

# Agreement and Between-Method Error of a Wearable Inertial Sensor and a Force Platform in Countermovement Jump Assessment

Jacek Wąsik<sup>1</sup>, Michalina Błażkiewicz<sup>2\*</sup>

<sup>1</sup> Institute of Physical Culture Sciences, Jan Długosz University in Częstochowa, Częstochowa, Poland

<sup>2</sup> Faculty of Rehabilitation, The Józef Piłsudski University of Physical Education in Warsaw, Warsaw, Poland

\*Corresponding author: Michalina Błażkiewicz, Faculty of Rehabilitation, The Józef Piłsudski University of Physical Education in Warsaw, Warsaw, Poland, e-mail address: [michalina.blazkiewicz@awf.edu.pl](mailto:michalina.blazkiewicz@awf.edu.pl)

**Submitted: 17<sup>th</sup> June 2026**

**Accepted: 25<sup>th</sup> September 2026**

---

## Abstract

### Purpose

The countermovement jump (CMJ) is widely used to assess lower-limb neuromuscular performance. Force platforms provide detailed biomechanical measurements, whereas wearable inertial sensors offer a portable alternative for field-based assessment. This study evaluated agreement between a BTS G-Sensor and a force-platform during CMJ assessment.

### Methods

Forty-six adult males residing in a semi-open correctional facility performed one maximal CMJ simultaneously measured using a BTS G-Sensor and a force-platform. Because records were incomplete or ambiguously labelled, complete paired observations varied by variable: CMJ height ( $n = 35$ ), peak power ( $n = 25$ ), peak force ( $n = 32$ ), and peak velocity ( $n = 23$ ). Agreement was assessed using ICC(2,1), while Bland-Altman analysis evaluated bias, 95% limits of agreement, and proportional bias.

### Results

The BTS G-Sensor produced significantly lower CMJ height values than the force-platform ( $25.58 \pm 5.73$  vs.  $31.20 \pm 6.79$  cm; bias =  $-5.61$  cm;  $p < 0.001$ ; ICC = 0.662) and substantially higher reported peak power values ( $3395.60 \pm 829.15$  vs.  $1449.56 \pm 435.04$  W; bias = 1946.04 W;  $p < 0.001$ ; ICC = 0.120). No significant differences were observed for peak force (bias =  $-31.72$  N;  $p = 0.729$ ; ICC = 0.533) or peak velocity (bias =  $-0.07$  m•s<sup>-1</sup>;  $p = 0.343$ ; ICC = 0.521). Significant proportional bias was observed for CMJ height and peak power.

### Conclusions

The BTS G-Sensor and force-platform should not be considered interchangeable for absolute CMJ assessment. Between-method differences varied substantially across variables, particularly for peak power. The BTS G-Sensor may nevertheless be useful for consistent, device-specific field-based CMJ monitoring.

Keywords: force platform, countermovement jump, inertial sensor, measurement error, agreement, Bland-Altman analysis

---

## 1. Introduction

Vertical jump performance, particularly the countermovement jump (CMJ) test, is a widely used tool for assessing lower-limb power generation capacity in biomechanical research and physical fitness diagnostics [2, 7]. Due to its simple testing procedure and high repeatability, the CMJ is applied both in laboratory and field conditions, enabling the analysis of mechanical parameters related to the vertical displacement of the body's center of mass and supporting comparisons between different measurement systems used in CMJ assessment [17, 24].

Among the most precise methods for measuring vertical jump parameters are force platforms, which allow for the direct measurement of ground reaction forces and the derivation of variables such as jump height, velocity, power, and impulse. The high accuracy of these systems makes them frequently regarded as reference methods in comparative studies [15, 20, 22], particularly in investigations focused on quantifying absolute differences, agreement, and measurement error between measurement techniques. At the same time, their use is associated with practical limitations, including high equipment costs, limited mobility, and the need to conduct measurements under controlled laboratory conditions.

An alternative to traditional measurement systems is provided by wearable inertial sensors, whose development in recent years has enabled the registration of movement parameters in field conditions with minimal equipment requirements. These sensors, based on acceleration and angular velocity measurements, are increasingly used to estimate vertical jump parameters [4, 5, 19, 21, 23, 27]. However, their growing availability highlights the need to assess differences relative to reference methods, the degree of agreement, and the magnitude of measurement error, especially when such devices are intended to replace or complement force platforms in applied settings.

Previous studies comparing inertial sensors with force platforms have often focused on assessing correlations or relative agreement between measurements, most commonly with respect to jump height [4, 5, 21, 23]. Such an approach does not allow for a full evaluation of method interchangeability, as high correlation coefficients or high intraclass correlation coefficients (ICC) do not necessarily indicate absolute agreement or low measurement error [1]. Metrological literature emphasizes the need to complement agreement analyses with methods that assess systematic bias and limits of agreement, such as Bland-Altman analysis [3].

A significant research gap remains due to the limited number of studies that comprehensively combine analyses of inter-method differences, ICC-based agreement, and absolute agreement [7, 23], together with practical measurement error expressed by the SEM and MDC. Moreover, few studies simultaneously compare CMJ height, power, force, and velocity, which limits a

---

comprehensive evaluation of inertial sensors as measurement tools across multiple biomechanical outcome variables and levels of neuromuscular performance [10, 13, 18, 26]. Therefore, conducting a comparative study aimed at assessing differences, relative agreement, absolute agreement, and between-method error of CMJ parameters obtained using a wearable inertial sensor and a force platform is justified and directly addresses current methodological recommendations for evaluating measurement interchangeability [1, 3]. The aim of the study was to evaluate absolute differences, ICC-based agreement, absolute agreement, and between-method error of CMJ parameters measured using a wearable inertial sensor and a force platform. The analysis included CMJ height, peak power, peak force, and peak velocity in order to determine the level of agreement between methods and their potential interchangeability using complementary statistical approaches, including paired comparisons, ICC, and Bland-Altman analysis.

