COMPARISON OF METHODS FOR ASSESSING VERTICAL JUMP HEIGHT PERFORMANCE

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Relationships, explained variance, measurement error, and limits of agreement were examined among field and laboratory countermovement vertical jump tests, including Vertec, 3D video, and force platform data. Data were simultaneously collected on a single countermovement jump trial for 13 female varsity volleyball players. Vertical jump height computed using maximum centre of mass (COM) velocity from force platform data demonstrated the greatest precision, as well as the strongest correlation (r=0.90), greatest explained variance (R^2=0.81), and lowest standard error of the estimate (0.02m) in vertical 3D video COM displacement. Jump height calculation using maximum COM velocity may highlight relevant performance measures, providing jump height estimations more quickly and easily, and with greater precision via force platform analysis.

KEY WORDS: centre of mass, takeoff, maximum, velocity

INTRODUCTION: Vertical jump performance is widely used to assess muscular strength and power in the lower body, with the goal of predicting athletic potential in sports such as football, basketball, volleyball and track-and-field (Markovic and Jaric, 2007). This test is used because it is simple to perform and closely replicates various sport movements (Vanezis and Lees, 2009). While a variety of jump height measurement methods exist, the selected method may have implications on the obtained jump height due to the associated measurement error (Atkinson and Nevill, 1998, Hatze, 1998; Street et al., 2001).

The most commonly used field measure of jump height is the jump-and-reach test, using a wall or jump system, such as a Vertec apparatus (Channell and Barfield, 2008). Laboratory measures include, but are not limited to, kinematic analysis of centre of mass (COM) displacement, and kinetic analysis through integration of ground reaction forces. One of the most valid methods used to assess vertical jump performance is to determine vertical jump height using 3D kinematic analysis via digitized video footage (Aragón-Vargas, 2000). In some situations, however, kinematic data may contain sources of measurement error including digitization, field of view, and data resolution that pose a threat to the validity of vertical jump height test score interpretations. These types of errors are not observed in measurements of ground reaction forces (Hatze, 1998; Street et al., 2001; Wilson, Smith, Gibson, Choe, Gaba, and Voels, 1999).

The fundamental objective of the vertical jump test is to maximize jump height (h), producing the greatest possible vertical velocity of the COM at takeoff, as seen in Equation 1 (Dowling and Vamos, 1993; Harman, Rosenstein, Frykman, and Rosenstein, 1990; Moir, 2008). Calculation of COM velocity at takeoff via force platform analysis relies on mechanically correct assumptions from uniform acceleration equations, but does not consider body position at takeoff (Aragón-Vargas, 2000; Dowling and Vamos, 1993; Moir, 2008).

$$h = v_{\text{toff}}^2/2\text{g} \qquad (1)$$

(g is the acceleration due to gravity and v_{toff} is vertical COM velocity). To provide more accurate results, Equation 2 has been used to correct for body position at takeoff (Aragón-Vargas, 2000; Moir, 2008).

$$h = v_{\text{toff}}^2/2\text{g} + h_{\text{toff}} - h_{\text{stand}} \qquad (2)$$

(h_{toff} and h_{stand} are vertical COM height at takeoff and standing, respectively). Combining video and force platform analyses can be used to improve jump height measures, but requires separate processing of kinetic and kinematic data. Corrected takeoff velocity, using COM takeoff height, may also be calculated through integration of COM velocities from force platform analysis alone, avoiding the reliance on video footage and minimizing sources of error and time requirements associated with video techniques (Moir, 2008).

While previous research has examined the use of force platform data for computing vertical jump height from COM takeoff velocity, this computational method falls short of providing a true estimation of vertical jump height when compared to video techniques (Aragón-Vargas, 2000; Dowling and Vamos, 1993; Moir, 2008). As a result, exploring the use of maximum vertical velocity, rather than takeoff velocity, may provide improved estimates of vertical jump height and offer insight into jumping proficiency.

The purpose of this study was to evaluate relationships, explained variance, measurement error, and limits of agreement among jump height measurement methods relative to vertical COM displacement from 3D video analysis. Jump height measurement methods included: 1) vertical COM displacement from 3D video (VID), 2) jump-and-reach test using a Vertec apparatus (VERT), 3) takeoff COM velocity in Equation 1 (TOV), 4) maximum COM velocity in Equation 1 (VMAX), 5) corrected takeoff velocity from video data in Equation 2 (TOV+s_{VID}), and 6) corrected takeoff velocity from force platform (FP) data in Equation 2 (TOV+s_{FP}).

