Evaluation of four vertical jump tests: methodology, reliability, validity, and accuracy.

Luis F. Aragón-Vargas, Ph.D., FACSM

Universidad de Costa Rica

luis.aragon@ucr.ac.cr

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Abstract

Vertical jump performance tests can give considerably different results, even when different methods are used to analyze a single jump trial. To evaluate and compare four different methods commonly used to measure vertical jump performance, 52 physically active males each performed five maximal vertical jumps. Kinetic and kinematic data were used to analyze each trial using the four methods: a criterion test based on body center of mass displacement (VJPT); two methods based on vertical take-off velocity as calculated form the force platform (JUMP2 and JUMP3); and one method based on time in the air (JUMPAIR). All four methods showed excellent reliability (R>0.97). Using VJPT as the criterion, the other three methods showed excellent coefficients of validity (R>0.95) but poor accuracy: the vertical jump results were statistically different among all methods (p<0.01). From the discussion, JUMPAIR is considered a relatively simple and inexpensive method to obtain valid and reliable measures of vertical jump performance without an arm swing, provided the appropriate adjustments are made to the jump results.

Key words:

Reliability Validity Vertical jump

Vertical jumping is regarded as an important and attractive element of many sports such as basketball and volleyball. Papers are regularly published in exercise science publications, both lay and scientific, about training methods for vertical jump performance improvement. A key step in any jump training study is vertical jump measurement. Vertical jump tests are also common in Physical Education, Fitness or Sports programs, as a means to assess lower limb "power". However, vertical jump performance results may be considerably different depending on the test used, even when different methods are used to analyze the same jump (H. Hatze, personal communication, November 11, 1992).

Traditionally, the most commonly used method is Sargent's test (Sargent's study from 1924, as cited in Johnson & Nelson, 1974), also known as the jump and reach test (e.g., Blattner & Noble, 1979; Clutch, Wilton, McGown & Bryce, 1983; Davies, Greenwood & Jones, 1988; Genuario & Dolgener, 1980). This method is simple to use, requiring only a wall or board and chalk powder to make marks with your fingers. Johnson & Nelson (1974) report a reliability of 0.93 and an objectivity also of 0.93 for this test. Many scientists, however, have resorted to other methods using video systems, landing mats, or force platforms, in order to be able to measure jump height during jumps without an arm swing or under more natural settings, or as an attempt to obtain a higher accuracy or better credibility. The most precise method, the standard hereby called Vertical Jump Performance Test (VJPT), involves calculating the exact position of the body center of mass (BCOM) over time, using cinematography or video techniques. Jump height is obtained by subtracting the position of BCOM when the subject is standing from the peak BCOM position during flight (Aragón-Vargas, 1997; Bobbert, Huijing & van Ingen Schenau, 1987; Pandy & Zajac, 1991). Alternatives include applying particle dynamics equations to calculate take-off velocity of the body and jump height from force plate data (Dowling & Vamos, 1993), or using basic particle kinematics equations to calculate jump height from flight time, as measured by different timing devices (Asmussen & Bonde-Petersen, 1974; Bosco & Komi, 1979; Bosco, Luhtanen, & Komi, 1983; Komi & Bosco, 1978). Since the necessary equipment is often costly and difficult to use, and given that some of the calculations involve assumptions that are not always acceptable, it is important to know the differences among jump height values obtained using each method.

Therefore, the purpose of this paper is to study the reliability of four different methods commonly used to measure vertical jump performance, to calculate the actual test result differences among methods, and to evaluate the ability of each test to predict "true" vertical jump performance, according to the VJPT standard. These are useful quantitative tools for the exercise scientist who wants to compare studies that have used different methodologies, or for the coach, trainer, or physical educator who needs to find out how much more accuracy is obtained by using more costly and sophisticated methods.

Methods

Data collection

Fifty-two physically active male college students each performed five maximal vertical jumps, starting from the position of their choice, with their hands on their hips (arms akimbo). All participants gave their informed consent in accordance with the policy statement of the University of Michigan. They completed three practice jumps before data collection, and were required to wait for one minute after each trial. Participants performed the jumps barefooted, wearing only a swimsuit or pair of shorts. Five reflective markers were placed on the right side of the body, on the glenohumeral joint (shoulder), the greater trochanter (hip), the lateral condyle of the femur (knee), the lateral malleolus (ankle), and the fifth metatarsal (toe). All five trials of all the subjects were used for calculating reliability, but only the best jump (as assessed using equation 1 below) was used for the other comparisons.