## 2. Materials and Methods

### 2.1. Participants

The study included 46 adult male individuals residing in a single semi-open correctional facility who were physically capable of performing a countermovement jump (CMJ) and had no diagnosed neurological disorders. The mean age of participants was  $36.1 \pm 11.0$  years (range: 19.6–61.7), the mean body mass was  $85.2 \pm 14.1$  kg (62.1–130.4), the mean height was  $179.3 \pm 6.2$  cm (165–193), and the mean body mass index (BMI) was  $26.5 \pm 4.1$  kg·m<sup>-2</sup> (21.1–39.3). Participants were informed that participation in the study was voluntary, that they could refuse to participate or withdraw at any time without any negative consequences, and that participation in the study would not affect their status in the correctional facility, privileges, treatment, or decisions regarding release. All participants were fully informed about the purpose and procedures of the study and provided written informed consent prior to participation. The study was conducted in accordance with the Declaration of Helsinki and received approval from the University Institutional Review Board (Reference No. SKE01-15/2023).

### 2.2. Study design

A cross-sectional methodological study was conducted to compare two measurement systems using CMJ performance. For each participant, CMJ data were collected simultaneously using a wearable inertial sensor BTS G-Sensor (BTS Bioengineering S.p.A., Garbagnate Milanese, Italy), and a force-platform (Zb. Staniak JBA, PL4P60k, PowerJump System PJS-4P60kS,

Warsaw, Poland) (Figure 1A, B). The BTS G-Sensor data were recorded at a sampling frequency of 100 Hz, whereas the force-platform signals were acquired at 1000 Hz and subsequently downsampled to 100 Hz for comparison. The use of 100 Hz for the final comparison was selected to match the sampling frequency of the BTS G-Sensor and ensure a common sampling frequency across the two datasets. Each participant performed one CMJ with their hands placed on the hips to eliminate the influence of upper-limb movement. The test started from an upright standing position, followed by a rapid downward movement of the body's center of mass and an immediate maximal vertical jump. Participants were instructed to jump with maximal effort while maintaining a consistent technique.

The BTS G-Sensor is designed for kinematic analysis in both clinical and research settings. The device weighs 37 g and measures  $70 \times 40 \times 18$  mm. It integrates a triaxial accelerometer (16-bit resolution per axis; selectable ranges:  $\pm 2$ ,  $\pm 4$ ,  $\pm 8$ ,  $\pm 16$  g), a triaxial gyroscope (16-bit resolution per axis; selectable ranges:  $\pm 250$ ,  $\pm 500$ ,  $\pm 1000$ ,  $\pm 2000$   $\text{deg}\cdot\text{s}^{-1}$ ), and a triaxial magnetometer (13-bit resolution;  $\pm 1200$   $\mu\text{T}$ ). During the tests, the sensor was securely attached to the participant's waist using a semi-elastic belt, allowing for non-invasive measurement of trunk kinematics. Data were transmitted wirelessly via Bluetooth® to a host computer for real-time monitoring and subsequent analysis.

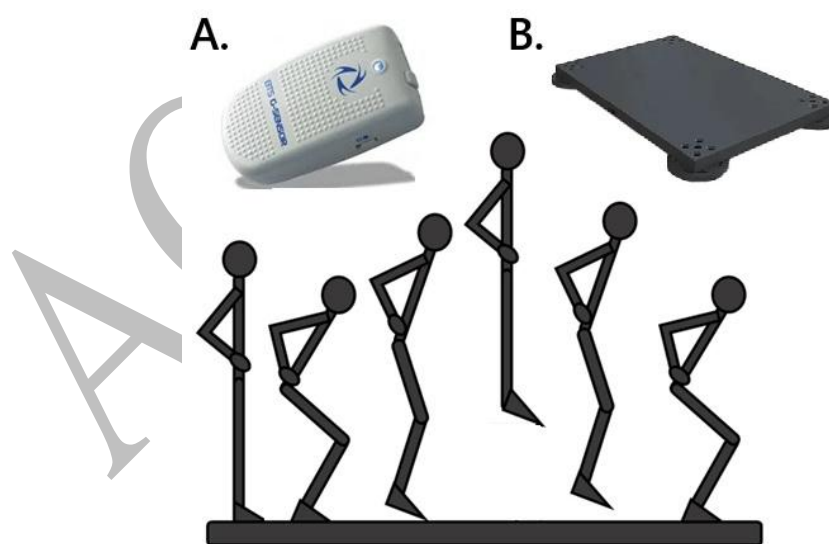


**Figure 1.** A. BTS G-Sensor, B. Force-platform in CMJ assessment.

The Zb. Staniak JBA force-platform consists of four strain-gauge load cells, each with a nominal capacity of 3 kN, providing a total system capacity of 12 kN. The strain gauges are configured in a full-bridge circuit with  $360 \Omega$  resistance, ensuring high measurement stability.

---

The system's declared linearity error is below 0.2% of full-scale output, indicating excellent accuracy across its operational range. The platform measures only the vertical component of the ground reaction force. Signals from the load cells were processed by an integrated amplifier (WT9VLJ) housed within the platform. This amplifier features four differential input channels, a 15-bit analog-to-digital converter, and a maximum sampling frequency of 1000 Hz, allowing simultaneous acquisition across all channels. An analog second-order anti-aliasing filter (350 Hz) is applied prior to digitization to minimize high-frequency noise. The force-platform signals were acquired at 1000 Hz and subsequently processed and downsampled to 100 Hz for comparison with the BTS G-Sensor data. Data are transmitted to the acquisition computer via a USB connection, which also provides power to the amplifier. The platform measures  $600 \times 600 \times 65$  mm, weighs 24 kg, and rests on four adjustable feet arranged on a  $534 \times 534$  mm base, allowing precise leveling and uniform load distribution. During testing, the platform was mounted on a rigid surface and leveled according to the manufacturer's instructions to ensure equal load across all sensors. The system was factory-calibrated and operated using the manufacturer's software (MVJ6v0), which facilitates synchronized force acquisition, signal processing, and biomechanical analysis.

