

## THE CONCURRENT VALIDITY OF MOTION X-RAY TECHNOLOGY UTILISING POLAR VERITY SENSE TO MEASURE VELOCITY, FORCE AND POWER – PILOT STUDY

Jelena Aleksić<sup>1</sup>, Sofia Gkatzaveli<sup>1</sup>, Lazar Tasić<sup>2</sup>, Miloš Obrenović<sup>3</sup>,  
Nenad Stojanović<sup>2</sup>, Ivan Ćuk<sup>1\*</sup>

<sup>1</sup>University of Belgrade, Faculty of Sport and Physical Education,  
Belgrade, Serbia

<sup>2</sup>Nissatech Inovation Centre, Niš, Serbia

<sup>3</sup>Nissatech Inovation Centre, Niš, Serbia; Univesity Union - Nikola Tesla,  
Faculty of Sport, Belgrade, Serbia

### Abstract

The assessment of force, velocity, and power is useful in order to develop an athlete's sports performance and avoid any possible injuries. The aim of this study is to assess concurrent validity by using Polar Verity Sense with Motion X-Ray technology in order to measure velocity, force, and power in bench press exercises and compare them with the golden standard (i.e., Qualisys 3D kinematics). This pilot study focused on three male recreational lifters aged 28, with between five and ten years of experience, and a 1RM bench press of 100kg. The procedure lasted for two days. On the first day, 1 RM was assessed on a Smith machine. After seven days, the participants performed two sets of seven bench press repetitions with a 50kg bar on the same machine. The first set was a trial, and the second was analysed. The collected data was analysed using the Polar Verity sensor with Motion X-Ray technology, and 3D kinematic analysis with Qualysis. There were no significant statistical differences between these two systems ( $p < 0.05$ ), while Pearson correlation showed a high and significant correlation between them ( $r > 0.692$ ;  $p < 0.999$ ;  $p < 0.05$ ). This research sets the basis of a new measurement process, which will be easier and more affordable. Future research could focus on bigger research samples, different types of exercise, and faster movements.

**Key words:** wearables, evaluation, bench press, kinetics, kinematics.

---

\* Corresponding author: Ivan Ćuk, University of Belgrade, Faculty of Sport and Physical Education, 156 Blagoja Parovića Street, 11000 Belgrade, Serbia, [ivan\\_cuk84@yahoo.com](mailto:ivan_cuk84@yahoo.com)

## КОНКУРЕНТНА ВАЛИДНОСТ *MOTION X-RAY* ТЕХНОЛОГИЈЕ КОЈА КОРИСТИ *POLAR VERITY* *SENSE* ЗА ПРОЦЕНУ БРЗИНЕ, СИЛЕ И СНАГЕ – ПИЛОТ СТУДИЈА

### Апстракт

Процена силе, брзине и снаге је корисна како би се развиле различите способности спортисте и избегле потенцијалне повреде. Циљ ове студије је да процени конкурентну валидност коришћењем *Polar Verity Sense* сензора са *Motion X-Ray* технологијом како би се брзина, сила и снага у вежби равнотисака са груди процениле и упоредиле са златним стандардом (*Qualisys 3D* система). Ова пилот студија обављена је на узорку три мушка рекреативна вежбача старости 28 година, са између пет и десет година искуства и максималним потиском на клупи (1РМ) од 100 кг. Поступак тестирања је трајао два дана. Првог дана, 1РМ је процењен на Смит машини. После седам дана, учесници су извели две серије од седам понављања равнотисака са груди са 50 кг на истој машини. Прва серија је била пробна, док је друга коришћена за даље анализе. За анализе су коришћени *Polar Verity Sense* сензори са *Motion X-Ray* технологијом и 3Д кинематичка анализа са *Qualisys* системом. Резултати су показали да није било значајних статистичких разлика између ова два система ( $p < 0,05$ ), док је Пирсонова корелација показала високу и значајну корелацију између њих ( $p > 0,692 < 0,999$ ;  $p < 0,05$ ). Ово истраживање поставља основу за нови процес мерења, који ће бити јефтинији и лакши. Будућа истраживања би могла да користе веће узорке испитаника, различите врсте вежби, као и брже покрете.

**Кључне речи:** преносиви уређаји, евалуација, равни потисак са груди, кинетика, кинематика.

### INTRODUCTION

The ability to generate optimal levels of velocity, force and power is essential for sports performance. It is well-known that improvements in these mechanical components play a significant role in achieving success across a wide range of sports (Baiget, Colomar, & Corbi, 2021; Cormie, McGuigan, & Newton, 2011; Nikolaidis, Fragkiadiakis, Papadopoulos, & Karydis, 2011).

