

Impact of accelerometer placement on assessment of vertical jump performance parameters

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Abstract

The vertical jump has been widely used in a sport setting for the assessment of lower-body power. Recently, accelerometry has gained popularity as an inexpensive testing modality for assessment of vertical jump performance characteristics. However, accelerometer anatomical placement could affect the accuracy of the data collected. The purpose of this study was to examine the impact of accelerometer placement on assessment of vertical jump performance parameters. Seventeen healthy recreationally active subjects performed three non-consecutive maximal vertical jumps with no arm swing. Subjects were instructed to keep the hands on the hips and reach 90-degrees internal knee flexion during the eccentric phase of the jumping motion. Two identical accelerometers sampling at 100 Hz were positioned on the abdomen (AB; 5 cm inferior to umbilicus) and on the hip (HP; 5 cm above greater trochanter). Both devices were secured with elastic bands and collected data simultaneously. Ground reaction force curves were computed from the raw accelerometry data from which the following variables were derived: peak concentric force (PCF), peak landing force (PLF), vertical jump height (VJH) based on flight time, and impulse (IMP) excluding subject's body weight. No significant differences were found between AB and HP accelerometer placement for PCF, PLF, and IMP. However, despite a small effect size, HP accelerometer placement resulted in a significantly lower VJH by 1.2 cm. Additionally, strong agreement and consistency of the measurements were observed across all dependent variables examined in the present investigation, suggesting that both AB and HP accelerometer placements may seem appropriate for analysis of vertical jump performance.

Key Words: force; testing; sport; power; sensors

Introduction

The vertical jump has been widely used in a sport setting for the assessment of lower-body power. As an inexpensive testing methodology, it can be implemented in both field and laboratory settings. Previous research has found a strong positive relationship between vertical jump ability and success in various aspects of performance in team sports such as basketball, soccer, American football, and volleyball (Fry & Kreamer, 1999; Kellis et al., 1999; Sheppard et al., 2008; Stolen et al., 2005; Ziv & Lidor, 2010). So, the ability to obtain a better insight into biomechanical parameters of vertical jump performance may provide strength and conditioning practitioners with essential information necessary for optimal training design and long-term athlete development.

Force plate technology has been considered a gold standard for in-depth analysis of kinetic and kinematic parameters of vertical jump performance. However, due to its cost, portability, and time-consuming data analysis it is often limited to laboratory usage. Recently, accelerometry has been used as a more feasible technology for the analysis of force-time characteristics. The validity and reliability of this innovative technology for vertical jump performance assessment is of critical importance, but current literature reveals mixed findings (Brooks et al., 2018; Cabarkapa et al., 2021; Hojka et al., 2018; Pino-Ortega et al., 2018). Brooks et al. (2018) found a strong agreement ($r=0.95$) and minimal mean difference (0.55 cm) in countermovement vertical jump height measurements when comparing the VERT (VERT, Mayfonk Athletic Company, USA) accelerometer system to force plate as a criterion measure. Similar findings emerged from an investigation conducted by Pino-Ortega et al. (2018) showing an almost perfect relationship ($r=0.97$) between the WIMU (RealTrack Systems, Spain) accelerometer device and force plate data, with only a 0.31 ms mean difference in flight time. On the other hand, despite exhibiting strong internal consistency ($\alpha=0.96$), Cabarkapa et al. (2021) found that an experimental accelerometer device tended to overestimate vertical jump height by 3.1 cm. A systematic bias of greater magnitude was also observed for the Myotest accelerometer (Myotest SA, Switzerland) which tended to overestimate vertical jump height by 8.0 cm (Hojka et al., 2018). In addition, the system significantly underestimated peak force, velocity, and power measurements (Hojka et al., 2018). The discrepancy in the previously mentioned findings may be attributed in part to sampling frequency and

computation algorithms used by the manufacturers to derive vertical jump kinetic and kinematic performance parameters.