CMJ parameters obtained from the BTS G-Sensor were derived from triaxial acceleration signals recorded during the jump. The acceleration data were processed using the manufacturer's proprietary algorithms, which include signal filtering, gravity compensation, and numerical integration to estimate vertical velocity and displacement of the body's center of mass. Jump height was calculated from the estimated vertical displacement, while peak velocity was identified from the velocity–time curve. Peak force and peak power during the concentric phase were subsequently estimated from the kinematic data based on inverse dynamics assumptions implemented within the software. The available manufacturer's documentation did not provide sufficient information to determine unequivocally whether the reported BTS peak force and peak power represented gross or net quantities, or whether power was reported as peak or mean power under the processing configuration used in the present study. Therefore, these outputs were treated as device-specific measures, and equivalence of their underlying definitions with the force-platform-derived variables was not assumed. Simultaneously, CMJ performance was assessed using a force-platform, which served as the reference method. The platform measured the vertical component of the ground reaction force throughout the entire jump cycle. Vertical acceleration of the center of mass was calculated from the net force (ground reaction force minus body weight) and integrated over time to obtain velocity and displacement. Jump height

---

was determined from flight time, whereas peak force was defined as the maximum vertical ground-reaction force obtained directly from the force–time curve. Thus, the reported peak force represented the measured vertical ground-reaction force rather than a separately calculated net-force value. Peak velocity and peak power were calculated using standard biomechanical procedures based on the force–velocity and force–power relationships. The following CMJ parameters were included in the analysis: jump height [cm], peak power [W], peak force [N], and peak velocity [ $\text{m}\cdot\text{s}^{-1}$ ]. Before statistical analysis, participant-level records from the BTS G-Sensor and force-platform datasets were matched using participant codes. During this process, several incomplete, duplicated, or ambiguously labelled records were identified. Consequently, the number of complete paired observations differed across outcome variables, with 35 paired observations available for CMJ height, 25 for peak power, 32 for peak force, and 23 for peak velocity. Records for which a reliable participant-level match or valid measurement could not be established were excluded from the respective analysis.

### 2.3. Statistical analysis

Statistical analyses were performed using standard descriptive, comparative, and agreement-based methods. The normality of the between-method differences was assessed using the Shapiro-Wilk test, complemented by visual inspection of quantile-quantile (Q-Q) plots (Figure 2). The distribution of the paired differences was used to guide the selection of the primary statistical test. For normally distributed differences, paired-samples *t*-tests were applied, whereas the Wilcoxon signed-rank test was used for differences that significantly deviated from normality.

Effect sizes for paired comparisons were expressed as Cohen’s *d* for paired *t*-tests, calculated from the mean and standard deviation of the paired differences [8]. For Wilcoxon signed-rank tests, the effect size was expressed as *r*. Statistical significance was set at  $p < 0.05$ .

Agreement between the BTS G-Sensor and the force-platform was assessed using the intraclass correlation coefficient (ICC). A two-way random-effects model with single measurements and absolute agreement [ICC(2,1)] was applied. ICC(2,1) estimates were accompanied by 95% confidence intervals calculated using a nonparametric bootstrap procedure, with paired participant-level observations resampled with replacement. ICC values were interpreted as poor ( $<0.50$ ), moderate ( $0.50\text{--}0.75$ ), good ( $0.75\text{--}0.90$ ), or excellent ( $>0.90$ ) [12].

Absolute agreement between methods was further examined using Bland-Altman analysis. The mean between-method difference (bias) and the corresponding 95% limits of agreement (LoA) were calculated as  $\text{bias} \pm 1.96 \times \text{SD}$  of the paired differences. Proportional bias was assessed

---

using linear regression of the between-method differences against the corresponding mean of the two measurement methods [16].

Between-method variability was described using the standard deviation of the paired differences, while SEM was calculated as the standard deviation of the paired differences divided by  $\sqrt{2}$ . Because each participant performed only one CMJ and repeated measurements were not available, SEM was not interpreted as a measure of test–retest reliability or sensitivity to change. All statistical analyses and data processing were performed using Python version 3.12 (SciPy, NumPy, pandas, and matplotlib). The level of statistical significance was set at  $p = 0.05$ .

### 3. Results

#### 3.1. Normality assessment and data distribution

The Q-Q plots showed approximate conformity to the theoretical normal distribution for CMJ height and peak velocity, whereas greater deviations, particularly in the tails of the distributions, were observed for peak power and peak force (Figure 2). The Shapiro-Wilk test indicated no significant departure from normality for the between-method differences in CMJ height ( $W = 0.966$ ,  $p = 0.337$ ) or peak velocity ( $W = 0.926$ ,  $p = 0.091$ ). In contrast, the between-method differences for peak power ( $W = 0.908$ ,  $p = 0.027$ ) and peak force ( $W = 0.897$ ,  $p = 0.005$ ) significantly deviated from normality. Accordingly, paired-samples  $t$ -tests were used for CMJ height and peak velocity, whereas Wilcoxon signed-rank tests were used for peak power and peak force.