Ground reaction forces and moments of force were collected with a Bertec force plate (model 4060A), and were sampled at 300 Hz. A video-based (60 Hz), real-time, 3-D motion analysis system (Motion Analysis Corp.) was used to collect and process kinematic data. Kinematic data were filtered with a low-pass, fourth-order Butterworth filter with an effective cutoff frequency of 8 Hz.

Basic anthropometric data were obtained using standard sliding calipers, tape measures, and the force platform. Body mass and body height were measured according to Lohman, Roche, & Martorell (1988). Thigh length, midthigh circumference, shank length, calf circumference, malleolus width, malleolus height, and foot length were obtained according to Vaughan, Davis, & O'Connor (1992). These data were used for the calculation of segmental centers of mass (see below).

Data analysis

The biomechanical model used and all analytic procedures have been described in detail elsewhere (Aragón-Vargas, 1994). Briefly, the human body was modeled as a planar, rigid-body system comprised of four segments linked by frictionless, hinge joints (figure 1). Kinetic and kinematic data were used to obtain the four different measures of jump height.

(Insert figure 1 about here)

The most accurate method for calculating vertical jump height (VJPT) requires a precise calculation of the body center of mass position throughout the movement from video data. Calculation of the body center of mass position was performed using the method of summation of torques, which in turn requires the calculation of the center of mass position of each segment over time. Segmental centers of mass were calculated according to the procedure of Vaughan et al. (1992), with the exception of HAT, which was calculated according to Aragón-Vargas (1994), based on Clauser, McConville, & Young (1969), and Hinrichs (1990).

VJPT was obtained directly from the body center of mass (BCOM) position data, by subtracting the vertical position of BCOM while standing from the peak vertical position of BCOM during flight:

$$VJPT = zBCOM_{peak} - zBCOM_{\text{standing}} \qquad (1)$$

VJPT is used in this study as the criterion or standard for comparison. Two alternate methods used in biomechanics for the calculation of jump height require calculating vertical take-off velocity (TOVEL). Take-off velocity was obtained from the instantaneous vertical velocity vs. time curve, which in turn was calculated according to:

$$\dot{z}BCOM = \frac{\int_{t_0}^{t_{to}} F_{zp}dt}{m} \quad (2)$$

Where F_{zp} is propulsive force, obtained from subtracting body weight from the vertical ground reaction force; t_0 is the beginning of data collection, and t_{to} is the instant of take-off.

Theoretically, jump height depends on both vertical take-off velocity and body center of mass position at take-off (Bobbert & van Ingen Schenau, 1988), according to the equation:

$$\text{JUMP2} = \left[(TOVEL)^2 * (2g)^{-1}\right] + zBCOM_{\text{to}} - zBCOM_{\text{standing}} \quad (3)$$

Equation (3) uses information from both the force platform and the video equipment. Ignoring BCOM elevation before take-off, vertical jump height may be obtained from vertical take-off velocity alone, requiring only force plate data:

$$\text{JUMP3} = (TOVEL)^2 * (2g)^{-1} \quad (4)$$

Lastly, time in the air may be calculated as the difference between the instant of take-off and the instant of landing. For the sake of this paper, take-off and landing times were obtained from ground reaction force data, when Fz < 3.0 N and Fz > 3.0 N, respectively. Jump height is then obtained using the equation:

$$\text{JUMPAIR} = g * \left(\frac{tair}{2}\right)^2 * 2^{-1} \quad (5)$$

Statistical analysis

The first step in assessing the usefulness of a test is to determine its reliability, that is, the ability of the test to give consistent results.

According to Kerlinger (1988), a correlation coefficient for reliability may be obtained by partitioning the variance obtained from *m* measurements applied to *n* subjects, into three components (variance among subjects, variance within subjects, and variance due to error), and obtaining the ratio:

$$r_{tt} = \frac{MSS - MSE}{MSS} \qquad (6)$$

where MSS is the Subjects Sum of Squares divided by (n-1) and MSE is the Residual (Error) Sum of Squares divided by [(m-1)(n-1)]. (See Kerlinger, 1988; Table 26.2; and equation 26.5).

It is possible then to obtain the standard error of measurement (*SEM*) using the group standard deviation (*SD*) and the reliability of the test (R_{tt}) (Baumgartner, 1989):

$$SEM = SD\sqrt{1 - R_{tt}} \qquad (7)$$

which is equal to MSE if calculated according to Kerlinger above.