Another crucial factor that needs to be considered when using accelerometry for assessment of vertical jump force-time characteristics is its anatomical placement. Some of the most commonly chosen accelerometer placements for external workload monitoring in team sports include scapulae, abdomen (near the center of mass), and sternum (Gomez-Carmona et al., 2020). It is also important to note that the accelerometer placement is contingent on the type of movement that is intended to be analyzed/observed (Nedegaard et al., 2017). While being correlated to the whole-body loading, body-worn accelerometers mainly capture the acceleration from the body segment where they are attached (Nedegaard et al., 2017). For example, to obtain the most relevant data in tennis it might be more appropriate to place the accelerometer device on the wrist, in swimming on the head, and in running on the tibia (Gomez-Carmona et al., 2020). In addition to accelerometer placement, the intensity of activity could further influence the accuracy of the data collected. Yngve et al. (2003) found no differences between hip and lower back accelerometer placement during low-intensity activities, while an increase in exercise intensity (e.g., walking, running) led to a significant discrepancy in the overall activity count.

Based on the previously mentioned literature, we can assume that the anatomical placement of the accelerometer could impact performance parameters during explosive lower-body motions such as vertical jump. Thus, the purpose of the present study was to examine if the change in the anatomical accelerometer placement (abdomen vs. hip) yields identical performance parameters during the maximal countermovement vertical jumping motion.

Material & Methods

Participants

Ten males ($\bar{x} \pm SD$; height = 180.9 ± 5.9 cm, body mass = 71.9 ± 5.9 kg, age = 19.9 ± 1.2 years) and seven females (height = 170.4 ± 4.1 cm, body mass = 70.9 ± 11.1 kg, age = 20.1 ± 1.4 years) who were healthy and recreationally active college students volunteered to participate in this study. An *a priori* power analysis was completed based on previous research (Howard et al., 2014; Welk et al., 2000; Yngve et al., 2003) to determine adequate sample size. The following parameters were used: t-test (same participants), $d = 1.84$, $\alpha = 0.05$, $1 - \beta = 0.8$. This revealed a minimum sample size of six for adequate power. All testing protocols were approved by the University's Institutional Review Board and prior to testing all subjects reviewed and signed the informed consent form.

Procedures

Upon arrival to the laboratory for a one-time testing session, participants performed a standardized warm-up procedure consisting of a set of dynamic body motions (e.g., A-skip, lunge and twist, high knee pulls, spine rotations). Each subject was familiarized with the jumping testing procedure, which involved one set of three non-consecutive maximal effort countermovement jumps with no arm swing. Subjects started in the upright standing position with hands placed on the hips and body weight evenly distributed on both feet. They were instructed to reach 90-degree of internal knee flexion during the eccentric phase of the jumping motion, followed by a rapid jump, and landing in an athletic position. An experienced research assistant was present to assure that the jumping technique remained consistent across all participants. To eliminate a possible effect of fatigue, each jump was separated by a 30-60 second rest period.

Two accelerometers (Strive Tech, Beta Version 1.0, Bothell, WA, USA) with sampling rates of 100 Hz were placed on the abdomen (AB; 5 cm inferior to umbilicus), and on the hip (HP; 5 cm above greater trochanter). Devices were secured with elastic bands and collected data simultaneously. Ground reaction force curves were computed from raw vertical acceleration data by adding acceleration due to the gravity ($9.81 \text{ m} \cdot \text{s}^{-2}$) and multiplying the resultant value with the subject's body mass. The following dependent variables were derived: peak concentric force (PCF), peak landing force (PLF), impulse (IMP), and vertical jump height (VJH). PCF and PLF were recorded at the greatest ground reaction force observed during the concentric and landing phases of the jumping motion, respectively. IMP was calculated as an average change in force during the concentric phase of jumping motion excluding the body mass. VJH was calculated based on the flight time using the following equation (Cabarkapa et al., 2021; Whitmer et al., 2015): $VJH = (t^2 \cdot g) / 8$; $g = 9.81 \text{ m} \cdot \text{s}^{-2}$, t = time in air (seconds) - determined as a change in time between the first and last timepoint when the ground reaction force curve crosses zero value.