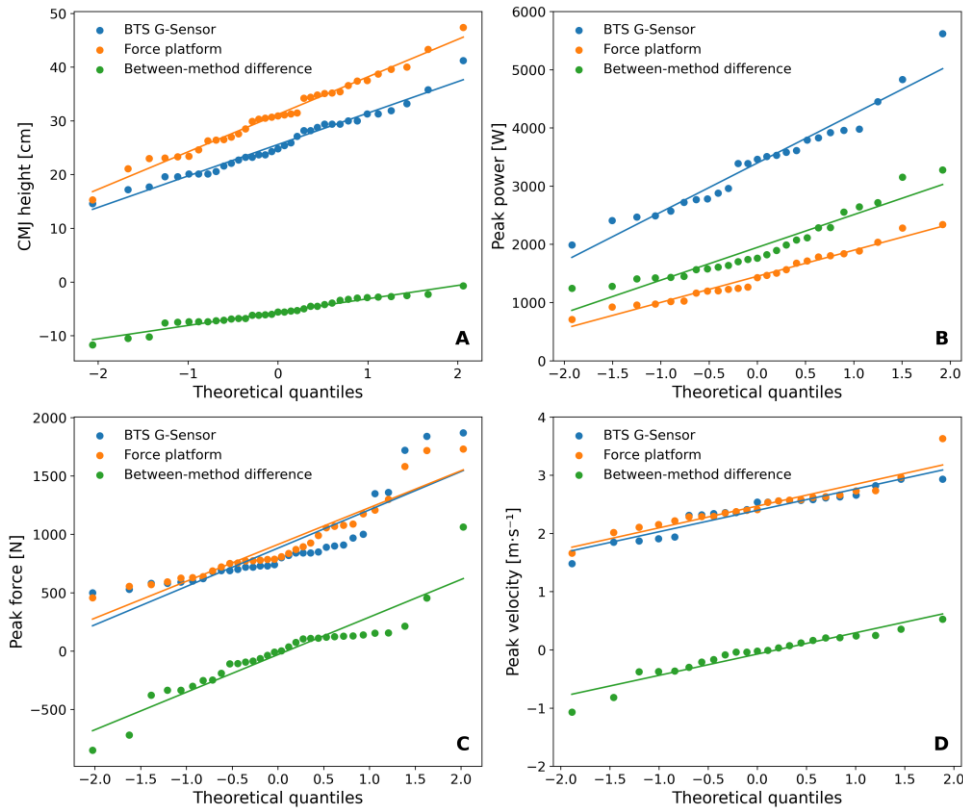


**Figure 2.** Quantile-quantile (Q-Q) plots for BTS G-Sensor measurements (blue), force-platform measurements (orange), and between-method differences (green) for: A. CMJ height, B. peak power, C. peak force, and D. peak velocity.

Between-method comparisons of CMJ variables are presented in Table 1. Significant differences between the BTS G-Sensor and force-platform were observed for CMJ height and peak power. CMJ height was significantly lower when measured using the BTS G-Sensor than the force-platform ( $25.58 \pm 5.73$  vs.  $31.20 \pm 6.79$  cm; bias =  $-5.61$  cm;  $p < 0.001$ ), with a large effect size (Cohen's  $d = -2.30$ ). Peak power was substantially higher when measured using the BTS G-Sensor than the force-platform ( $3395.60 \pm 829.15$  vs.  $1449.56 \pm 435.04$  W; bias =  $1946.04$  W;  $p < 0.001$ ), with a large effect size ( $r = 0.872$ ). No significant difference was observed for peak force between the BTS G-Sensor and force-platform ( $881.25 \pm 360.80$  vs.  $912.97 \pm 322.55$  N; bias =  $-31.72$  N;  $p = 0.729$ ;  $r = 0.059$ ). Similarly, no significant difference was observed for peak velocity ( $2.40 \pm 0.37$  vs.  $2.47 \pm 0.38$  m·s<sup>-1</sup>; bias =  $-0.07$  m·s<sup>-1</sup>;  $p = 0.343$ ; Cohen's  $d = -0.20$ ).

**Table 1.** Comparison of CMJ variables between the BTS G-Sensor and force-platform. Data are presented as mean  $\pm$  standard deviation (SD). Between-method differences were assessed using paired-samples  $t$ -tests for normally distributed paired differences and Wilcoxon

signed-rank tests for non-normally distributed paired differences. Mean differences (bias) were calculated as BTS G-Sensor minus force-platform values; negative values indicate higher measurements obtained from the force-platform. Normality of paired differences was assessed using the Shapiro-Wilk test and visual inspection of Q-Q plots. Cohen's *d* was reported for paired-samples *t*-tests, whereas *r* was reported for Wilcoxon signed-rank tests. An asterisk (\*) indicates a statistically significant difference between the BTS G-Sensor and force-platform measurements ( $p < 0.05$ ).

| Variable                                      | n  | BTS G-sensor        | Force-platform<br>m | Bias    | Test         | p-value  | Effect size |
|-----------------------------------------------|----|---------------------|---------------------|---------|--------------|----------|-------------|
| <b>CMJ height</b><br>[cm]                     | 35 | 25.58 ± 5.73        | 31.20 ± 6.79        | -5.61   | $t = -13.58$ | < 0.001* | $d = -2.30$ |
| <b>Peak power</b><br>[W]                      | 25 | 3395.60 ±<br>829.15 | 1449.56 ±<br>435.04 | 1946.04 | $W = 0.00$   | < 0.001* | $r = 0.872$ |
| <b>Peak force</b><br>[N]                      | 32 | 881.25 ±<br>360.80  | 912.97 ±<br>322.55  | -31.72  | $W = 245.50$ | 0.729    | $r = 0.059$ |
| <b>Peak veloc-<br/>ity [m·s<sup>-1</sup>]</b> | 23 | 2.40 ± 0.37         | 2.47 ± 0.38         | -0.07   | $t = -0.97$  | 0.343    | $d = -0.20$ |

### 3.2. ICC-based agreement between methods

The ICC-based agreement between the BTS G-Sensor and the force-platform is presented in Table 2. CMJ height showed moderate agreement, with an ICC(2,1) of 0.662 (95% CI: 0.495–0.768). Peak power demonstrated poor agreement between the two measurement systems (ICC(2,1) = 0.120, 95% CI: 0.059–0.176). Moderate agreement was observed for both peak force (ICC(2,1) = 0.533, 95% CI: 0.059–0.825) and peak velocity (ICC(2,1) = 0.521, 95% CI: 0.297–0.753). Thus, among the analyzed CMJ variables, peak power showed the lowest level of relative agreement between the two measurement systems, whereas CMJ height showed the highest ICC value.