Validity coefficients, regression coefficients, and prediction errors were calculated using simple linear regression techniques, with VJPT as the dependent variable and each of the other methods as the independent variable, according to the general linear model:

$$y = \beta_0 + \beta x + \mathrm{E}_j \qquad (8)$$

This evaluation of validity is in agreement with common procedures to assess criterion-related evidence of validity (Kerlinger, 1988; Wood, 1989). Usually, when such procedures are used, the criterion test and the "new" test have different units of measurement and have been administered on separate occasions. In this case, however, all results are in meters, and it is possible to evaluate not only the correlation of the measurements (concurrent validity) and the regression coefficients (predictive validity), but also whether all tests provide the same results, a reasonable expectation given that they are all measures of the same performance of the same subjects. This agreement between tests is called *accuracy* in this paper.

To evaluate the accuracy, average jump heights obtained using each of the four methods were compared using Student's t-test for paired samples, making Bonferroni's adjustment for multiple comparisons, at a significance level of $p < 0.01$. The 95% family confidence intervals for the difference between VJPT and each of the other three methods were also calculated, using Bonferroni's adjustment for family confidence coefficients.

Results

Table 1 shows basic descriptive statistics for the subjects. Average body weight (74.3 kg) was slightly above the U.S. population average for a body height of 1.79 m (71.8 kg) (Metropolitan Life Insurance Company, 1959). Best trial jump heights (VJP) ranged from 0.372 m to 0.663 m (mean = 0.520 m), and had a coefficient of variation of 13.4%. There were 16 subjects, or 31% of the sample, outside ±1 *SD* of the average VJP.

(Insert table 1 about here)

Reliability data are presented in Table 2. The standard or criterion method (VJPT) shows a correlation coefficient of 0.9936, for a standard error of measurement of 12.7 mm.

(Insert tables 2 and 3 about here)

Table 3 shows descriptive statistics for the jump height results according to each of the four methods used. The highest values were obtained for the standard method, VJPT. The other three methods (JUMP2, JUMP3 and JUMPAIR) resulted in jump height averages that were 15 mm, 159 mm, and 118 mm lower than VJPT, respectively. These three differences were statistically significant ($p < 0.01$); furthermore, all the differences between any two methods were statistically significant. Figure 2 presents the 95% confidence intervals for each difference between VJPT and one of the other three methods. This figure graphically shows the underestimation of jump height normally obtained from using each of those methods.

(Insert figure 2 about here)

Table 4 shows the simple regression analysis results.. Coefficients of correlation (*R*) represent the validity of each method, using VJPT as the criterion or previously validated test. All methods were able to explain more than 90% of the vertical jump height variability (see column for R^2). The estimated prediction error of all three methods is close to 20 mm. Lastly, it must be pointed out that the β coefficients for models 2 and 3 are very close to 1.0, and therefore the β_0 constant is similar to the jump height average differences indicated above.

(Insert table 4 about here)

Discussion

Reliability

Before making any meaningful comparisons among jump test methods, it is necessary to have a good standard or criterion. In this particular case, VJPT had been chosen as the standard based on theoretical arguments. This test shows an excellent reliability and a small *SEM* (see

Table 2). VJPT was compared with three other methods for testing vertical jump height, but not with the one most commonly used, Sargent's jump-and-reach test. Sargent's test involves an arm swing during the propulsion phase, and this additional variable precludes any meaningful comparisons from being made[1].

Under normal testing circumstances, variability in the results comes from two major sources: "true" variability, showing differences in performance both between and within subjects, and the error introduced by the measuring method. The four variables presented in tables 2 and 3 are measures of the same vertical jump performance. Therefore, "true" variability (in this case only from differences between subjects, as only the best trial was used for the analysis) must be the same for all methods, and it is then possible to use VJPT as the standard to compare both the absolute (*SD*) and relative (Coefficient of Variance, *CV*) variability (Table 3) introduced by the other methods. Relative variability is higher for all three methods compared to VJPT.

Additional absolute variability is only introduced by JUMP2 (ΔSD = 7 cm), while JUMP3 and JUMPAIR show smaller values than VJPT. An instrument or method may show less variability because it is less sensitive and does not discriminate so clearly among different performances, or because it really has a smaller error of measurement. Using this information together with the reliability coefficients and *SEM* values (Table 2), it is clear that VJPT and JUMPAIR are the most stable, consistent measures of the true vertical jump, while JUMP2 is the least consistent.