Statistical Analysis

Descriptive statistics ($\bar{x} \pm SD$) was calculated for each of the dependent variables. Paired samples t-tests were used to determine statistically significant differences in the dependent variables between the two anatomical locations for accelerometer placement (AB vs. HP). Intraclass correlation coefficients (ICC) were calculated to determine the internal consistency of measurements. Due to the sample size ($n < 20$), Hedge's g effect sizes were calculated to measure the magnitude of the difference and Bland-Altman plots graphically displayed the agreement between the AB and HP accelerometer placements. For each dependent variable, HP value was divided by the AB value and multiplied by 100 to derive percent difference. Then, the average SD of the difference was multiplied by 1.96 to calculate upper and lower 95% confidence intervals represented in

Bland-Altman plots. Statistical significance was set priori to $p \leq 0.05$. Microsoft Excel 2016 (Microsoft Corporation, Redmond, WA, USA) and SPSS Version 26.0 statistical software (SPSS Inc., Armonk, NY, USA) were used for the statistical analyses.

Results

No significant differences were found between the AB and HP accelerometer placement for PCF, PLF, and IMP ($p > 0.05$). However, VJH derived from the AB was significantly greater when compared to the HP accelerometer placement. Furthermore, all dependent variables demonstrated moderately-strong to strong levels of internal consistency of the measurements. Please refer to Table 1 for detailed results. Bland-Altman plots showing agreement between the accelerometer locations for each of the dependent variables are presented in Figures 1-4. Regression lines for the data are also shown on the Bland-Altman plots.

Table 1. Descriptive statistics ($\bar{x} \pm SD$) for each dependent variable and the accelerometer anatomical location. AB – abdomen accelerometer placement; HP – hip accelerometer placement; PCF – peak concentric force; PLF – peak landing force; VJH – vertical jump height; IMP – impulse.

Variable	AB	HP	<i>p</i> -value	Effect Size	ICC
PCF [N]	1753.4 $\pm$ 361.5	1776.8 $\pm$ 453.7	0.645	0.06	0.768
PLF [N]	2773.7 $\pm$ 529.2	2692.3 $\pm$ 525.1	0.075	0.15	0.901
VJH [cm]	34.5 $\pm$ 9.3	33.3 $\pm$ 9.8	0.001	0.13	0.986
IMP [N·s]	238.9 $\pm$ 57.5	230.1 $\pm$ 67.4	0.079	0.14	0.917

Figure 1. Agreement for peak concentric force between abdominal (AB) and hip (HP) accelerometer placement. Bolded line represents the line of agreement. Dashed lines represent 95% confidence interval. Dotted line represents regression line.

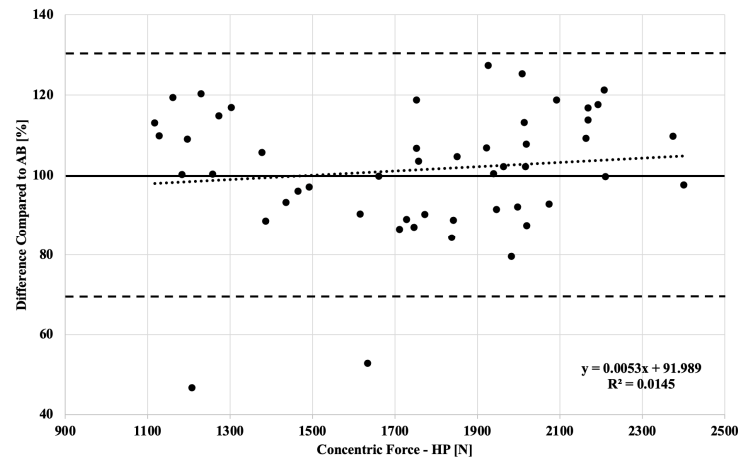


Figure 2. Agreement for peak landing force between abdominal (AB) and hip (HP) accelerometer placement. Bolded line represents the line of agreement. Dashed lines represent 95% confidence interval. Dotted line represents regression line.