Velocity (V) is defined as the rate of change in the position of an object or a person over time (Schmidt & Lee, 2019). This component is an important determinant of an athlete's ability to move quickly and efficiently. It is often considered a critical component in explosive sports, such as sprinting and jumping (Morin & Samozino, 2016). Similarly, in sports like tennis or baseball, this component indirectly impacts performance by contributing to greater racket or bat speeds through generated kinetic chain velocity (Elliott, 2006).

Another important mechanical component that is closely related to velocity is force (F). As defined by Newton's Second Law, force is the product of mass and acceleration (Newton, 1999). As this component en-

ables an individual to overcome external resistance, generate movement, and change directions, it is crucial in many sports, for example in weightlifting (Stone et al., 2005), wrestling (Chaabene et al., 2017; Chaabene et al., 2019), rugby (Cronin & Hansen, 2005;), ice hockey (Hoff, Kemi & Helgerud, 2005), and rowing (Černe et al., 2013).

Skeletal muscle power (P) is the result of force and velocity (Reid & Fielding, 2011), and it plays a remarkable role in sport activities that require a great amount of force generated in a short amount of time. This component has often been considered a good predictor of success in jumping disciplines (Cronin & Sleivert, 2005), kickboxing (Nikolaidis, Fragkiadiakis, Papadopoulos, & Karydis, 2011), tennis (Baiget, Colomar, & Corbi, 2021), and many team sports, such as soccer and volleyball (Bangsbo, 1994; Giatsis, 2001; Künstlinger et al., 1987).

As these mechanical components are closely interconnected, an individualised approach to programming is necessary to achieve optimal levels specific to the athlete's capabilities and the requirements of their sport. With that in mind, accurate measurements of velocity, force and power are essential for the effective programming, tracking and optimisation of sports performance. When measuring these components, it is important to ensure their precision in order to avoid inefficient training loads and potential injuries (Suchomel et al., 2017; Weakley et al., 2021). There are various instruments that can be used to accurately measure these parameters during exercise. For example, force platforms are considered the gold standard in directly measuring ground reaction force (GRF), which is generated during a specific movement, and indirectly quantifying power and velocity output. However, these platforms have a limited measurement area, and are typically used to measure forces in the vertical direction (Hansen et al., 2011; Whittle, 2007). With that in mind, they are usually paired with other instruments such as 3D motion-capture cameras, linear position transducers, and linear encoders to obtain a more comprehensive understanding of kinetic and kinematic parameters (Hansen et al., 2011; Spudić et al., 2021; van den Tillaar & Ettema, 2013). While these instruments provide valid and reliable data, they are usually expensive, complex and primarily used in laboratory settings. As a result, their practical applications are very limited (Crewther et al., 2011; Cronin et al., 2004).

With advancements in technology, portable and wearable velocity-based devices have emerged as a more accessible alternative for everyday use (Fritschi, 2021). These devices are usually connected to mobile apps and implement different technologies, including linear position transducers (ex. GymAware PowerTool and Tendo Unit), linear encoders (ex. VITRUVÉ), and movement or inertial sensors (ex. PUSH Band and Beast Sensor) to track various parameters during exercise. Although most of these devices show good reliability and validity in tracking velocity, force, or power, the issue of cost-effectiveness still remains in question

(Chéry & Ruf, 2019; Garnacho-Castaño et al., 2015; Kilgallon et al., 2022; Lake et al., 2018; van den Tillaar & Ball, 2019).

Polar Verity Sense (Polar Electro Ltd., Kempele, Finland) was recently introduced as a significantly less expensive option for both recreational and professional use. Furthermore, Polar sensors are open to connecting to other devices (e.g., smart watches, smartphone apps), or to being analysed by other systems (e.g., Motion X-Rays, Movella), making them rather a useful tool (Merrigan et al., 2022). This lightweight, wearable device includes an optical heart rate sensor to monitor physiological parameters during exercise, as well as an accelerometer, gyroscope and magnetometer to track movement and quantify velocity, force, and power. Many researchers have already reported on the good reliability and validity of previous models of Polar sensors in measuring physiological and biomechanical parameters, such as heart rate and energy expenditure (Hinde et al., 2021; Speer et al., 2020; Gilgen-Ammann, 2019; Düking et al., 2018; Olstad et al., 2020), total distance covered during various running speeds (Akyildiz et al., 2022), step-count (Wahl et al., 2017) and velocity and power during running (Cerezuela Espejo et al., 2020; Huggins et al., 2020). Despite the increasing amount of scientific evidence demonstrating the versatility of Polar wearable sensors, there is still a lack of research specifically evaluating Polar Verity Sense. Previous studies have reported on the good validity of this model in measuring average and continuous heart rate (Fullmer et al., 2021; Gil et al., 2021; Merrigan et al., 2022); however, there is a lack of studies concerning the reliability and validity of this model in measuring velocity, force and power.

