

# Evaluation of reliability and concurrent validity of two optoelectric systems used for recording maximum vertical jumping performance versus the gold standard

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*Purpose:* The objective of this study was to evaluate the reliability and validity of two alternative systems used for jumping performance measurement. *Methods:* Two groups of subjects were tested. The first group consisted of 15 male adults ( $21.3 \pm 1.7$  years) and the second group consisted of 16 female volleyball players ( $17.2 \pm 0.9$  years). We used three different systems of data collection in the study. Two of the used systems are based on optoelectric components. The Optojump Next system is referred to as the optoelectric system, and BTS Smart-E is referred to as the video system. Concurrent validity of these systems was verified with the use of “gold standard” which is force platform. All systems were used to estimate the height of vertical jumps. *Results:* Both optoelectric systems turned out to be highly reliable with the ICCs = 0.98 for Optojump and 0.9 for BTS Smart. Their concurrent validity with the force platform data was also very high  $r = 0.99$  and  $r = 0.97$ , respectively. *Conclusions:* Comparison of these two systems shows distinct differences between them. Out of the two systems, Optojump system is more suitable for quick and reliable sports testing while when BTS-Smart is better for research and clinical testing.

*Key words:* reliability, counter movement jump, motion capture, sports performance, optoelectric

## 1. Introduction

Maximum vertical jumps have been studied for various purposes, such as investigating the design and function of the human locomotor apparatus [3], [9], exploring the optimum training regimens [10, 27], or assessing the effect of body size on physical performance [13]. However, the maximum vertical jump is one of the most popular tests of motor abilities and movement performance, commonly used in athletic and recreational testing to evaluate the force and power of lower limbs [1], [6], [14], [21], [22], [28]. In some of them, like volleyball, basketball or

football vertical jump height is considered to be an essential skill which determines performance [4], [14]. In other sports it is often used as a predictor of speed-strength performance [5], [29] and power [12], [17], [19]. Due to the movement simplicity and being one of the basic skills acquired in healthy development, it is natural for almost every human and simple to do for people on every level of sports experience. Another important value of this testing methodology is its interpretation, which is simple and straight forward. Various sport disciplines developed its own specialized tests based on vertical jumps [7], [20], [23], [26], such as counter movement jump (CMJ) and squat jump (SJ).

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With the development of technology variety of tools and methods of different sophistication became available to measure vertical jump height. In laboratory conditions a force platform or motion capture systems are used. This kind of equipment is usually expensive and often inaccessible for on-field diagnostics due to the lack of portability, time consuming measurement procedures or specific demands concerning external conditions (limited space and light conditions). These methods are commonly used in the research area.

Growing demands of sports professionals for a quick, valid and reliable estimate of performance induced development of alternative, easy to use methods of vertical jump height measurements. This includes simple devices like Vertec (Sports Imports, Hilliard, OH 43026), different kinds of contact mats [15] and more sophisticated wireless microelectromechanic based systems [24], which show high reliability and validity with “the gold standard” being the force platform. Currently, sports professionals face the problem of abundance in the measurement and testing area. First, it is due to the wide range of devices they can use. Secondly, there are a number of testing protocols that can be applied to the measurement of vertical jump. Finally, there are several methods of data processing of the raw data that might lead to different outcomes. Another problem might arise when dealing with different groups of subjects, for instance, young, elderly, inexperienced and experienced sportsmen.

Literature review reveals a number of studies that even if explored various properties of the devices that can be used to measure the jumping performance there is an apparent lack of their comprehensive evaluations and comparisons. Although using the force platform in the experiments would make it possible to obtain the measures of power, we have focused only on the jump height which is more adequate for we use of the optoelectronic systems. Therefore, the aim of the present study is to evaluate two relatively novel systems that allow jumping performance testing through the assessment of the maximum jump height versus the “gold standard”. We have evaluated the Optojump Next and BTS Smart-E systems through their intersession reliability and concurrent validity as compared to the standard force platform data. The results are expected to reveal whether the evaluated systems (as well as other systems based on recording the flight time) can be used in routine testing of jumping performance in various athletic, recreational and other populations.