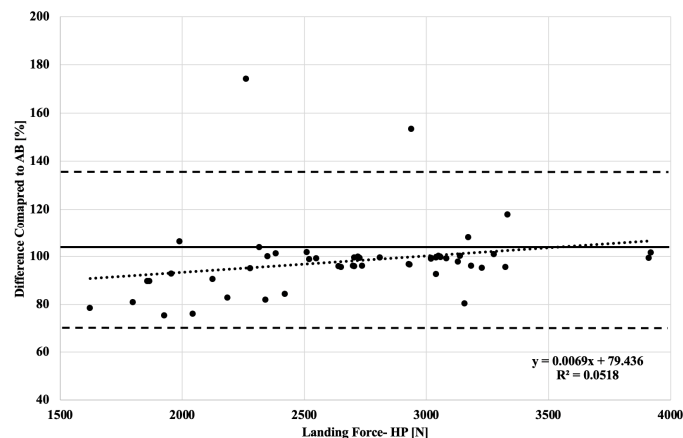


Figure 3. Agreement for vertical jump height between abdomen (AB) and hip (HP) accelerometer placement. Bolded line represents the line of agreement. Dashed lines represent 95% confidence interval. Dotted line represents regression line.

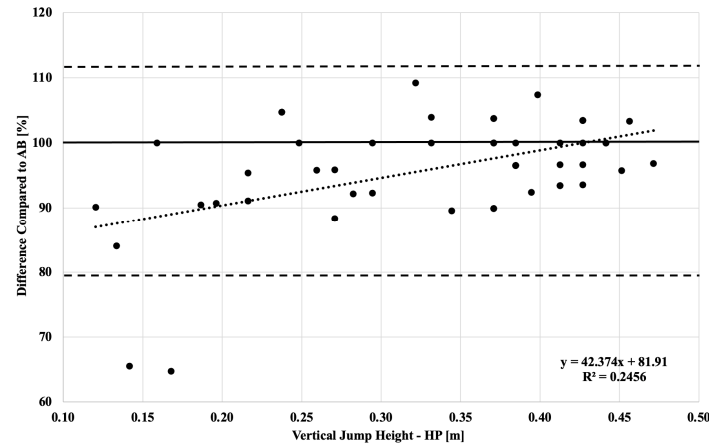
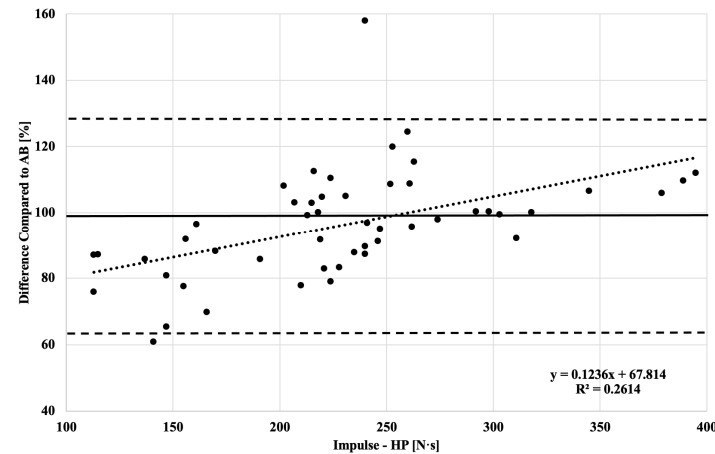


Figure 4. Agreement for impulse between abdomen (AB) and hip (HP) accelerometer placement. Bolded line represents the line of agreement. Dashed lines represent 95% confidence interval. Dotted line represents regression line.



Discussion

The findings of the present study indicate that changing the accelerometer anatomical placement had no impact on PCF, PLF, and IMP. However, significant differences were observed for VJH derived from the flight time. On average, HP accelerometer placement estimated VJH as 1.2 cm lower than for the AB location. Despite this difference, strong consistency of the measurements (as indicated by effect sizes and ICC values) were observed across all dependent variables examined in the present investigation.