With that in mind, the aim of this study is to assess the concurrent validity of the Motion X-Ray technology that uses Polar Verity Sense to measure velocity, force and power in a commonly used gym exercise (i.e., bench press). We hypothesise that Polar Verity Sense data analysed with Motion X-Ray technology will be valid in comparison with the golden standard (i.e., Qualisys 3D kinematics) in measuring velocity, force, and power in the bench press exercise.

## *METHODS*

### *Subjects*

This pilot study included three participants (mean age 28, mean body height 178.4 cm, mean body mass 80.45 kg), all of whom are recreational lifters, with experience ranging between 5 and 10 years and 1RM bench press of 100kg. The participants are healthy adults, and they reported no chronic diseases, heart problems, or any musculoskeletal injuries in the six months preceding the study. They signed a written consent form to participate in this pilot study. Both the consent and the experi-

mental procedure are in accordance with the Declaration of Helsinki, and they were approved by the Institutional Review Board of the Faculty of Sport and Physical Education of the University of Belgrade (848/23-2).

### *Experimental Protocol*

The experiments were conducted within two days. On the first day, participants were familiarised with the experimental protocol, and they signed a written consent form. Furthermore, we measured their body height and body mass, followed by a 1RM bench press test. On the second day, which occurred seven days after the first, participants performed the main tests, which included bench press reps with a 50kg bar that represents 50% of their 1RM. Prior to all testing procedures including lifting, a standard warm-up protocol was conducted (5 minutes of cycling and 5 minutes of upper-body calisthenic and dynamic stretching; Leontijevic et al., 2012; Sreckovic et al., 2015). The participants performed two sets of 7 repetitions at 50% of their 1RM. The first set served as a trial, while the second one was used for further analyses.

### *Experimental Procedures*

Body mass and height were assessed by a digital scale and a standard anthropometer, respectively.

A Smith machine was used to test the 1RM, according to the standard procedure. Following three sets of warming up with progressively increased loads, the participants attempted a 1RM load lift. Two to three trials were performed until the participant was unable to reach the full extension of the arms with the highest possible load. The previous trial was taken as 1RM. The period of rest between the trials was 4 minutes long. The bar was positioned 1 cm above the participant's chest and supported by the bottom stops of the measurement device. The participant was instructed to perform the bench press while maintaining the position of their shoulders at 90° of abduction to ensure consistency of the shoulder and elbow joints throughout the tested movement (Newton et al., 1997). No bouncing or arching of the back was allowed. The feet had to remain in contact with the floor while the pelvis remained in contact with the bench.

Bench press lifts were performed on a Smith machine according to the same procedure. Participants performed two sets of seven repetitions at 50 to 60% of 1RM at their own pace, while the second set was used for further analyses. During the entire testing procedure, the Polar Verity Sense was positioned around the right-hand wrist. One of the reflective markers was positioned on the same wrist, glued to the strap of the Polar Verity Sense, while the other was positioned at the far end of the lifting bar.

### *Data Analysis*

A Polar Verity Sense sensor was utilised by Motion X-Ray<sup>1</sup> to track body motion. Motion X-Ray is a physical movement analysis technology that uses acceleration and gyroscope data for recognising athletes' complex motion patterns, calculating their biomechanical parameters (like velocity, force, etc.), and discovering (even small) instabilities and variations to be improved for achieving peak performances. The Polar Verity Sense is equipped with an accelerometer, gyroscope, and magnetometer for measuring acceleration, angular velocity, and the magnetic field (of Earth) with a sample rate of 50Hz. An android device is used to record data from the sensor and send it to the Motion X-Ray service. Motion X-Ray could estimate kinematic parameters (velocity, position, and time) and kinetic parameters (force, energy, power, etc.). To estimate kinetic parameters, Motion X-Ray required the height and weight of the participant, the mass of the weights, and the name of the exercise that the participant was performing during the test. The analysis includes body mass, and the mass of each body part is calculated by the Dempster model (Dempster, 1955).