**Table 2.** Absolute-agreement intraclass correlation coefficients [ICC(2,1)] between the BTS G-Sensor and force-platform for CMJ variables.

| Variable        | n  | ICC(2,1) | 95% CI - bootstrap | Interpretation |
|-----------------|----|----------|--------------------|----------------|
| CMJ height [cm] | 35 | 0.662    | 0.495–0.768        | moderate       |

|                                    |    |       |             |          |
|------------------------------------|----|-------|-------------|----------|
| Peak power [W]                     | 25 | 0.120 | 0.059–0.176 | poor     |
| Peak force [N]                     | 32 | 0.533 | 0.059–0.825 | moderate |
| Peak velocity [m·s <sup>-1</sup> ] | 23 | 0.521 | 0.297–0.753 | moderate |

279

### 3.3. Absolute agreement, Bland-Altman analysis and measurement error

280

Bland-Altman analysis showed variable levels of agreement between the BTS G-Sensor and force-platform (Table 3). For CMJ height, the mean bias was  $-5.61$  cm, with 95% limits of agreement ranging from  $-10.41$  to  $-0.82$  cm. A significant proportional bias was observed (slope =  $-0.174$ ,  $p = 0.008$ ), indicating that the magnitude of the between-method difference varied according to the level of performance. Peak power showed a substantial positive bias of  $1946.04$  W, with 95% limits of agreement ranging from  $842.85$  to  $3049.23$  W. A significant proportional bias was also observed for peak power (slope =  $0.694$ ,  $p < 0.001$ ), indicating increasing disagreement between the two methods with increasing measurement magnitude. For peak force, the mean bias was  $-31.72$  N, with relatively wide 95% limits of agreement ranging from  $-683.72$  to  $620.28$  N. No significant proportional bias was detected (slope =  $0.146$ ,  $p = 0.474$ ). Similarly, peak velocity showed a small mean bias of  $-0.07$  m·s<sup>-1</sup>, with 95% limits of agreement ranging from  $-0.79$  to  $0.64$  m·s<sup>-1</sup>, and no significant proportional bias was observed (slope =  $-0.040$ ,  $p = 0.872$ ). Overall, the largest between-method disagreement was observed for peak power, whereas peak velocity showed the smallest mean bias.

281  
282  
283  
284  
285  
286  
287  
288  
289  
290  
291  
292  
293  
294  
295

**Table 3.** Bland-Altman analysis and proportional-bias assessment of agreement between BTS G-Sensor and force-platform measurements. Bias represents the mean difference between BTS G-Sensor and force-platform measurements (BTS G-Sensor – force-platform). The 95% limits of agreement (LoA) were calculated as bias  $\pm 1.96 \times$  SD of the paired differences. SEM represents the standard error of measurement and was calculated as the standard deviation of the paired differences divided by  $\sqrt{2}$ . The 95% error threshold represents  $1.96 \times$  SD of the paired differences. Proportional bias was assessed using linear regression of the between-method differences on the mean of the two measurement methods. An asterisk (\*) indicates a statistically significant between-method difference ( $p < 0.05$ ).

296  
297  
298  
299  
300  
301  
302  
303  
304

| Variable | Bias | LoA low | LoA high | SEM | 95% error threshold | Slope | p-value |
|----------|------|---------|----------|-----|---------------------|-------|---------|
|----------|------|---------|----------|-----|---------------------|-------|---------|

|                                    |         |         |         |        |         |        |         |
|------------------------------------|---------|---------|---------|--------|---------|--------|---------|
| CMJ height [cm]                    | -5.61   | -10.41  | -0.82   | 1.73   | 4.79    | -0.174 | 0.008   |
| Peak power [W]                     | 1946.04 | 842.85  | 3049.23 | 398.00 | 1103.19 | 0.694  | <0.001* |
| Peak force [N]                     | -31.72  | -683.72 | 620.28  | 235.22 | 652.00  | 0.146  | 0.474   |
| Peak velocity [m·s <sup>-1</sup> ] | -0.07   | -0.79   | 0.64    | 0.26   | 0.71    | -0.040 | 0.872   |

#### 4. Discussion

The aim of this study was to evaluate the agreement between the BTS G-Sensor and a force-platform for selected countermovement jump (CMJ) variables. The analysis demonstrated that the level of agreement was strongly dependent on the variable assessed. The BTS G-Sensor produced significantly lower CMJ height and substantially higher reported peak power values than the force-platform, whereas no significant between-method differences were observed for peak force and peak velocity. However, the absence of a significant mean difference does not by itself demonstrate interchangeability between measurement methods, as absolute agreement also depends on the magnitude of individual differences and the corresponding limits of agreement [1, 3].

For CMJ height, the BTS G-Sensor produced significantly lower values than the force-platform, with a mean bias of -5.61 cm. The ICC(2,1) indicated moderate ICC-based agreement (0.662). Previous studies have demonstrated moderate-to-good validity and reliability of accelerometric or inertial systems for assessing vertical jump performance [5, 7, 21, 23]. The present results are generally consistent with these findings but also demonstrate that acceptable relative agreement does not necessarily indicate agreement in absolute values. The significant proportional bias observed for CMJ height (slope = -0.174,  $p = 0.008$ ) further indicates that the magnitude of the difference between the systems varied according to the level of performance. Similar methodological differences between systems based on inertial or acceleration-derived measurements and force-platform approaches have been reported previously [6, 14].