## 2. Materials and methods

### 2.1. Evaluated systems

In this study, we used three different systems of data collection. The systems were: Optojump Next (optoelectric), BTS Smart-E (motion capture) and the standard force plate. All systems were used to estimate the height of vertical jumps performed by the subjects. The study was divided into two experiments. Such necessity arose when we tried to use the motion analysis system in parallel with the Optojump Next system. Unfortunately, it was impossible due the interference the two systems exerted on each other. The link between these two experiments was the use of the same force platform during of them.

### 2.2. Subjects

Two groups of subjects were tested in two separate experiments. The first group consisted of 15 male adults which voluntarily agreed to participate in the first experiment. These subjects were recruited from the students of the physical education course. Their average age, body mass and height were  $21.3 \pm 1.7$  years,  $73.8 \pm 7.7$  kg and  $177.5 \pm 1.5$  cm, respectively (mean  $\pm$  SD). The second group of subjects consisted of 16 female athletes recruited from the students of the athletic school. Their average age, body mass and height were  $17.2 \pm 0.9$  years,  $68.6 \pm 8.4$  kg and  $181.3 \pm 9.2$  cm, respectively (mean  $\pm$  SD). They were volleyball players at the level of first league competition. None of the subjects reported any muscle or skeletal disorders. Prior to the experiment, subjects signed an informed consent. The study was approved by the Institutional Review Board of the Academy and conducted in accordance with the Declaration of Helsinki.

### 2.3. Optojump Next test

#### 2.3.1. Apparatus

In the first experiment subjects' jumping performance was tested by means of two systems used in parallel. In particular, The Optojump Next system (Microgate, Italy) was used in parallel with a force platform (Kistler, AGWinterthur, Schweiz, Model 9281C). The force platform recorded the vertical component of

ground reaction forces (Fz; sampling frequency of 1 kHz). The data were obtained from the photoelectric cells built-in 1 meter long parallel bars (receiver and transmitter). The transmitter contains 100 diodes emitting infrared light, positioned 1 mm from ground level at 10 mm intervals. The system measures the flight time of a jump with an frequency of 1/1000 seconds (1 kHz). The Optojump bars were connected to a personal computer with the proprietary software (Optojump Next, version 1.6) which instantly provides the measured outcomes (i.e., flight time and contact time). The Optojump Next system is an example of portable and easy to use device. Measurement can be conducted in any condition on stable, horizontal surface without engaging specialist or special preparations (markers, electrodes, etc.) of the participant. The Optojump Next software calculates the height of vertical jump from flight time using simple method ( $9.81 \times \text{flight time}^2/8$ ) described by Bosco [6]. The Optojump bars were placed 1 m apart parallel to each other and where the ground surface was the surface of the force platform, thus allowing for the concurrent registration of the subjects' performance with both devices.

### 2.3.2. Procedure

Prior to the first experiment, subjects warmed-up with the use of jump rope for approximately 2 min. After that, they were instructed to stand quietly on a force platform between Optojump bars. Their first task was to perform a squat jump (SJ) with their knee joint bent approximately 100 degrees. The task was repeated 5 times with 10-second intervals. After that, subjects performed 5 consecutive counter movement jumps (CMJ) with the same break between jumps. In order to eliminate the interference of jumping technique and concentrate only on the jumping performance, CMJ were performed with the hands held akimbo (no arm swing was allowed). A 2 minutes rest was allowed between the two series.

## 2.4. BTS-Smart test

### 2.4.1. Apparatus

The force platform (Kistler, AGWinterthur, Schweiz, Model 9281C) was also used in the second experiment also with 1kHz sampling frequency. The measurement was conducted in parallel with motion capture system BTS Smart-E (BTS Bioengineering, Italy). The force platform sampling frequency again was set at 1 kHz.