The data obtained from the cameras used for 3D kinematic analysis was sampled at a rate of 300 Hz and low-pass filtered using the recursive Butterworth filter with a cut-off frequency of 10 Hz. A custom-made software (National Instruments LabVIEW 2013, Austin, TX, USA) was developed to calculate the 3D movement trajectory of the reflective markers over a period of time (i.e., velocity), as well as velocity over time (i.e., acceleration). Additionally, the same custom-made software was utilised to calculate force as a product of mass (lifted weights + mass of participants' arms, calculated from the Dempster model; Dempster, 1955) and acceleration. Finally, power was calculated as a product of force and velocity.

From both Polar Verity Sense and the Qualysis system (2 reflective markers), several variables were obtained for each of the seven repetitions and for both concentric and eccentric contractions: (1) V\_avg (m/s) – Average velocity of each contraction expressed in meters per second; (2) V\_max (m/s) – Maximal velocity of each contraction expressed in meters per second; (3) F\_avg (N) – Average force of each contraction expressed in Newtons; (4) F\_max (N) – Maximal force of each contraction expressed in Newtons; (5) P\_avg (W) – Average velocity of each contraction expressed in Watts; and (6) P\_max (W) – Maximal velocity for each contraction expressed in Watts.

---

<sup>1</sup> <https://www.motionxrays.com/>

### Statistical Analysis

Descriptive statistics were calculated as the mean and standard deviation before all statistical tests. Data distribution normality was confirmed by the Kolmogorov-Smirnov test, and visual inspection of histograms and QQ plots.

The Pearson correlation coefficient was performed to assess the concurrent validity of the Polar Verity Sense data analysed with Motion X-Rays in regard to the Qualysis 3D kinematics (i.e., the 'golden standard'). Correlation coefficients were interpreted as: small,  $r = 0.10-0.29$ ; moderate,  $r = 0.30-0.49$ ; and large,  $r = 0.50-1.0$  (Cohen, 1988). Furthermore, for the same purpose, Bland-Altman analysis was conducted to assess the agreement between measurements and detect any potential bias, along with one-way ANOVAs to examine differences among biomechanical variables obtained using Polar Verity Sense via Motion X-Rays, and those acquired from the two reflective markers measured with Qualysis 3D kinematics.

The significance level was set to  $p < 0.05$ . The statistical analyses were conducted using Microsoft Office Excel 2017 (Microsoft Corporation, Redmond, WA, USA) and SPSS 26 (IBM, Armonk, NY, USA).

### RESULTS

Descriptive statistics for velocity, force and power variables are shown in Table 1.

*Table 1. Descriptive statistics for velocity, force and power variables obtained during bench press with 50kg*

Variable	Equipment	Mean	Std. Dev.	N
V_avg (m/s)	Qualysis (wrist)	0.510	0.092	42
	Qualysis (bar)	0.518	0.089	42
	Polar (wrist)	0.453	0.094	42
V_max (m/s)	Qualysis (wrist)	0.763	0.152	42
	Qualysis (bar)	0.779	0.145	42
	Polar (wrist)	0.711	0.168	42
F_avg (N)	Qualysis (wrist)	455.36	203.73	42
	Qualysis (bar)	455.42	203.67	42
	Polar (wrist)	452.05	206.17	42
F_max (N)	Qualysis (wrist)	681.10	277.92	42
	Qualysis (bar)	688.83	290.97	42
	Polar (wrist)	592.71	249.91	42
P_avg (W)	Qualysis (wrist)	218.83	78.84	42
	Qualysis (bar)	221.76	78.52	42
	Polar (wrist)	195.52	78.20	42
P_max (W)	Qualysis (wrist)	349.58	118.51	42
	Qualysis (bar)	357.13	116.76	42
	Polar (wrist)	301.69	114.90	42

Correlation matrices presenting relationships between kinematic and kinetic data obtained from the Qualisys 3D kinematic system and the Motion X-Ray system utilising Polar Verity Sense are presented in Tables 2 through 4.