The most pronounced disagreement was observed for peak power. The BTS G-Sensor produced substantially higher peak power values than the force-platform, with a mean bias of 1946.04 W and 95% limits of agreement ranging from 842.85 to 3049.23 W. In addition, the ICC(2,1) was only 0.120, indicating poor ICC-based agreement. The significant proportional bias (slope = 0.694,  $p < 0.001$ ) demonstrates that the discrepancy increased with the magnitude of the measurement. Differences in the algorithms used to derive power from acceleration and force-time data may contribute to such discrepancies. However, the precise definitions of the

BTS peak power output could not be established from the available manufacturer's documentation. In particular, it could not be determined whether the BTS output represented gross or net power or whether it corresponded to peak or mean power under the processing configuration used in this study. Therefore, the observed difference in reported power should not be interpreted as evidence of a systematic measurement bias of the BTS G-Sensor, because differences in the underlying variable definitions and proprietary processing procedures may also contribute to the observed discrepancy. Previous research has demonstrated that measurement system characteristics and computational procedures can influence estimates of jump power and height [6, 20, 21, 23].

The results for peak force differed from those observed for CMJ height and peak power. No statistically significant difference was found between the BTS G-Sensor and force-platform, the Wilcoxon signed-rank test did not indicate a statistically significant systematic difference. However, the ICC indicated only moderate agreement (0.533), while the 95% limits of agreement were relatively wide, ranging from  $-683.72$  to  $620.28$  N. No significant proportional bias was observed ( $p = 0.474$ ). Thus, although the two systems produced similar mean peak-force values, the individual differences were sufficiently large to limit their interchangeability when precise individual measurements are required. This finding is consistent with previous work showing that agreement between different vertical-jump assessment systems can vary considerably depending on the variable and measurement technology used [6].

Peak velocity showed a similar pattern. The mean difference between the BTS G-Sensor and force-platform was small ( $-0.07 \text{ m}\cdot\text{s}^{-1}$ ) and was not statistically significant. The ICC indicated moderate agreement (0.521), while the 95% limits of agreement ranged from  $-0.79$  to  $0.64 \text{ m}\cdot\text{s}^{-1}$ . No significant proportional bias was detected ( $p = 0.872$ ). Therefore, although the two systems showed relatively small systematic differences for peak velocity, the moderate ICC and relatively wide limits of agreement indicate that the measurements should not automatically be considered interchangeable at the individual level. Differences in signal processing and the calculation of velocity-derived variables may contribute to discrepancies between measurement systems [6].

Taken together, the present findings emphasize the importance of distinguishing between ICC-based agreement and absolute agreement when evaluating measurement systems. The ICC provides information about the degree of agreement between measurements but does not, by itself, establish interchangeability between methods [1, 12]. Bland-Altman analysis complements the ICC by quantifying systematic differences and the range within which individual differences are expected to occur [3, 16]. In the present study, this distinction was particularly

---

evident for CMJ height and peak power. Although CMJ height demonstrated moderate ICC-based agreement, systematic and proportional bias were present. For peak power, both the ICC and Bland-Altman analysis indicated poor agreement and substantial systematic disagreement.

From a practical perspective, wearable inertial sensors offer important advantages for field-based assessment because they are portable and can be used outside laboratory environments [4]. The BTS G-Sensor may therefore be useful for assessing CMJ performance when a force-platform is not available. However, the present findings indicate that values obtained from the BTS G-Sensor should be interpreted within the context of the measurement system used. In particular, peak power values should not be directly substituted for force-platform measurements or compared with reference values obtained using a different measurement technology. Similar caution should be applied to individual comparisons of CMJ height, peak force, and peak velocity because the limits of agreement indicate that meaningful differences between methods may occur even when mean differences are small.

The present study has several limitations. First, participant-level matching of the datasets resulted in different numbers of paired observations for individual CMJ variables because incomplete, duplicated, or ambiguously labelled records could not always be reliably matched. Although the datasets were carefully reconstructed before analysis, the smaller sample sizes for some variables may have reduced the precision of the agreement estimates. Second, each participant performed only one CMJ, and therefore the present study evaluated between-method agreement rather than within-session or between-session reliability. Repeated measurements would be necessary to separate between-method disagreement from within-device variability and to determine whether either system can reliably detect individual changes over time [9, 11]. Third, the BTS G-Sensor data were recorded at 100 Hz, whereas the force-platform signals were acquired at 1000 Hz and subsequently downsampled to 100 Hz for comparison. Although this approach ensured a common sampling frequency for the final analysis, downsampling may have influenced the representation of rapidly changing force-time characteristics and should therefore be considered when interpreting variables such as peak force and peak power. Fourth, the study evaluated one inertial sensor and one force-platform, and the findings should therefore not be generalized to all commercially available devices or proprietary processing algorithms. Finally, the relatively broad age range of the participants may have contributed to between-subject variability and limits the generalizability of the findings to more specific populations.

---

Future studies should incorporate multiple CMJ trials within a session and repeated testing sessions to evaluate both within-device reliability and between-method agreement. Such studies should also provide detailed descriptions of the algorithms used to derive velocity and power and examine whether differences in signal processing, force definitions, and sampling characteristics contribute to systematic discrepancies between measurement systems.

Overall, the findings demonstrate that the BTS G-Sensor and the tested force-platform should not be considered interchangeable for absolute assessment of CMJ variables. The magnitude and direction of disagreement varied substantially between variables, with the most pronounced discrepancy observed for peak power. CMJ height showed moderate agreement but systematic and proportional bias, whereas peak force and peak velocity showed no significant mean differences but only moderate relative agreement and relatively wide individual limits of agreement. Therefore, the BTS G-Sensor may provide useful field-based measurements of CMJ performance, but its results should be interpreted as device-specific measurements rather than direct equivalents of force-platform-derived values.