The BTS Smart-E system was used to calculate the flight time from movement kinematics. It consists of six infrared cameras with a 120 Hz sampling frequency. The reflective markers were placed on the tip of a shoe and the end of the shoe at the level of tuber calcanei. The marker on the tip of the shoe was the last to lose the contact with the ground and the first to regain it when the landing phase was initiated. Based on the change of its trajectory in time the velocity of the marker was calculated. The flight phase initiation was estimated by the change in the velocity, when its vector pointed up accordingly to the initial phase of the flight. The end of the flight was marked out when the vertical value of velocity equaled zero – the lack of the vertical movement of fore foot.

### 2.4.2. Procedure

In the second experiment, after the 2-minute warm-up, subjects performed one series of 5 consecutive CMJ on the force platform with a short break between them (approx. 10 sec.). Again, during each series of jumps subjects were holding their hands on their hips. Both systems were registering performance concurrently.

## 2.5. Data analysis

The systems used in the experiment are based on different measuring mechanisms. This may lead to different results obtained in the same tests. However, the main was focus on reliability and validity of these devices when different methods of raw data analysis were applied. The Optojump Next system estimates the jump height using calculation algorithms based on main measurement parameters which is the time of flight ( $T_f$ ). The following equation is used:

$$H_{\text{Opto}} = \frac{T_f^2 \times 9.81}{8}; \quad (1)$$

The use of force platforms gives more ways to calculate jumping performance. Similarly to Optojump system, it is possible to use time of flight in calculations ( $H_{\text{flight}}$ ). The platform sensitivity allows for precise measurement of time of contact of feet with its surface. Based on this the height of the jump is calculated with the same equation as above. Another way to calculate the jump height is to use maximal velocity at the take-off in order to estimate the height of the jump ( $H_{\text{vel}}$ ). This method is based on the law of conservation of energy.

Finally, the third method, commonly used for vertical jump height calculations, is based on the trajectory of the center of mass (COM) point ( $H_{\text{traj}}$ ). It is calculated by double integration of force being the difference between maximal elevation of the center of mass and its elevation when the maximal velocity was reached (center of mass flight trajectory), where the initial conditions are as follows  $V = 0$  and  $H = 0$ . These three methods are commonly used with force platform software.

## 2.6. Statistical analysis

Standard descriptive statistics were conducted to estimate the data distribution and decide on further statistical methods of data analysis. The Kolmogorov–Smirnov test revealed deviations from normality in none of the tested variables (all  $p > 0.05$ ), which allowed use of parametric statistics.

Correlation analysis was used to show the concurrent validity of the Optojump Next system and force platform. In order to demonstrate possible differences in the results obtained from different devices one-way ANOVA was used, with Tukey HSD *post-hoc* comparisons when needed. The alpha level was set at  $p < 0.05$ .

The reliability of conducted measurements was estimated by the use of intraclass correlation coefficients (ICCs) (2,1) described by Shrout and Fleiss [25] with 95% confidence intervals (CI). Derived from the ANOVA results, the ICC compares within subject variability with between subject variability. This model considers random effect over time (Eq. (2)):

$$ICC_{2,1} = \frac{MS_B - MS_E}{MS_B + (n-1)MS_E + n(MS_R - MS_E) / k} \quad (2)$$

where: MSB, MSR, and MSE are the mean squares of the 2-way ANOVA,  $n$  is the number of subjects, and  $k$  the number of trials.

Additionally, coefficients of variation (CV) were calculated together with their 95% confidence intervals and standard error of measurement (SEM). The CV is defined as  $(s/\text{mean}) * 100$  where  $s$  is the standard deviation and mean is the mean of the change scores of the measure [2]. All calculations were made with the use of *Statistica* software package.