Validity and accuracy

While validity coefficients and prediction errors obtained are excellent, it is clear that all four vertical jump test methods give different results, i.e., the three alternative methods are not accurate. JUMP2 is theoretically correct, but it requires a perfect synchronization between the force plate and video signals. A synchronization error will cause the test administrator to use a take-off position (obtained from video data) which does not correspond to the same instant of the take-off velocity (obtained from the force platform). An error of only 16.7 ms (one frame at a sampling rate of 60 Hz) would result in under- or over-estimating the relative position of take-off (and therefore jump height) by 44 mm (Aragón Vargas, 1994).

The calculation of JUMP3 involves only force-plate data, and therefore has no signal synchronization problems. On the other hand, it does not take into account the relative take-off height of the subject. This should not pose any problem, since previous studies have shown that the major contribution to vertical jump height differences among subjects comes from take-off velocity (TOVEL), while the relative take-off height is very similar from one subject to another (Aragón-Vargas, 1997). The 95% confidence interval for relative take-off height in the present study was 14.4 ± 0.73 cm which, according to equations (1), (3), and (4), should agree with the difference between JUMP3 and VJPT. The 95% confidence interval for the difference was 15.9 ± 0.7 cm, showing a discrepancy between VJPT and "corrected" JUMP3 of 15 mm that we are unable to account for.

Lastly, the calculation of jump height using the method JUMPAIR has been criticized in the literature because some of the assumptions involved are not correct (Dowling & Vamos, 1993; H. Hatze, personal communication, November 11, 1992). One clear limitation is that equation (5) assumes that the time the center of mass of the body is falling is equal to one-half of the time in the air. In other words, the time that BCOM travels upwards should be equal to the time it travels downwards, which is only true if the subject takes off and lands with his body in the same position. In the present study, the time down was significantly longer than time up (average difference = 0.016 s, $p < 0.0001$), suggesting the subjects landed with their bodies partially crouched[2]. This results in an overestimation of the distance from take-off to peak, as may be seen comparing JUMPAIR with JUMP3, a method that does not consider relative take-off height either (see Table 3). The final result, however, is lower than VJPT.

Practical recommendations.

Results from Tables 2 to 4, and figure 2, provide the necessary information for choosing from the three alternative methods for predicting true jump height, as measured by VJPT. All three methods have excellent reliability, an essential first step. Validity coefficients are also excellent for all three tests. JUMP2 gives the smallest average difference in jump height, but regression analysis (cf. Table 4) shows that the estimation error is larger for this method. Furthermore, since its slope (β coefficient) is significantly different from 1.0, the estimation error will vary with the level of the results, underestimating true jump height for some subjects, and overestimating it for others. JUMP3 and JUMPAIR show larger average differences with the criterion test, but the differences are more stable, independent of the level of the results, and the prediction error is smaller.

Most vertical jump performance studies seek to compare jump height before and after a particular treatment (a training program). For this type of comparison, it is not really important if different methods give different results, provided the same method is used for the pre- and post-tests, and provided the method used shows good reliability and validity coefficients, as is the case for all the three methods evaluated in this study[3]. If the investigator or coach is more interested in being able to compare results obtained with different methods, it is clear that comparisons will be meaningless unless the differences inherent to each method are considered. The parameters presented in this study will allow making the necessary adjustments to achieve a reasonable degree of accuracy.

Considering all the criteria above, and taking into account the equipment necessary for testing according to each method, the most simple and less expensive method is the one that calculates jump height from time in the air, using a landing mat and a timer. Time in the air may also be obtained from force plate data, as in the present study. According to the present data, very little reliability and validity is compromised, and the results may be used to calculate true jump height with confidence.

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Notes

[1]A separate study using the Sargent jump test with 56 subjects performing five jumps each, showed a reliability correlation coefficient of 0.9859, which is still very good. (Unpublished data).

[2]Apparently, this situation is worsened when using an arm swing. A separate study (mentioned in footnote #1) has shown the reliability of JUMPAIR to decrease under these circumstances, to 0.9558, which may be partially accounted for by the variation in the position of the arms at takeoff and landing (Unpublished data).

[3] This practical application assumes that the reliability obtained in this study when trials are separated by only a few minutes can be extrapolated to a study when trials are separated by several weeks or months.

Table 1.

Subject characteristics (*N* = 52).

Variable (units)	**Mean**	***SD***	***CV* (%)**
Age (years)	20.20	2.10	10.4
Weight (kg)	74.27	8.65	11.6
Height (m)	1.79	0.06	03.4
VJPT (m)	0.506	0.07	14.2

Note. VJPT statistics include all five trials. *CV*: coefficient of variance. *CV* = 100 *SD* / Mean.