### *Practical Implications*

The present findings have several practical implications for the assessment of countermovement jump performance. The BTS G-Sensor may provide a useful and practical alternative for field-based assessment when access to a force-platform is limited, particularly because of its portability and ease of use. However, the results indicate that measurements obtained with the BTS G-Sensor should be interpreted as device-specific values rather than direct equivalents of force-platform measurements.

The BTS G-Sensor produced substantially higher power values than the force-platform, showed poor ICC-based agreement, and demonstrated significant proportional bias. However, because the precise gross/net and peak/mean definitions of the proprietary BTS power output could not be established, this difference should not be interpreted as definitive evidence of a systematic measurement bias of the BTS G-Sensor, as differences in the underlying variable definitions and proprietary processing procedures may also contribute to the observed discrepancy. Therefore, peak power values obtained with the BTS G-Sensor should not be directly compared with force-platform reference values or used interchangeably with them. CMJ height, peak force, and peak velocity showed moderate relative agreement, but the observed limits of agreement indicate that individual measurements may still differ considerably between systems. Consequently, practitioners should use the same measurement system con-

---

sistently when monitoring CMJ performance over time and avoid interpreting differences 434  
between devices as changes in an individual's performance. 435

For practitioners working outside laboratory settings, the BTS G-Sensor may therefore be 436  
valuable for monitoring CMJ performance within a standardized measurement protocol. 437  
However, device-specific reference values and longitudinal comparisons should be established 438  
using the same system. When precise absolute measurements or direct comparison with 439  
force-platform-derived data are required, a force-platform remains preferable. 440

### *Study Limitations* 441

Several limitations should be considered when interpreting the findings of the present study. 442  
First, the number of paired observations differed between CMJ variables because incomplete, 443  
duplicated, or ambiguously labelled records could not be reliably matched at the participant 444  
level. Consequently, the analyses were based on 23–35 paired observations, which may have 445  
affected the precision of the agreement estimates, particularly for variables with smaller sample 446  
sizes. 447

Second, each participant performed only one CMJ, and therefore the study assessed agreement 448  
between the two measurement systems rather than test–retest reliability. The lack of repeated 449  
trials prevents the separation of between-method differences from within-device variability and 450  
does not allow conclusions to be drawn regarding the ability of either system to detect 451  
meaningful changes in individual performance over time. 452

Third, the study compared one specific BTS G-Sensor configuration with one force-platform 453  
system. The findings may therefore reflect characteristics of the particular devices, 454  
data-processing procedures, and algorithms used to derive CMJ variables and should not 455  
necessarily be generalized to other inertial sensors or force-platform. 456

Fourth, the BTS G-Sensor data were recorded at 100 Hz, whereas the force-platform signals 457  
were acquired at 1000 Hz and subsequently downsampled to 100 Hz for comparison. Although 458  
the common 100 Hz sampling frequency facilitated direct comparison, the downsampling of 459  
force-platform data may have influenced the representation of rapidly changing biomechanical 460  
signals, particularly variables derived from force- and velocity-time data, such as peak force 461  
and peak power [20, 25]. Fifth, an additional limitation concerns the underlying definitions of 462  
the force- and power-related variables. The force-platform peak force was defined as the 463  
maximum measured vertical ground-reaction force, whereas the available manufacturer's 464  
documentation did not allow us to determine unequivocally whether the BTS peak force and 465  
peak power outputs represented gross or net quantities or whether the power output 466  
467

---

corresponded to peak or mean power under the processing configuration used in this study. 468  
Consequently, between-method differences, particularly for power, may partly reflect 469  
differences in variable definitions and proprietary signal-processing procedures rather than 470  
differences in measurement accuracy alone. 471

Finally, the study included adults residing in a semi-open correctional facility, representing a 472  
specific population. The wide age range (19.6–61.7 years) reflects the characteristics of the 473  
available adult population in the correctional facility. We acknowledge that this age 474  
heterogeneity may increase between-subject variability in physical performance and 475  
consequently influence ICC estimates. Together with the specific correctional-facility setting 476  
and male-only sample, this limits the generalizability of the findings to more age-homogeneous 477  
and typical user populations, such as athletes, healthy recreationally active individuals, or 478  
clinical populations. Future studies should include larger and more diverse samples, with more 479  
age-homogeneous groups, multiple CMJ trials, and repeated testing sessions to further evaluate 480  
both between-method agreement and the reliability of the measurement systems. 481

## 5. Conclusions 484

The present study demonstrated that the agreement between the BTS G-Sensor and 485  
force-platform varied substantially across CMJ variables. CMJ height, peak force, and peak 486  
velocity showed moderate relative agreement, whereas peak power demonstrated poor agree- 487  
ment and a substantial systematic difference between the two measurement systems. Signifi- 488  
cant proportional bias was observed for CMJ height and peak power, further indicating that the 489  
differences between methods were dependent on the magnitude of the measurements. These 490  
findings suggest that the BTS G-Sensor should not be considered interchangeable with the 491  
force-plaform for absolute assessment of CMJ variables, particularly peak power. Nevertheless, 492  
the BTS G-Sensor may provide a practical option for field-based assessment when measure- 493  
ments are performed consistently using the same device and interpreted within device-specific 494  
reference values. 495

## References 498

- [1] ATKINSON, G., NEVILL A.M., *Statistical methods for assessing measurement error 499*  
(reliability) in variables relevant to sports medicine, *Sports Med*, 1998, 26(4), 500  
217-238. 501