*Table 2. Correlation matrix of the averaged and maximal velocity obtained from the Qualisys 3D kinematic system and Motion X-Ray system utilising Polar Verity Sense*

Velocity (m/s)	Qualisys (w) - avg	Qualisys (b) - avg	Polar (w) - avg	Qualisys (w) - max	Qualisys (b) - max	Polar (w) - max
Qualisys (w) - avg	1.000	0.929**	0.692**			
Qualisys (b) - avg	0.929**	1.000	0.727**			
Polar (w) - avg	0.692**	0.727**	1.000			
Qualisys (w) - max				1.000	0.943**	0.783**
Qualisys (b) - max				0.943**	1.000	0.795**
Polar (w) - max				0.783**	0.795**	1.000

Avg – averaged; Max – maximal; w – wrist; b – bar; \*\* p < 0.05.

*Table 3. Correlation matrix of the averaged and maximal force obtained from the Qualisys 3D kinematic system and Motion X-Ray system utilising Polar Verity Sense*

Force (N)	Qualisys (w) - avg	Qualisys (b) - avg	Polar (w) - avg	Qualisys (w) - max	Qualisys (b) - max	Polar (w) - max
Qualisys (w) - avg	1.000	0.999**	0.994**			
Qualisys (b) - avg	0.999**	1.000	0.993**			
Polar (w) - avg	0.994**	0.993**	1.000			
Qualisys (w) - max				1.000	0.972**	0.924**
Qualisys (b) - max				0.972**	1.000	0.935**
Polar (w) - max				0.924**	0.935**	1.000

Avg – averaged; Max – maximal; w – wrist; b – bar; \*\* p < 0.05.

In all cases, large positive correlations were observed for both instruments (i.e., Polar Verity Sense and Qualisys 3D kinematics) and both marker positions. Furthermore, Figure 1 showed the Bland-Altman plots of the averaged and maximal velocity, force and power, obtained from the Qualisys 3D kinematic system and the Motion X-Ray system utilising Polar Verity Sense. The Bland-Altman analysis showed that results consistently fall within the upper and lower limits of agreement, with 95% confidence limits.



Table 4. Correlation matrix of the averaged and maximal power obtained from the Qualisys 3D kinematic system and Motion X-Ray system utilizing Polar Verity Sense-

Power (W)	Qualisys (w) - avg	Qualisys (b) - avg	Polar (w) - avg	Qualisys (w) - max	Qualisys (b) - max	Polar (w) - max
Qualisys (w) - avg	1.000	0.977**	0.863**			
Qualisys (b) - avg	0.977**	1.000	0.879**			
Polar (w) - avg	0.863**	0.879**	1.000			
Qualisys (w) - max				1.000	0.945**	0.810**
Qualisys (b) - max				0.945**	1.000	0.815**
Polar (w) - max				0.810**	0.815**	1.000

Avg – averaged; Max – maximal; w – wrist; b – bar; \*\* p < 0.05.

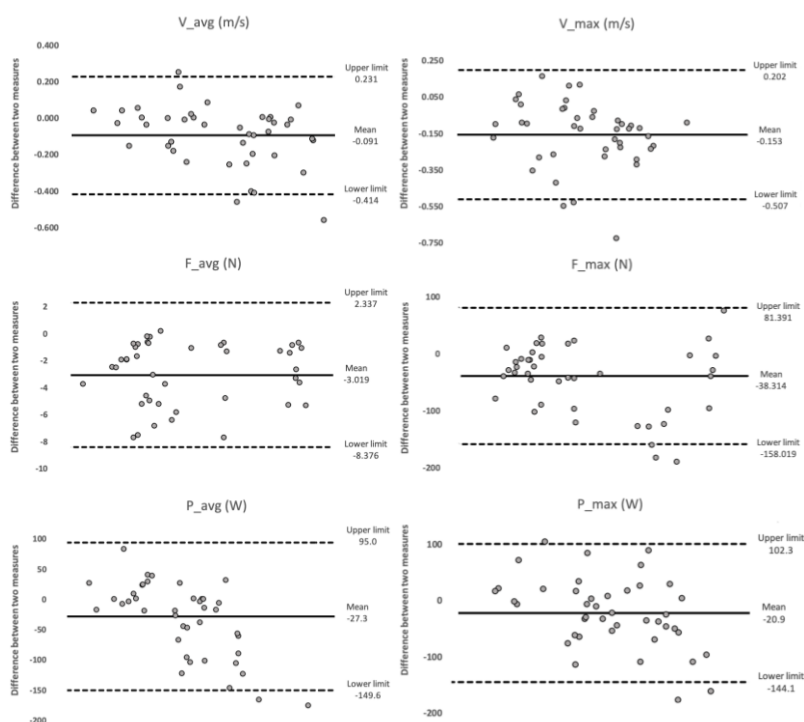


Figure 1. Bland-Altman plots for the averaged and maximal velocity, force and power obtained from the Qualisys 3D kinematic system and Motion X-Ray system utilizing Polar Verity Sense.