Table 2.

Reliability calculations for four jump tests. (*N*=49, i=5).

	VJPT	**JUMP2**	**JUMP3**	**JUMPAIR**
R_{tt}	0.9936	0.9704	0.9859	0.9936
$(R_{tt})^2$	0.9873	0.9417	0.9719	0.9872
SEM (mm)	12.7	27.8	18.0	12.1

Note. R_{tt} is the reliability correlation coefficient; $(R_{tt})^2$ is the reliability coefficient of determination.

Table 3.

Descriptive statistics for each jump height method ($N = 52$).

	VJPT	JUMP2	JUMP3	JUMPAIR
Average (m)	.520[a]	.505[a]	.361[a]	.402[a]
Minimum (m)	.372	.365	.240	.263
Maximum (m)	.663	.667	.503	.550
SD (m)	.070	.077	.066	.067
CV (%)	13.4	15.3	18.3	16.6

Note. The best trial from each subject was used in the calculations. From "Comparación de cuatro métodos para la medición del salto vertical", by L.F. Aragón-Vargas, 1996, Revista Educación, 20(1), p. 37. Copyright 1996 by the Editorial de la Universidad de Costa Rica. Reprinted with permission.

a) All mean differences are statistically significant, $p < 0.01$.

Table 4.

Simple regression analysis ($N = 52$).

Model	***R***	R^2	**MSE**	**Error**
1) VJPT = 0.087 + 0.857[a] JUMP2	.952	.906	.464E-03	.0215
2) VJPT = 0.154 + 1.014[b] JUMP3	.961	.924	.376E-03	.0194
3) VJPT = 0.117 + 1.002[b] JUMPAIR	.962	.926	.369E-03	.0192

Note. Only the best trial was used in the analysis. All statistical models are significant ($p < 0.0001$). From "Comparación de cuatro métodos para la medición del salto vertical", by L.F. Aragón-Vargas, 1996, Revista Educación, 20(1), p. 38.

a) This coefficient is significantly different from 1.0, ($p < 0.01$).

b) These coefficients are NOT significantly different from 1.0, ($p > 0.01$).

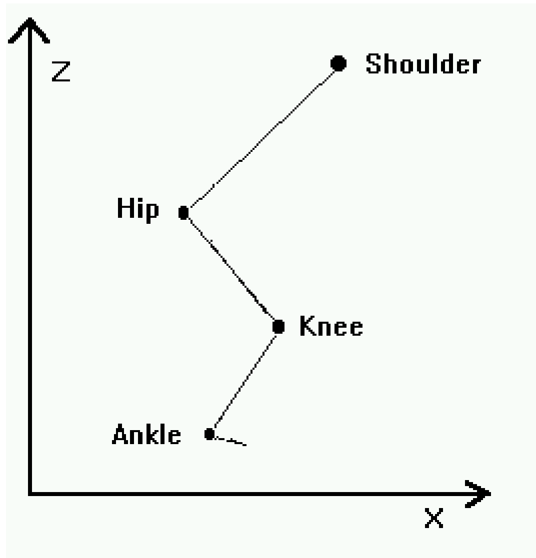

Figure 1. Biomechanical model. Segments (i = 1 to 4) are defined by the markers: segment 1, head, arms and trunk (HAT), from shoulder to hip; segment 2, thighs (THI), from hip to knee; segment 3, shanks (SHA), from knee to ankle, and segment 4, feet (FET), from ankle to toe.

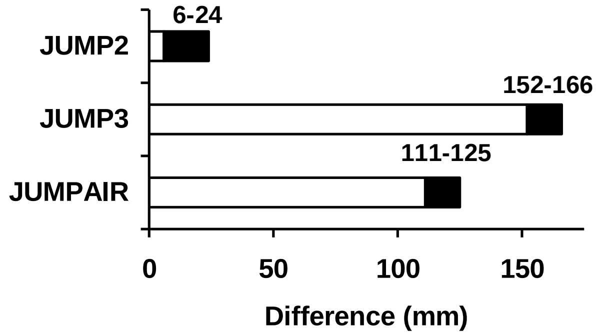

Figure 2: 95% confidence intervals for the difference between the standard method and each one of the other methods (best trial only, $N = 52$). From "Comparación de cuatro métodos para la medición del salto vertical", by L.F. Aragón-Vargas, 1996, Revista Educación, 20(1), p. 37. Copyright 1996 by the Editorial de la Universidad de Costa Rica. Reprinted with permission.