- 
- [2] BARTOSZ, M., LATOCHA A., MOTOWIDŁO J., KRZYSZTOFIK M., ZAJAC A., *The relationship between countermovement jump performance and sprinting speed in elite sprinters*, Physical Activity Review, 2024, 12.
- [3] BLAND, J.M., ALTMAN D.G., *Statistical methods for assessing agreement between two methods of clinical measurement*, Lancet (London, England), 1986, 1(8476), 307-310.
- [4] CAMOMILLA, V., BERGAMINI E., FANTOZZI S., VANNOZZI G., *Trends Supporting the In-Field Use of Wearable Inertial Sensors for Sport Performance Evaluation: A Systematic Review*, Sensors, 2018, 18(3), 873.
- [5] CASARTELLI, N., MÜLLER R., MAFFIULETTI N.A., *Validity and reliability of the Myotest accelerometric system for the assessment of vertical jump height*, J Strength Cond Res, 2010, 24(11), 3186-3193.
- [6] CASTAGNA, C., GANZETTI M., DITROILO M., GIOVANNELLI M., ROCCHETTI A., MANZI V., *Concurrent validity of vertical jump performance assessment systems*, J Strength Cond Res, 2013, 27(3), 761-768.
- [7] CLEMENTE, F.M., BADICU G., HASAN U.C., AKYILDIZ Z., PINO-ORTEGA J., SILVA R., RICO-GONZÁLEZ M., *Validity and reliability of inertial measurement units for jump height estimations: a systematic review*, Hum Mov., 2022, 23(4), 1-20.
- [8] COHEN, J., *Statistical Power Analysis for the Behavioral Sciences*, ed. Routledge. 1988.
- [9] CORMACK, S.J., NEWTON R.U., MCGUIGAN M.R., DOYLE T.L., *Reliability of measures obtained during single and repeated countermovement jumps*, International journal of sports physiology and performance, 2008, 3(2), 131-144.
- [10] GONZÁLEZ-GARCÍA, J., CONEJERO M., GUTIÉRREZ-HELLÍN J., *Assessing Jump Performance: Intra- and Interday Reliability and Minimum Difference of Countermovement Jump and Drop Jump Outcomes, Kinetics, Kinematics, and Jump Strategy*, Applied Sciences, 2024, 14(6), 2662.
- [11] HOPKINS, W.G., *Measures of reliability in sports medicine and science*, Sports Med, 2000, 30(1), 1-15.
- [12] KOO, T.K., LI M.Y., *A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research*, Journal of chiropractic medicine, 2016, 15(2), 155-163.
- [13] KUMAR, S., SINGH J., PRADHAN P., KUMAR S., THAPA R., *Validity and Reliability of an Inertial Measurement Unit (BTS G-Walk) for Measurement of Countermovement Jump Height: A pilot-study*, Journal of Anthropology of Sport and Physical Education, 2023, 7.
- [14] LAKE, J., MUNDY P., COMFORT P., MCMAHON J.J., SUCHOMEL T.J., CARDEN P., *Concurrent Validity of a Portable Force Plate Using Vertical Jump Force-Time Characteristics*, J Appl Biomech, 2018, 34(5), 410-413.
- [15] LINTHORNE, N.P., *Analysis of standing vertical jumps using a force platform*, American Journal of Physics, 2001, 69(11), 1198-1204.

- 
- [16] MANSOURNIA, M.A., WATERS R., NAZEMIPOUR M., BLAND M., ALTMAN D.G., *Bland-Altman methods for comparing methods of measurement and response to criticisms*, Global Epidemiology, 2021, 3100045.
- [17] MARKOVIC, G., DIZDAR D., JUKIC I., CARDINALE M., *Reliability and factorial validity of squat and countermovement jump tests*, J Strength Cond Res, 2004, 18(3), 551-555.
- [18] MIRANDA-OLIVEIRA, P., BRANCO M., FERNANDES O., *Accuracy of Inertial Measurement Units When Applied to the Countermovement Jump of Track and Field Athletes*, Sensors, 2022, 22(19), 7186.
- [19] MORASSUTTI, O.N., VAN WYK P.M., DUQUETTE A.M., *Vertical jumping power normative-reference values: Utilizing a large cohort of Canadian University students*, Biomedical Human Kinetics, 2025, 17(1), 147-157.
- [20] OWEN, N.J., WATKINS J., KILDUFF L.P., BEVAN H.R., BENNETT M.A., *Development of a criterion method to determine peak mechanical power output in a countermovement jump*, J Strength Cond Res, 2014, 28(6), 1552-1558.
- [21] PICERNO, P., CAMOMILLA V., CAPRANICA L., *Countermovement jump performance assessment using a wearable 3D inertial measurement unit*, J Sports Sci, 2011, 29(2), 139-146.
- [22] PODSTAWSKI, R., BORYSŁAWSKI K., GRODŹ D., *Validity and reliability of a repeated 5 x 20-s maximal rowing test in trained young volleyball players*, Physical Activity Review, 2024, 131-13.
- [23] RANTALAINEN, T., GASTIN P.B., SPANGLER R., WUNDERSITZ D., *Concurrent validity and reliability of torso-worn inertial measurement unit for jump power and height estimation*, Journal of Sports Sciences, 2018, 36(17), 1937-1942.
- [24] SINGH, D., SINGH S., *Effects of vertical, horizontal, and combination depth jump training on long jump performance*, Biomedical Human Kinetics, 2012, 4(2012), 107-111.
- [25] STREET, G.M., MCMILLAN S., BOARD W.J., RASMUSSEN M., HENEGHAN J.M., *Sources of Error in Determining Countermovement Jump Height with the Impulse Method*, Journal of Applied Biomechanics, 2001, 1743-54.
- [26] THAPA, R., KUMAR G., YADAV P., SORTWELL A., RAMIREZ-CAMPILLO R., *Intra- and inter-session reliability of countermovement jump and gait analysis in collegiate athletes measured using an inertial measurement unit (BTS G-Walk)*, Montenegrin Journal of Sports Science and Medicine, 2024, 1337-47.
- [27] VILLAREJO-GARCÍA, D.H., MORENO-VILLANUEVA A., SOLER-LÓPEZ A., RECHE-SOTO P., PINO-ORTEGA J., *Use, Validity and Reliability of Inertial Movement Units in Volleyball: Systematic Review of the Scientific Literature*, Sensors, 2023, 23(8), 3960.