## 3. Results

### 3.1. Experiment 1

#### *Reliability of Optojump*

The results of ICC show that both methods are reliable with a low number of repetitions needed to obtain very good reliability (Table 1). Interestingly, differences in the reliability coefficients of measurements of the height of jump were observed when we used different algorithm to process the data from the force platform. These differences were very small but noticeable. Another interesting result was the difference between the reliability of the measurements of the CMJ and SJ when using Optojump system. The force platform measurements using the trajectory of force platform data in the jump height calculations are claimed to be “gold standard”. It was observed that the highest values of reliability were obtained with the algorithm using time of flight with the smallest SEM (0.45 cm in the case of CMJ and 1.01 in case of SJ). Similar results were obtained with the Optojump Next system indicating its high reliability of measurement. In spite of very high con-

Table 1. Reliability of counter movement jump (CMJ) and squat jump (SJ) heights estimated with the use of different methods

Device	Test	ICC(2.1)	SEM (cm)	95% CI	ICC 95% CI	CV (%)
FP_H <sub>vel</sub>	CMJ	0.88	1.11	36.84–41.20	0.782–0.946	0.17
FP_H <sub>traj</sub>	CMJ	0.86	1.17	39.14–43.72	0.758–0.939	0.16
FP_H <sub>Tflight</sub>	CMJ	0.98	0.45	40.21–41.97	0.961–0.991	0.17
Optojump	CMJ	0.98	0.48	35.11–36.97	0.958–0.991	0.20
FP_H <sub>vel</sub>	SJ	0.77	1.56	30.14–36.24	0.615–0.894	0.20
FP_H <sub>traj</sub>	SJ	0.80	1.31	32.89–38.03	0.632–0.910	0.17
FP_H <sub>Tflight</sub>	SJ	0.88	1.01	32.68–36.65	0.735–0.951	0.18
Optojump	SJ	0.89	1.00	27.90–31.82	0.744–0.955	0.21

Note: FP = force plate, ICC = intra class correlation coefficients, SEM = standard error of measurement, CV = coefficient of variance.

current validity of the measurements the actual results obtained from the devices used in the experiment differ. In the case of CMJ these differences are not statistically significant ( $F(3.64) = 1.95$   $p = 0.12$ ) (Fig. 1). However, in the case of SJ results obtained with Optojump Next and force platform are significantly different ( $F(3.67) = 2.92$ ,  $p = 0.04$ ) (Fig. 2). The Optojump Next system has a tendency to give smaller values of jump height.

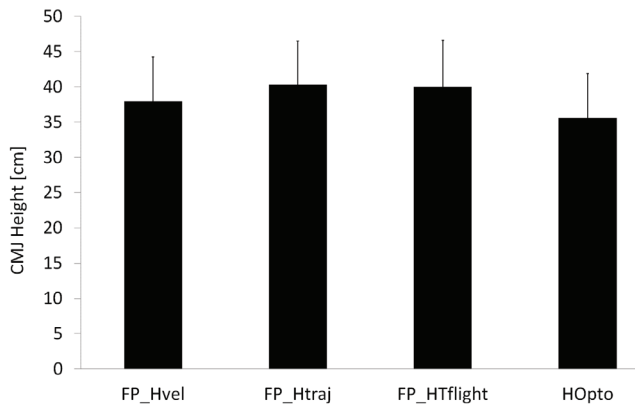


Fig. 1. Mean counter moment jump (CMJ) heights from Optojump Next and force platform calculated using of different algorithms

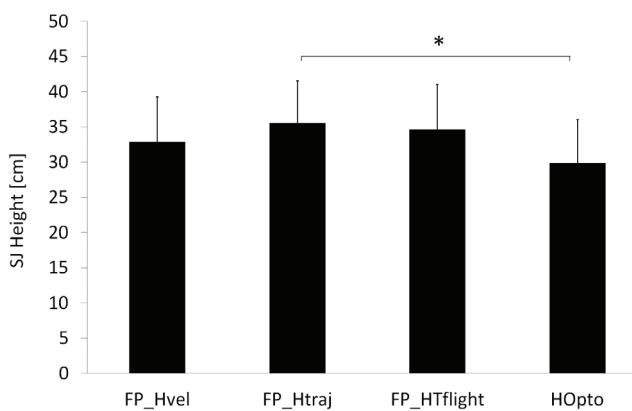


Fig. 2. Mean squat jump (SJ) heights from Optojump Next and force platform calculated using of different algorithms

