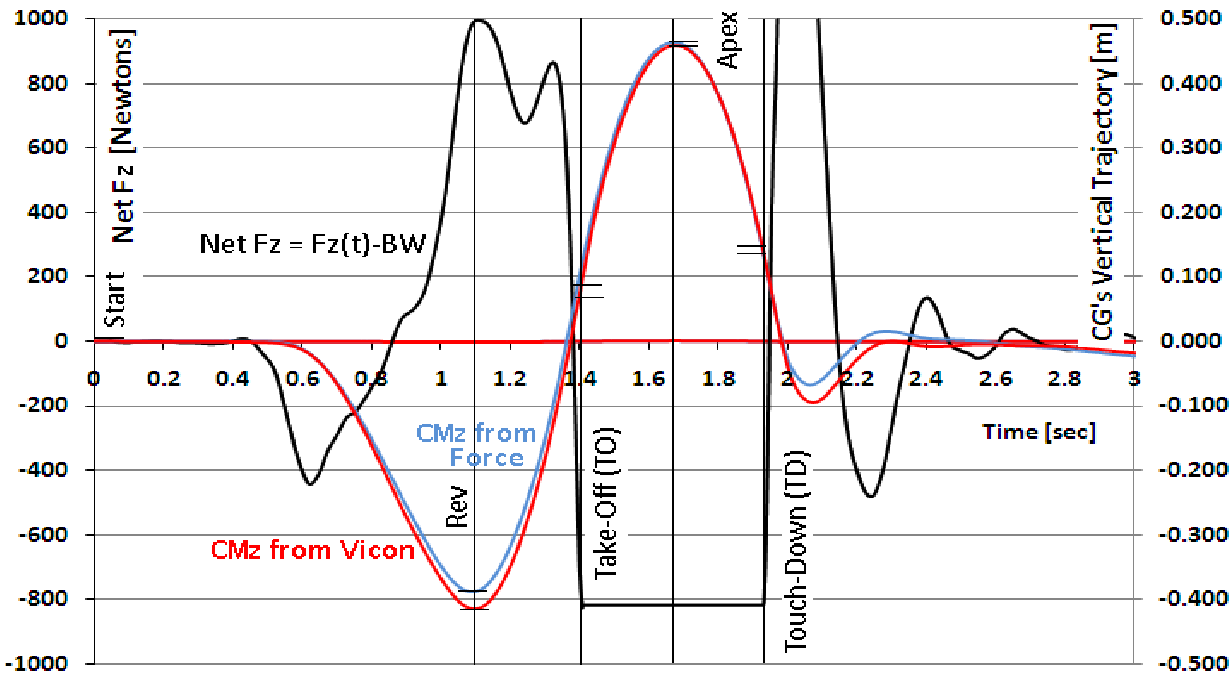

Figure 14: One subject's time histories of the Net FZ and Net CMZ during a CMJ calculated by both methods, showing the five events identified in Table 1

The start of the movement was also determined manually by selecting the last stationary instant prior to any changes in FZ readings. Integration was numerically performed using Boole's rule (2012) with the resulting curve compared against the curve simultanously

obtained by Vicon. This was then subtracted by the initial CM height (averaged in (a, b)), in the same way as used to obtain BW and to allow point-to-point comparisons (Fig. 1).
The curves were analyzed in a custom-made spreadsheet which extracted the CM_Z from both methods at each of the events described in Table 1. A specialized spreadsheet (Hopkins, 2000) was used to obtain the mean bias (absolute and standardized) of each event to quantify accuracy; and the absolute typical error, which represents the typical amount by which a repeated measurement deviates from the true value, as a measure of precision.

RESULTS: Eight jumps were discarded from the analysis due to syncing problems. Figure 2 shows the mean bias and typical error in cm with 90% confidence limits calculated at every point listed in Table 1. For the sake of clarity, units are reported in cm. Figure 3 shows the standardized mean bias and typical errors with 90% confidence limits for each event as determined by dividing the mean bias and typical errors by the standard deviation of the mean.

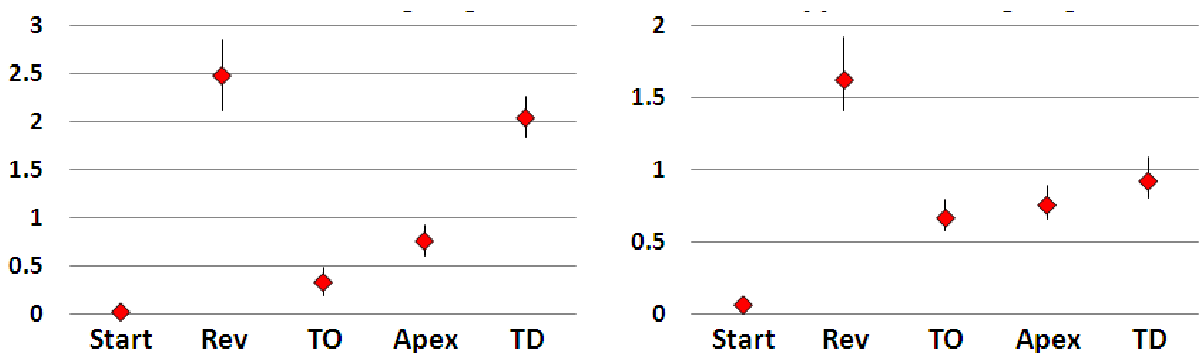

Figure 15: Mean bias (left) and typical error (right) with 90% confidence limits in cm