METHODS: Participants included 13 female varsity university volleyball players (age 19.3 ± 1.3 years; height 1.71m ± 0.06m; mass 69.9kg ± 7.9kg) who were familiar with the countermovement jump, a naturally occurring movement in volleyball training and competition settings. Participant informed consent was obtained prior to participation as approved by the Lakehead University Research Ethics Board.

Prior to data collection, participants completed a standard warm up incorporating dynamic stretches. Three-dimensional video acquisition was completed using a 2-camera (Basler A602f-2) Vicon system sampling at 100Hz. A 19-point spatial model was used in computing the COM using 3D video via placement of reflective markers on bony landmarks.

A Vertec apparatus was aligned over the force platform and used to obtain jump-and-reach height. Ground reaction forces were measured via a 46cm x 46cm AMTI force platform sampling at 1000Hz. Force platform data, 3D video data, and jump reach height using the Vertec were acquired simultaneously for each trial. Each participant completed a single maximal effort jump trial, with additional trials performed if necessary to ensure that the entire movement was captured by both the force platform and video system.

Data processing was carried out separately for force platform (AMTI Netforce) and video data (Vicon Motus Version 8.0). Kinematic data smoothing and filtering employed a cubic (3rd order) spline and fourth order low-pass Butterworth filter, respectively.

Descriptive and inferential statistics were computed using SPSS 17. Pearson product-moment correlations were calculated to identify the nature of the relationships between each vertical jump height measurement method and vertical COM displacement from 3D video.

Linear regression analyses provided the predictive ability of each measurement method relative to 3D video jump height, including explained variance and associated measurement error. Limits of agreement, representing 95% confidence intervals for observed differences between each method and 3D video jump height were also assessed, providing insight into measurement accuracy and precision (Bland and Altman, 2007; Sim and Reid, 1999). Acknowledging the relatively low sample size, diagnostic tests were conducted to ensure conformity to the assumption of normality.

RESULTS: Descriptive statistics demonstrated that mean jump height computed from 3D video (VID; 0.47±0.05m) exceeded the mean height computed from takeoff COM velocity (TOV; 0.30±0.05m) and maximum center of mass velocity (VMAX; 0.35±0.05m), but was similar to mean heights computed from Vertec measurement (VERT; 0.48±0.06), and using corrected takeoff velocity methods (TOV+s_{VID} and TOV+s_{FP}; 0.47±0.06m and 0.47±0.07m, respectively). In each case, jump heights from each measurement method were normally distributed (Kolmogorov-Smirnov test of normality, $p>0.05$).

Correlations between VID and each respective jump height measurement method are summarized in Table 1. Despite observed discrepancies between jump height values measured from 3D video versus those computed from takeoff and maximum COM velocities, the sole use of COM velocity showed the strongest correlations with 3D video jump height (Table 1). Exploring linear regression diagnostics, residual plots demonstrated normality in each case, with constant variance along the regression line. Linear regression analyses indicated that VMAX explained the greatest proportion of the variance in VID, with the lowest standard error of the estimate (Table 1). Limits of agreement highlighted large mean differences between TOV and VMAX relative to VID, while VMAX showed the narrowest limit of agreement (*CI*; Table 1).

Table 1
Linear regression & limits of agreement summaries

Dependent Variable	Predictor	*r*	R^2	*SEE* (m)	Mean diff. (m)	*LOA* (lower, upper)
VID	VERT	0.48	0.23	0.05	0.01	(-0.10, 0.12)
VID	TOV	0.87	0.76	0.03	-0.16	(-0.22, -0.11)
VID	VMAX	0.90	0.81	0.02	-0.12	(-0.17, -0.08)
VID	TOV+s_{VID}	0.75	0.56	0.04	0.01	(-0.07, 0.08)
VID	TOV+s_{FP}	0.75	0.56	0.04	0.00	(-0.09, 0.09)

Note.
SEE is standard error of the estimate; Mean diff. is Predictor-Dependent Variable difference; *LOA* is limit of agreement (95% confidence interval for mean difference);
VID is vertical COM displacement from 3D video; VERT is jump height from Vertec jump-and-reach; TOV is jump height from takeoff COM velocity; VMAX is jump height from maximum COM velocity; TOV+s_{VID} is jump height from takeoff velocity + video COM takeoff height; TOV+s_{FP} is jump height from takeoff velocity + force platform COM takeoff height