### 3.2. Experiment 2

#### Reliability of BTS-Smart

The results of ICC show again very high reliability of measurements and are close to the ICC's obtained in the first experiment (Table 2).

Contrary to the Optojump Next test the ANOVA results showed statistically significant differences between the results of CMJ obtained with force platform and the motion capture system (BTS Smart) ( $F(3.60) = 6.61$   $p < 0.001$ ) (Fig. 3). The higher values of vertical jump were registered with the force platform.

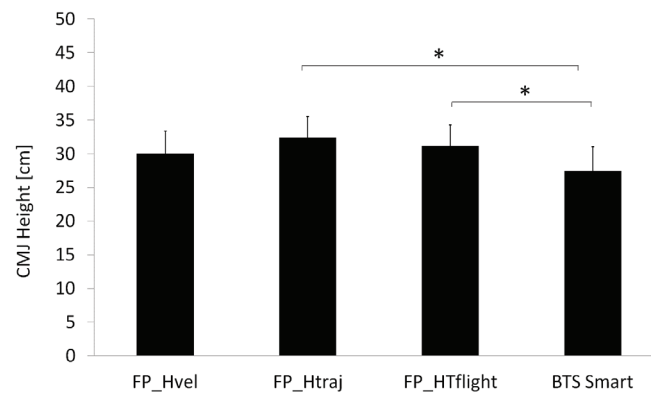


Fig. 3. Mean CMJ heights obtained with motion capture system BTS Smart and force platform calculated using of 3 different algorithms

Finally, in order to show the high concurrent validity of results obtained from the force platform and Optojump Next system as well as the motion capture system BTS Smart the Pearson's correlation analysis was conducted (Table 3). The analysis shows almost linear dependencies of these results and the strongest in case of algorithms using time of flight as the base variable in calculations.

Table 2. Reliability of counter movement jump (CMJ) height estimated with the use of force platform and motion capture systems (BTS)

Device	Test	ICC(2,1)	SEM	95% CI	ICC 95% CI	CV (%)
FP_Hvel	CMJ	0.91	0.45	29.06–30.81	0.840–0.966	0.11
FP_Htraj	CMJ	0.91	0.45	31.39–33.16	0.819–0.961	0.10
FP_HTflight	CMJ	0.92	0.44	30.20–31.94	0.825–0.963	0.10
BTS Smart	CMJ	0.90	0.50	26.43–28.40	0.808–0.963	0.13

Note: FP = force plate, BTS – motion capture system BTS Smart, ICC = intra class correlation coefficients, SEM = standard error of measurement, CV = coefficient of variance.

Table 3. Correlation coefficients between Optojump Next (OJ) and BTS Smart (BTS) vs. Force Platform (FP) counter movement jump and squat jump heights calculated using of different algorithms

	OJ_H_CMJ	OJ_H_SJ	BTS_CMJ
FP_H <sub>vel</sub>	0.92	0.95	0.96
FP_H <sub>traj</sub>	0.91	0.95	0.94
FP_H <sub>Tflight</sub>	0.99	0.99	0.97

Note: CMJ = counter movement jump, SJ = squat jump.