Finally, One Way ANOVA showed no statistical significance between the biomechanical variables obtained with Motion X-Rays using Polar

Verity Sense and the two reflective markers measured with Qualisys 3D kinematics ( $F_{(2,123)} > 0.242 < 2.113$ ;  $p > 0.05$ , ranging from 0.125 to 0.785).

### DISCUSSION AND CONCLUSION

This study aimed to assess the concurrent validity of the Motion X-Ray technology that uses Polar Verity Sense when measuring velocity, force and power in a commonly used gym exercise (i.e., bench press). We confirmed our hypothesis that Polar Verity Sense data analysed with Motion X-Ray technology will be valid compared with the golden standard (i.e., Qualisys 3D kinematics) in measuring velocity, force and power in the bench press exercise. Specifically, large and significant correlations between Qualisys 3D kinematics and Polar Verity Sense variables were observed, while no significant differences between them were shown.

The descriptive statistics values (Table 1) for mean and peak velocity (i.e.,  $V_{avg}$ ,  $V_{max}$ ), force ( $F_{avg}$ ,  $F_{max}$ ) and power ( $P_{avg}$ ,  $P_{max}$ ) are consistent with the results from previous studies done on the bench press exercise with individuals of a similar level of physical fitness, i.e. recreational weight-lifters (Król & Gołaś, 2017; Lake et al., 2019; Perez-Castilla et al., 2019). Both instruments (i.e., Polar Verity Sense and Qualisys 3D kinematics) corresponded well in measuring velocity, force, and power across all variables; only minimal differences were observed in mean and standard deviation (SD) values, which indicates a good accuracy of Polar Verity Sense in measuring these parameters.

Given the large positive correlations and no significant differences between measurements obtained from both instruments (i.e., Polar Verity Sense and Qualisys 3D kinematics), we can assume that Polar Verity Sense data analysed with Motion X-Ray can be used as a valid tool for measuring velocity, force and power during the bench press exercise. Additionally, the results of the Bland-Altman analysis further confirmed a strong agreement and no observable bias between the measurements obtained from both instruments (i.e., Polar Verity Sense and Qualisys 3D kinematics). All measurements, including averaged and maximal velocity, force, and power, consistently fall within the upper and lower limits of agreement, with 95% confidence limits. This underscores the reliability and consistency of the data obtained from the two systems, and further supports the validity of the Motion X-Ray system utilising Polar Verity Sense compared to the golden standard (i.e., Qualisys 3D kinematics). The averaged force data particularly shows great consistency of measurements compared to the maximal values. This may be attributed to the Polar sensor's heightened sensitivity to rapid movements, occasionally resulting in greater peaks in force when the subject lifts the bar more rapidly, whereas the oscillations observed in the averaged force values are minimal. The rationale for favouring averaged force values becomes

more apparent when we consider the oscillations in muscle force that correspond to the range of motion of the joint involved in the execution of the movement. On occasion, the highest force measurement may coincide with a specific phase of the movement where muscles experience a mechanical advantage due to a more favourable lever arm. This can lead to artificially elevated peaks in force, especially in exercises which are performed at a more rapid pace. Therefore, using averaged force values, as opposed to relying solely on peak values, appears to be a more stable and reliable method for measuring force with Polar Verity Sense. This approach not only ensures greater measurement consistency but also provides a more accurate representation of the genuine effort exerted throughout the entirety of the exercise (Picerno, 2017).

Compared to previous studies which assessed the validity of other portable and wearable devices (i.e., PUSH Band, Beast Sensor), Polar Verity Sense showed similar or better validity for measuring these variables during the bench press exercise (Lake et al., 2019; Perez-Castilla et al., 2019; van den Tillaar & Ball, 2019). However, some devices, such as linear position transducers (i.e., GymAware Power Tool) did show better validity in measuring velocity (Balsalobre-Fernández et al., 2017; Dorrell et al., 2018). This can be due to the fact that linear position transducers directly measure velocity through linear position displacement (Garnacho-Castaño et al., 2015), while accelerometers integrated into Polar Verity Sense estimate velocity by integrating the acceleration signal over time, thus displaying greater susceptibility to noise and integration error (Zhu & Lamarche, 2007). Another possible explanation is related to technical limitations regarding the sampling rate, which is restricted to 50Hz. This can lead to a quantisation error, which is directly related to the sampling rate of the obtained velocity signal (Zhu & Lamarche, 2007).

