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Validating Methods of the Standing Broad Jump Test

Billy Lozowski[1], Anthony W. Fava[1], Jaimie A. Roper[2] and Gretchen D. Oliver[1*]

[1]Sports Medicine and Movement Laboratory, School of Kinesiology, Auburn University, Auburn, AL, USA

[2]Department of Locomotor and Movement Control Laboratory, Auburn University, Auburn, USA

[*]Corresponding author: Gretchen D. Oliver,Sports Medicine and Movement Laboratory, School of Kinesiology, Auburn University, Auburn, AL, USA.

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Abstract

The Standing Broad Jump (SBJ) is a field test widely-used to approximate athletes' lower-body power. Horizontal jump distance is measured from toes placed on a starting line to the heel of rearmost foot upon landing. However, this does not consider foot-length. Consequently, a longer foot length may be more of a disadvantage than a shorter foot. This study aimed to investigate whether the current field-based method is valid for assessing SBJ by comparing to lab-based motion capture. Nine participants completed 3 SBJs. Jump distance was measured from Toe-to-Heel (TH), Toe-to-Toe (TT), and Heel-to-Heel (HH) using field-based measurements and were compared to a motion-capture system. A repeated-measures analysis of variance test revealed that jumps from TH were significantly different from motion capture using ankle joint centre displacement ($p<0.001$), and both HH and TT methods ($p<0.001$). There was no significant difference between the HH and TT ($p>0.05$), or between the TT and HH compared to motion-capture ($p>0.05$). A correlation analysis revealed that foot length was significantly related to the magnitude of measurement error ($R=0.962$, $p<0.001$). These findings suggest that SBJ might be best administered by measuring jump distance from the same part of the foot at the start and end of the test.

Keywords: Field testing; Foot length; Jump performance; Lower-body power; Measurement error

Introduction

Athlete testing is used to identify potential in sport performance or determine the effectiveness of a training program [1,2]. The Standing Broad Jump (SBJ) is a widely used field test that is an inexpensive, time-efficient method of assessing of lower-body strength and power without the need for specialized instrumentation [3,4]. Further, Modified Box Long Jump (MBLJ) tests were shown to be a better predictor of track and field performance than any other anaerobic power test [5].

The SBJ measures the horizontal distance travelled by an individual between a take-off point (toes behind a starting line) and a landing point (heel of the foot that has travelled the least distance), and has been shown to elicit the lowest within-subject variation compared to six other jumps tests [6-10]. However, since toe placement is the same for all participants at the beginning of the SBJ, the ankle joint position will vary behind the start line dependent on the length of the foot. Individuals with a longer foot will begin with their ankle joint further away from the starting line, and those with a shorter foot will start with their ankle joint closer to the starting line. Consequently, individuals with a longer foot may be at more of a disadvantage and have shorter jump distances recorded by the TH method than were achieved, as their foot's length was not considered.

An alternative to field testing is laboratory-based testing. Specialized motion-capture equipment is used to calculate the displacement of markers or sensors fixed to anatomical landmarks, such as the ankles and feet. When assessing lower-body kinematics, motion-capture systems use the same landmarks for start and end points. This is in contrast to the current manual Toe-to-Heel (TH) method for the SBJ uses different landmarks on the foot [11]. Thus, a discrepancy is evident, and as the TH method does not currently account for the length of the participant's foot, it is unclear whether foot length could be a contributing factor to the outcome of the test.

Determining valid SBJ methodology is important for evaluating athletes who partake in sports that utilize an explosive horizontal movement. Improving the validity of jump tests, especially the SBJ, using technology such as motion-capture would further make the SBJ a valid field test for indicating an athlete's lower body power. To date, little attention has been given to whether the TH method for measuring SBJ performance adequately reflects jump values obtained with motion-capture equipment. Specifically, the distance travelled by the ankle joint from start to finish. Further, establishing a more valid method for measuring the SBJ which considers participants' foot length could improve the ability of the SBJ to approximate lower body power; especially in populations (e.g., youth) where changes in foot length may vary from one test to another [12].

This paper aims to compare SBJ distances recorded by field-based methods to measurements obtained using a Vicon motion-capture system (Vicon Motion Systems Ltd, Oxford, UK). We hypothesized that jump distance values recorded for lab-based and manual methodologies would differ due to one using the same landmarks on the foot and ankle (Vicon) and the other using different landmarks (TH method). Therefore, two additional manually administered methods (Toe-to-Toe (TT) and Heel-to-Heel (HH)) are included to establish if there is a more valid way to measure SBJ performance than the TH method.