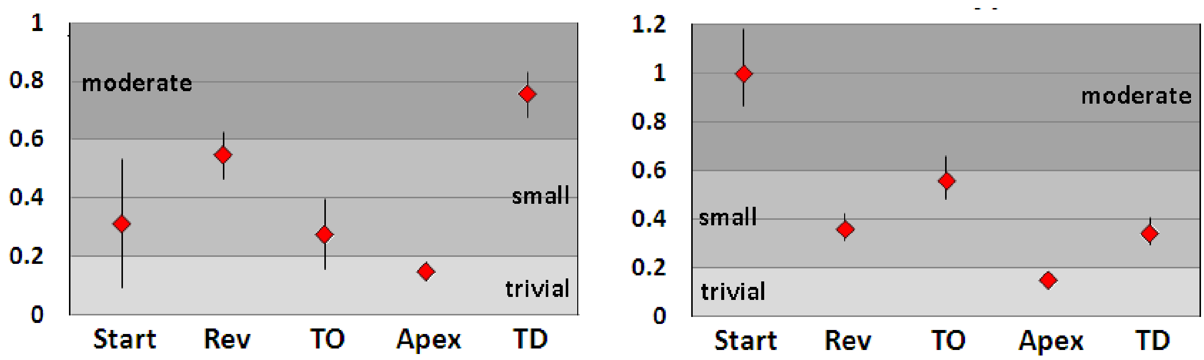

Figure 3: Standarized mean bias (left) and typical error (right) with 90% confidence limits, showing the ranges of the Cohen's Scale modified by Hopkins (Hopkins, 2000)

DISCUSSION: The absolute bias is less than 1 cm for all events except for the Rev and TD (Figure 2), which tends to increase with time from the Start. This may be due to drift or double integration errors (Street et al., 2001). The same trend was described by Palazzi and Williams (2012) when analyzing drop jumps The greater bias seen in Rev may be due to inability for Plug-In Gait model to accurately calculate the CMz during the squat position: this model works based on rigid body segments, and in this position it may lack accuracy due to the compression and stretching of moving segment masses.
According to the modified Cohen scale and using the normalized measurements of accuracy and precision (Figure 3), bias and standardized typical error are trivial at the Apex (which is the most important descriptor of performance), and it is at least small for most events. The standardized typical error around 1 obtained at the Start point, is due to the order of

magnitude obtained by the bias and its standard deviation: both are in the order of a hundredth of a cm.

CONCLUSION: The standardized bias and typical errors reported suggest that the dynamic method of analyzing the CMJs used in this study can be considered to display similar accuracy as the kinematic method. Special attention should be given while testing to ensure the subject is motionless prior to the Start. In addition, a criterion should be set to automatically determine the start of the jump and hence the start of the calculations. Executing the whole movement in as short as possible a time will also help to minimize errors by potentially reducing time associated drift in the force plate. More research is still needed to identify and correct for other sources of error.
The differences found in the Rev point against a 3D analysis system could lead to review whether the impulse method should be taken as the gold standard to measure jump performance.

REFERENCES:

Bobbert, M.F., Mackay, M., Schinkelshoek, D., Huijing, P. A. & Van Ingen Schenau, G.J. (1986) Biomechanical analysis of drop and countermovement jumps. *European Journal of Applied Physiology,* 54, 566-573. Springer-Verlag.

Boole's rule (2012). *Wolfram Math World:* http://mathworld.wolfram.com/BoolesRule.html

Hopkins, W.G. (2000). Analysis of validity by linear regression (Excel spreadsheet). *A new view of statistics*. sportsci.org: Internet Society for Sport Science, sportsci.org/resource/stats/xvalid.xls

Dowling, J.J. & Vamos, L. (1993) Identification of Kinetic and temporal factors related to vertical jump performance. *Journal of Applied Biomechanics,* 9, 95-110. Human Kinetics Publishers, Inc. U.S.A.

Kibele, A. (1998) Possibilities and limitations in the biomechanical analysis of the countermovemt jump: a methodological study. *Journal of Applied Biomechanics,* 14, 105-117. Human Kinetics Publishers, Inc. U.S.A.

Kistler Instrumente A.G. (2004). *Instruction manual of Bioware software V3.2.x type 2812A for force plates*. Switzerland

Kistler Instrumente A.G. (2004). *Instruction manual of multicomponent force plate for biomechanics, type 9287B.* Switzerland

Linthorne, N.P.(2001). Analysis of standing vertical jumps using a force platform. *American Journal of Physics,* 69 (11): 1198-1204. American Association of Physics Teachers with American Institute of Physics, U.S.A.

Moir, G.L. (2008). Three different methods of calculating vertical jump height from force platform data in men and women. *Measurement in Physical Education and Excercise Science,* 12: 207-218. Routledge, Taylor & Francis Gruop, LLC, U.S.A.

Palazzi, D.A. & Williams, B.K. (2012) Accuracy and precision of the kinetic analysis of drop jump performance. *Proceedings of the XXX International Conference on Biomechanics in Sports,* Melbourne, Australia

Street, G., McMillan, S., Board, W., Rasmussen, M. & Heneghan, J.M. (2001). Sources of error in determining countermovement jump height with the impulse method. *Journal of Applied Biomechanics*, 17, 43-54. Human Kinetics Publishers, Inc. U.S.A.

Winter, D. (2009). Smoothing and curve fitting of data. In *Biomechanics and motor control of human movement*, 4th Edition (pp 67-75). John Wiley & Sons, Inc, New York. U.S.A.

Yu, B. (1996) Choosing the cut-off frequencies. *Biomech-L Archives.* May 31st.

Yu, B., Gabriel D., Noble L. & Kai-Nan A. (1999). Estimate of the optimum cut-off frequency for the Butterworth low-pass digital filter. *Journal of Applied Biomechanics*, 15, 318-329. Human Kinetics Publishers, Inc. U.S.A.