The results also showed nearly identical large positive correlations between measurements obtained by Polar Verity Sense data analysed with Motion X-Ray and Qualisys reflective markers placed at both positions (i.e., wrist and bar). These results suggest that Polar Verity Sense and the reflective marker attached to its belt remain stationary on the wrist during exercise, which explains the large correlations with measurements obtained from the marker on the bar. Furthermore, this implies that future studies of this kind may only require the marker placed at the wrist to facilitate testing. The results also confirmed that the hand remains fixed during the bench press exercise, thus justifying that wearing Polar Verity Sense on the wrist will not impair the accuracy of the velocity, force and power measurements. This makes it a very convenient tool for practitioners interested in monitoring these parameters during exercise. Furthermore, this opens the possibility of using Polar Verity Sense with Motion X-Ray technology to calculate the force-velocity (F-V) relationship, which can provide valuable insights into the mechanical properties of

muscles and adaptations that occur in order to achieve optimal dynamic output (Cuk et al., 2014; Jaric & Markovic, 2009; Suzovic et al., 2013). This can facilitate the assessment of technique efficiency and areas in need of improvement, and can reduce the risk of injury and accommodate targeted F-V profile-based programming (Jiménez-Reyes et al., 2017; Edouard et al., 2021). Finally, this system can be also used for in-depth monitoring of the physical activities of the youth. This can be particularly important knowing the importance of sport and exercise in the process of youths' education (Рањеловић & Савић, 2016).

Nevertheless, it is important to acknowledge that the present study has several limitations that need to be addressed. Firstly, this was a pilot study done on a sample comprised of only three participants, which greatly limits the generalisability of the results. Secondly, this study only assessed the validity of Polar Verity Sense in measuring velocity, force, and power during a single exercise (i.e., bench press). Moreover, the exercise performed in this study (i.e. the bench press) is characterised by a moderate speed movement, so it remains unclear whether Polar Verity Sense data analysed with Motion X-Ray is valid for measuring velocity, force, and power during high-speed movements.

In conclusion, the results of this study suggest that Motion X-Ray technology when using Polar Verity Sense data is a valid system for measuring velocity, force and power during the bench press exercise. Considering its compact, portable design and its affordable price, this can potentially be used as an alternative to expensive devices that are currently available for measuring the mechanical properties of muscles (i.e., velocity, force and power). Nonetheless, as this was only a preliminary attempt to validate this device, further research is necessary to better understand its practical applicability. Future studies should focus on investigating the reliability, validity, and sensitivity of this device on a larger sample and across a more extensive scope of exercises involving various speeds. This can open the possibility of regularly using the aforementioned system to monitor the velocity, force, and power parameters during exercise, and potentially lead to improved training outcomes and less injuries in sports.

## REFERENCES

- Akyildiz, Z., Yıldız, M., & Clemente, F. M. (2020). The reliability and accuracy of Polar Team Pro GPS units. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*, 236, 83-89.
- Baiget, E., Colomar, A., & Corbi, F. (2021). Importance of strength and power qualities for endurance athletes: A review. *Journal of Human Kinetics*, 78, 5-17.
- Balsalobre-Fernández, C., Marchante, D., Baz-Valle, E., Alonso-Molero, I., Jiménez, S. L., & Muñoz-López, M. (2017). Analysis of wearable and smartphone-based