Methodology

Participants

Nine participants (26 ± 3 years; 1.73 ± 0.10 m; 72.1 ± 12.9 kg) performed SBJ protocols which were approved by the University's Internal Review Board (21-379EP2108). All were free of lower-limb injuries in the past six months and gave written informed consent prior to data collection. For this study it was not a necessary requirement that individuals were jump trained.

Procedures

The trajectories of 20 retro reflective markers were captured using a 17-camera Vicon motion capture system recording at 100 Hz (Vicon Motion Systems Ltd, Oxford, UK). Leg length (Anterior Superior Iliac Spine (ASIS) to medial malleolus), knee width (medial to lateral femoral epicondyle), and ankle width (medial to lateral malleolus) were measured for each leg using a standard body measuring tape and a manual calliper (Lafayette Instrument Company, IN, USA). Markers were applied bilaterally to 20 locations on the lower-body, 12 at bony landmarks (ASIS, PSIS, lateral femoral condyle, lateral malleolus, Achilles insertion, and the head of the 3rd metatarsal) and 8 as segmental reference points (midpoint of the lateral thigh, anterior surface of the thigh, midpoint of the lateral shank, and anterior surface of the shank) (Figure 1). A calibration trial was then completed, which ensured all markers were visible by cameras and allowed the Plug-in Gait lower-body functional AI model (Vicon) to be applied once trials had been recorded. A short outline of testing procedures was given to participants before they completed three maximal SBJs. A closed wheel measuring tape (HOGARSWE, Yuyao, China) was extended for 4 m across the centre of the lab. Participants began with their heels aligned to the starting line marked as 0 cm on the measuring tape, and a measurement at their heel and toes was recorded. Participants were then instructed to jump out as far as possible (arm swing permitted). Using a metal T-square aligned to the tape measure, a measurement was taken of the heel and big toe of the rearmost foot.

Figure 1: Marker placements for the lower body.

Note: Marker placements for the plugin gait lower-body functional AI model (Vicon).

Data analysis

Labelled marker trajectories were exported for analysis. A frame before the initiation of the jump (i.e. the knees moving into flexion), and a frame after landing (i.e. the participant returning to a neutral stance) were used to define the beginning and end of the jump. The lab's coordinate system was defined so that the Y-axis represented anterior-posterior direction (with positive in the direction of the jump), the Z-axis represented the transverse plane (with the positive pointing up), and the X-axis as the cross-product of the Y- and Z-axes (negative pointing to the left). Lateral ankle marker displacement values in the y-direction (direction of the horizontal jump) from these two frames were then used to calculate overall jump distance in millimetres (mm). Displacement values of the ankle joint centre obtained from Vicon were used as references for manual measurements. Values for the manual measurement techniques were compared against Vicon values by calculating the error (difference between the manual measurement and the motion capture measurement). A repeated-measures analysis of variance (ANOVA) test, with significance set to $p<0.05$, was performed to establish if any differences existed between the three manual measurement styles (TH, TT, and HH) and the lab-based motion-capture technique. Lastly, a Pearson's R correlation analysis was performed to determine if participants' foot length was related to measures of the SBJ test.

Results

Mean jump distance and error values for each participant are presented in Table 1. Data were normally distributed; however, sphericity was violated according to Mauchly's Test ($\chi^2=23.033$, $p<0.001$) so a Greenhouse-Geisser correction was applied. Tests of within-subjects effects indicated that there was a significant main effect of measurement technique on recorded jump distance ($F_{3,24}=1034.073$, $p<0.001$) with a large effect size ($\eta^2=0.992$). Pairwise comparisons showed that jump distance in the TH group was significantly shorter than the HH and TT techniques ($p<0.001$) and the lab-based (Vicon) technique ($p<0.001$).

There was no statistically significant difference between the HH and the TT methods ($p=0.295$), or between the HH and the TT

	Vicon	Heel-to-Heel		Toe-to-Toe		Toe-to-Heel	
	Jump Distance	**Jump Distance**	**% error**	**Jump Distance**	**% error**	**Jump Distance**	**% error**
P01	2459.6	2447.7	0.49	2447.7	0.49	2158.7	12.24
P02	1756.4	1756.7	-0.02	1758.7	-0.13	1526.7	13.08
P03	2165.3	2171.7	-0.29	2173.3	-0.37	1907.3	11.91
P04	2007.9	2011.7	-0.19	2012.3	-0.22	1767.3	11.98
P05	2601.6	2589.7	0.46	2596.7	0.19	2300.3	11.58
P06	2054.4	2068	-0.66	2076.3	-1.07	1808	11.99
P07	1962.1	1967.7	-0.29	1966.7	-0.23	1723.7	12.15
P08	1669.6	1675.7	-0.36	1669.3	0.02	1397.3	16.31
P09	1623.9	1630.3	-0.4	1632.7	-0.54	1377.3	15.18
mean	2033.4	2035.4	-0.14	2037.1	-0.21	1774.1a,b,c	12.94
SD	336.3	330.4	0.39	332.4	0.44	317.6	1.67

Note: asignificant difference (p<0.5) compared to Vicon, bsignificant difference to Heel-to-Heel (p<0.5), csignificant difference to Toe-to-Toe (p<0.5).