To the best of the author's knowledge, this is the first study to examine the impact of change in anatomical accelerometer placement on force-time characteristics during a countermovement vertical jump with no arm swing. Previous research has been primarily focused on addressing validity and reliability of force-time characteristics between body-worn and barbell-attached accelerometers with a laboratory force plate as a criterion measure (Grioux et al., 2015; Howard et al., 2014). Despite excellent agreement for minimum eccentric force, peak concentric force derived from an accelerometer placed near the body center of mass showed moderate levels of agreement and a significant bias with a large overestimation tendency of 35.8% (Howard et al., 2014). In addition, the bias for peak landing force during a drop jump was even greater with difference of 53.6% (Howard et al., 2014). On the other hand, an accelerometer directly fixed to the barbell showed strong reliability scores for mean concentric force and was a valid tool for squat jump performance assessments across various external loads (Grioux et al., 2015). While PCF, PLF, and IMP in the present study were not impacted by the anatomical accelerometer placement, future research needs to examine how these measurements compare to those from a force plate as a criterion measure.

The findings of the present study indicate that the HP accelerometer placement resulted in lower VJH when compared to the AB location as recommended by the manufacturer. In a similar manner, Lutzner et al. (2014) found that anatomical location for accelerometry placement had a significant impact on step count

measurement accuracy during slow exercise at velocities below $1.0 \text{ m}\cdot\text{s}^{-1}$, and that alternative location (i.e., anterolateral aspect of middle shank) yielded more accurate results. Since ground reaction forces from a force plate as a criterion measure were not measured in the present study, it is not feasible to determine which anatomical location (AB vs. HP) provided more accurate VJH measurements. Moreover, it is important to note that the jumping technique in the present study did not involve upper-body motion. In a recently conducted study, it was found that use of an arm-swing during a maximal countermovement vertical jump motion produced 13.6% increase in VJH (Mosier et al., 2019). Thus, future research needs to take this into account and examine if the observed discrepancy in VJH measurements between AB and HP accelerometer placement remains consistent with use of full arm swing during jump motion. Also, Whitmer et al. (2015) have found that jumping mat tended to underestimate vertical jump heights derived from flight times in high performers when compared to a force plate system as a criterion measure. Although the Bland-Altman plots for VJH and IMP indicated strong agreement between the two accelerometer locations, the regression lines for the data (Figures 3 and 4) suggest that the discrepancy in these measurements may occur for high performers in a similar manner. Whether this is the cause for the slope of the regression lines, or whether this is simply due to several outlier values that should be examined in future research.

Another factor that needs to be considered when using accelerometry technology to accurately assess force-time characteristics of various explosive lower-body movements is body composition, more specifically the amount of adipose tissue and its location. It has been suggested by Gindre et al. (2016) that undesirable movements of the externally worn accelerometers are unavoidable and may be enlarged when placed over clothing and around soft tissues, especially in the abdomen region. Ultimately, this can impact the validity and reliability of the accelerometer-based systems and lead to a decrease in the accuracy of the measurements for individuals with higher waist circumference (Gindre et al., 2016). While the body composition was not examined, and presents a limitation of the present investigation, we can hypothesize that the discrepancy in VJH measurement could be potentially attributed to the excessive movement of the accelerometer placed in the AB region such as suggested by Gindre et al. (2016). In addition, Shepherd et al. (1999) found that the absolute error of a pedometer was positively correlated with body mass index (BMI), with greater error for participants with $\text{BMI} > 30 \text{ kg/m}^2$. Conversely, Swartz et al. (2003) found no significant effect of BMI on the accuracy of the pedometer measurements across multiple walking speeds. The inability to observe the impact of BMI in the previously mentioned studies may be mainly attributed to the movement intensity (e.g., walking) which is notably lower than VJ, which is an explosive lower body motion.

Conclusions

The findings of present investigation demonstrated that changes in the accelerometer anatomical placement (AB vs. HP) did not have an impact on PCF, PLF, and IMP. However, VJH derived from the AB was significantly greater when compared to the HP accelerometer placement. On average, HP accelerometer placement estimated VJH as 1.2 cm lower than for the AB location. Despite this difference, strong consistency of the measurements was observed across all dependent variables examined in the present investigation, suggesting that both AB and HP accelerometer placements seem to be appropriate for analysis of vertical jump performance.

Conflicts of Interests

The authors declare no conflict of interest.

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