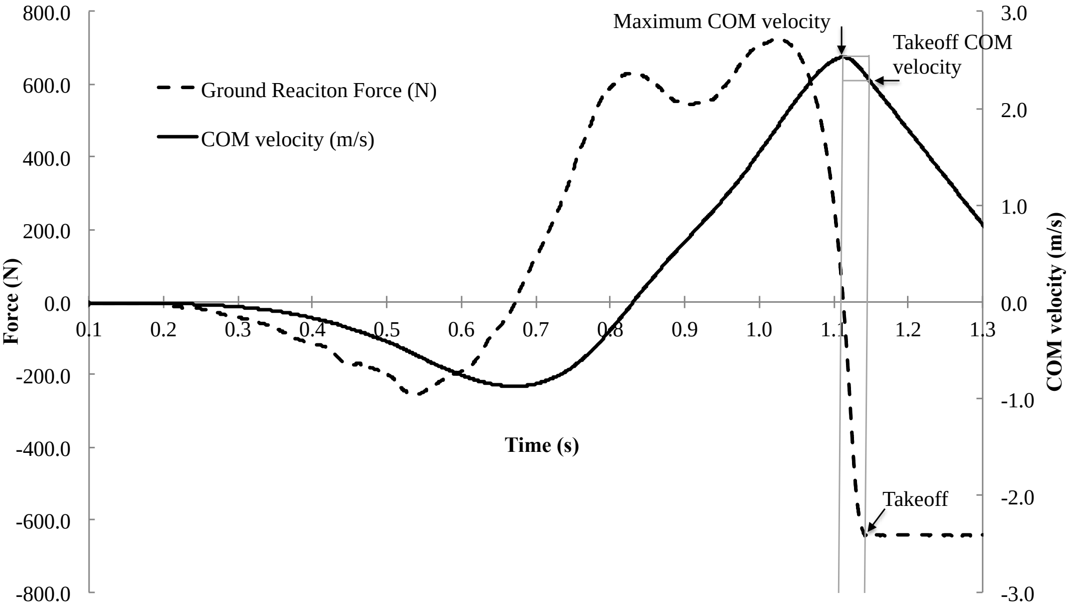

Figure 1: Vertical ground reaction force and vertical COM velocity vs. time curves during a countermovement jump, showing the difference between maximum and takeoff COM velocities

DISCUSSION: Although previous research has used takeoff COM velocity to compute vertical jump height (Aragón-Vargas, 2000; Moir, 2008), computation of vertical jump height using maximum COM velocity has received limited attention as a means of more effectively predicting vertical jump performance from force platform data. Figure 1 illustrates that takeoff COM velocity occurs after maximum COM velocity, and is of lesser magnitude; providing additional potential insight into underestimations of jump height from takeoff COM velocity. The aim of maximizing vertical jump height is to achieve the greatest possible vertical velocity at takeoff. The present research, however, identifies preliminary evidence for maximum vertical COM velocity, prior to takeoff, as a key factor in optimizing performance.
Maximum COM velocity (VMAX) underestimated 3D video jump height (-0.12m), but demonstrated the narrowest limit of agreement (-0.17, -0.08), the strongest correlation with

vertical 3D video COM displacement (VID; *r*=0.90), the greatest explained variance (R^2=0.81), and the lowest standard error of the estimate (0.02m; Table 1). Maximum COM velocity therefore showed lesser overall accuracy, but greater precision expressed relative to 3D video vertical COM displacement (Sim and Reid, 1999). These results may be of importance to researchers and practitioners in helping to improve performance estimates from force platform analysis. Temporal and magnitude differences between takeoff and maximum COM velocities may be of additional interest in vertical jump performance.

The present research supports previous findings, showing that takeoff COM height from video footage can be used to correct takeoff COM velocity from force platform data (Aragón-Vargas, 2000). Comparatively, this approach is more resource-intensive and time-consuming than force platform measures alone, or direct measurement of jump height from video data or Vertec. As well, the exclusive use of force platform data (TOV and VMAX) in the present study produced greater precision, as well as a stronger relationship (stronger correlation and greater explained variance) with 3D video COM displacement (VID) than the combined use of force platform and video data (TOV+s_{VID}). Weaker overall relationships in the current study may be attributed to the use of a smaller sample size, while in each case TOV demonstrated a stronger relationship with VID than TOV+s_{VID} (Aragón-Vargas, 2000). Similarly, the relationship between VID and TOV+s_{FP} was lesser than the relationship between VID and VMAX, with lesser precision.

CONCLUSION: In summary, of the examined jump height measurement methods, despite the observed mean offset, maximum COM velocity provided the strongest correlation, the greatest explained variance and precision, and contained the least measurement error relative to 3D video jump height. This preliminary research provides potential insight into a predictor of vertical jump height that may improve upon existing estimations. These findings may be of interest to researchers and practitioners examining vertical jump performance. Future investigations into vertical COM displacement may be explored with less measurement error and greater precision compared to Vertec measurements, also offering a less time consuming alternative to video acquisition techniques. Future research examining changes in COM velocity from maximum to takeoff via ground reaction force data may provide avenues for researchers to further explore vertical jump proficiency.

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