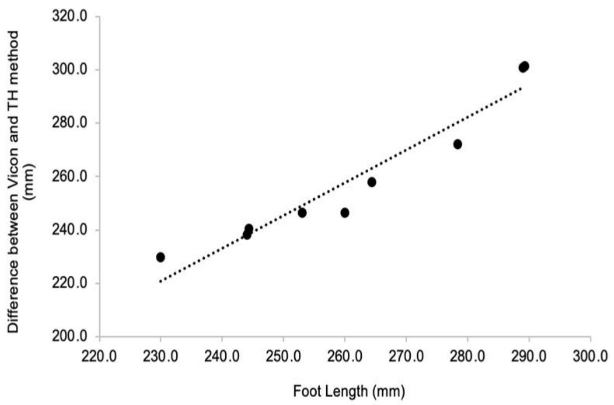
Table 1: Individualised jump distances for the 4 measurement techniques and their respective error compared to Vicon.

methods with Vicon (p=0.497 and p=0.297, respectively). A Pearson's R correlation analysis revealed a statistically significant strong positive correlation between foot length and the magnitude of difference between jump distance in the TH group compared to Vicon (R=0.962, p<0.001). Moderate positive correlations were also observed for the difference in HH (R=0.554, p=0.130) and TT (R=4.96, p=0.175) measurements to Vicon, however, these were not statistically significant (Table 1).

Discussion

This study aimed to investigate whether the current field-based method for assessing the SBJ was representative of values obtained by specialist motion-capture equipment (Vicon). Our findings showed a significant discrepancy between the TH method of measurement and measurement via a motion-capture system, suggesting modifications may be needed. The difference (error) between the two methods was ~13%, which can be attributed to differences in a participant's foot length (R=0.962) (Figure 2). As a result, individuals with a longer foot are currently at a greater disadvantage than those with a shorter foot when attempting to accurately measure their jump distances (and potentially approximate their lower-body power).

Figure 2: The relationship between foot length and the difference to lab-based measurements in the TH condition.



Note: The figure illustrates that as foot length increases, the difference between recorded measeurments for Vicon and the TH method increases.

This notion was confirmed by adding two proposed alternative methodologies for in-field testing. TT and HH methods measured jump distance from the same part of the participant's foot and showed no significant difference to the measures of jump distance recorded with Vicon. Error values of less than 0.5% were observed, suggesting that measuring from the same part of the participant's foot is a key to ensure an accurate measure of SBJ performance. Small differences were observed between HH and TT measures which might be attributed to some degree of external rotation of the foot as individuals landed.

As we wanted to ensure initial measurements were as precise as possible, participants' feet were aligned with their toes pointing straight forward. Thus, upon starting their jumps, participants' feet may have been in a position that was not strictly representative of a normal stance. Consequently, upon landing, some degree of external rotation of the foot could have occurred as they assumed a more normal, slightly externally rotated (toe-out) position [13]. Nonetheless, HH and TT methods were not statistically significant from each other, or from the Vicon measurements. Therefore, either method appears to be a viable option when testing SBJ performance without access to a specialist motion-capture system.

Conclusion

As demonstrated in this study, the current method for measuring SBJ in the field (via the TH method) does not appear to be adequate to ensure accurate measures of jump performance as it does not account for the individual's foot length. When the individual's foot length is not considered, significant discrepancies between lab-based and field-based values are observed (~13%), which is magnified as foot length increases. When the jump is measured manually from the same part of the foot (TT or HH) however, the measurement error between lab-based and manual methods is negligible (0.5%). It might therefore be concluded that accounting for foot length is a crucial component of SBJ performance. Accounting for the athlete's foot length would provide more precise jump values that could be used to better approximate lower-body power, and would allow lab-based methods to be replicated more easily in the field.

Conflict of Interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

Study conception and design: B.L., A.F. Data collection: B.L., A.F. Data analysis and interpretation: B.L., A.F., J.R., G.O. Drafting manuscript: B.L., A.F., J.R., G.O. All authors reviewed the results and approved the final version of the manuscript.

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