## 4. Discussion

Vertical jump height is a very common and straight forward measurement in sports. The main aim of the study was to verify the reliability of two measurement systems used for vertical jump performance and their concurrent validity with force platform data considered to be the golden standard. Optojump Next is a relatively inexpensive solution for evaluation of jumping performance while BTS-Smart might be considered an expensive one. Each of the examined methods presented excellent reliability. They also presented very high concurrent validity with the force platform data. Depending on device choice practitioners or researchers will face different challenges. Methods like force platforms or motion capture systems are usually costly and training is demanded to use them. Another thing in the case of motion capture systems is time consuming procedures of preparing the subject for the measurement. For these reasons they are not available for sports professionals in the regular training sessions. This is possible with the use of Optojump Next system, which is very intuitive and does not need special installment for its use. It is also portable, thus available to use in almost every training setting.

The results of this study are in accordance with previous studies examining the reliability and validity of Optojump Next [8, 11]. In our study the highest ICCs were obtained with the time of flight algorithms. The highest concurrent validity of the results was also obtained with the use of the algorithms using time of flight to estimate the height of the jump. Therefore, it was important to point out that researchers should be aware of differences coming from the use of different calculation algorithms or devices. These differences are not statistically significant within the force platform. However, we have observed statistically significant differences between the force platform data and Optojump Next as well as BTS-Smart were observed. This leads to another important observation, that with

Optojump Next system or BTS-Smart system the results of vertical jump have tended to be smaller. This can be explained by the way the subjects' performance is registered and the construction of these devices. With the Optojump Next system it is possible to achieve better results simply by bending legs before landing. Such behavior will extend the time spent in the air after takeoff and alter the real results. This is also possible in force platforms when using time of flight algorithms. This is very important for the researcher conducting research or screening athletes to be aware of these possible alterations to the final result and to carefully control the execution of the task. This can be easily avoided using different calculation algorithms with a force platform (e.g., algorithms using the initial velocity of the subject). It is also harder to track the motion capture system and when the placement of the markers is appropriate (according to acknowledged standards) it usually solves the problem [18].

Smaller indices of vertical jump height in squat jumps (SJ) were also observed in this study compared to counter movement jumps (CMJ). The force at the start of the upward phase of the jump in the SJ is smaller than in CMJ and equal to the jumper's body weight. This courses only low level of muscle activation and produces just enough force to keep the squatting position. The jumper has to significantly increase the activation of the leg muscles in order to achieve desirable force for takeoff. In contrast, the ground reaction force at the start of the upward phase of CMJ is much greater than body weight. The levels of activation and force in the jumper's leg muscles are high because the jumper has to slow down and then reverse the initial downward motion. The jumper thus performs more work at the start of the upward phase of the jump than in the SJ. That results in a higher take-off velocity and a greater flight height of the jumper [16]. It was noticed that trials with SJ produced lower indices of ICC, therefore, have lower reliability in comparison to CMJ (*Optojump Next test*). The movement structure of SJ is not very natural for human and might produce some difficulties in proper execution, thus generating more variability. Also, in the case of SJ, Optojump Next shows superiority to force platform data giving more reliable results. These differences are very small but noticeable and prove that the Optojump Next system is a very good alternative to force plate or motion capture measurements. Comparison of the Optojump Next's and BTS-Smart's price vs. value can get two completely different devices in very different price range, which can be used for the same purpose. Both reliability and concurrent

validity of these methods are excellent but BTS-Smart stands as a research-grade device with much more flexibility of its use in a laboratory setting. Although Optojump Next offers motion analysis it is limited to stills and has large probability for error. The strongest point for its use is, apart from high reliability, its portability and diversity of possible measurements and applications (not examined in this study) in the field. Another plus is quick access and the intuitive software presenting the registered data. This device is most suitable for sports measurement and monitoring, however, in our opinion it can be successfully used in research success.

Final observation was made that the high level sportsmen are more consistent in their performance which gives better reliability. While this was not the focus of this study, higher indices of ICCs in the second experiment with trained sportsmen were noticed. This is significant considering the fact that the measurement of jump height is important not only for training and testing but also in research, and that the maximum vertical jumps are the most often used “model” for studying fundamental processes and phenomena related to human movements.

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