- technologies for the measurement of barbell velocity in different resistance training exercises. *Frontiers in Physiology*, 8.
- Bangsbo, J. (1994). The physiology of soccer - with special reference to intense intermittent exercise. *Acta Physiologica Scandinavica*, 151(Suppl 619), 1-155.
- Cerezuela Espejo, V., Belmonte, A., Courel Ibáñez, J., Conesa-Ros, E., Mora-Rodríguez, R., & Pallarés, J. G. (2020). Are we ready to measure running power? Repeatability and concurrent validity of five commercial technologies. *European Journal of Sport Science*, 21, 1-22.
- Chaabene, H., Negra, Y., Bouguezzi, R., Mkaouer, B., Franchini, E., Julio, U., & Hachana, Y. (2017). Physical and physiological profile of wrestler athletes: a short review. *Journal of Strength and Conditioning Research*, 31(5), 1411-1442.
- Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.
- Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power: part 2-training considerations for improving maximal power production. *Sports Medicine*, 41(2), 125-146.
- Chaabene, H., Negra, Y., Bouguezzi, R., Mkaouer, B., Franchini, E., Julio, U., & Hachana, Y. (2019). Physical and physiological attributes of wrestlers: An update. *Journal of Strength and Conditioning Research*, 33(5), 1434-1456.
- Chéry, C., & Ruf, L. (2019). Reliability of the load-velocity relationship and validity of the PUSH to measure velocity in the deadlift. *Journal of Strength and Conditioning Research*, 33(9), 2370-2380.
- Crewther, B. T., Kilduff, L. P., Cunningham, D. J., Cook, C., Owen, N., & Yang, G. Z. (2011). Validating two systems for estimating force and power. *International Journal of Sports Medicine*, 32, 254-258.
- Cronin, J., & Hansen, K. T. (2005). Strength and power predictors of sports speed. *Journal of Strength and Conditioning Research*, 19(2), 349-357.
- Cronin, J. B., Hing, R. D., & McNair, P. J. (2004). Reliability and validity of a linear position transducer for measuring jump performance. *Journal of Strength and Conditioning Research*, 18, 590-593.
- Cronin, J., & Sleivert, G. (2005). Challenges in understanding the influence of maximal power training on improving athletic performance. *Sports Medicine*, 35(3), 213-234.
- Cuk, I., Markovic, M., Nedeljkovic, A., Ugarkovic, D., Kukulj, M., & Jaric, S. (2014). Force-velocity relationship of leg extensors obtained from loaded and unloaded vertical jumps. *European Journal of Applied Physiology*, 114(8), 1703-1714.
- Dempster, W. T. (1955). Space requirements of the seated operator. *WADC Technical Report*, 55-159, Wright-Patterson Air Force Base.
- Černe, T., Kamnik, R., Vesnicer, B., Gros, J. Ž. & Munih, M. (2013). Differences between elite, junior and non-rowers in kinematic and kinetic parameters during ergometer rowing. *Human Movement Science*, 32(4), 691-707.
- Dorrell, H. F., Moore, J. M., Smith, M. F., & Gee, T. I. (2018). Validity and reliability of a linear positional transducer across commonly practised resistance training exercises. *Journal of Sports Sciences*, 36(21), 2405-2411.
- Düking, P., Fuss, F. K., Holmberg, H. C., & Sperlich, B. (2018). Recommendations for assessment of the reliability, sensitivity, and validity of data provided by wearable sensors designed for monitoring physical activity. *JMIR mHealth and uHealth*, 6(4), e102.
- Edouard, P., Lahti, J., Nagahara, R., Samozino, P., Navarro, L., Guex, K., & Mendiguchia, J. (2021). Low horizontal force production capacity during sprinting as a potential risk factor of hamstring injury in football. *International Journal of Environmental Research and Public Health*, 18(15), 7827.

- Elliott, B. (2006). Biomechanics and tennis. *British Journal of Sports Medicine*, 40(5), 392-396.
- Fullmer, W. B., Carrier, B., Malek, E., Gil, D., Cruz, K., Aguilar, C., Davis, D., Bodell, N., Montes, J., Manning, J., Debeliso, M., Navalta, J., & Lawrence, M. M. (2021). Validity of average heart rate and energy expenditure in Polar armband devices while self-paced biking. *International Journal of Exercise Science: Conference Proceedings*, 14(1), Article 26.
- Fritschi, R. (2021). Validität von sechs Messsystemen bei der Bestimmung der Langhantelgeschwindigkeit. Master's thesis, Université de Fribourg.
- Garnacho-Castaño, M. V., López-Lastra, S., & Maté-Muñoz, J. L. (2015). Reliability and validity assessment of a linear position transducer. *Journal of Sports Science & Medicine*, 14(1), 128-136.
- Giatsis, G. (2001). The importance of the force-velocity relationship in resistance training. *Strength and Conditioning Journal*, 23(5), 27-29.
- Gil, D., Carrier, B., Fullmer, W., Cruz, K., Aguilar, C. D., Davis, D. W., Malek, E. M., Bodell, N., Montes, J., Manning, J. W., Navalta, J. W., Lawrence, M. M., & DeBeliso, M. (2021). Validity of average heart rate and energy expenditure in Polar OH1 and Verity Sense while self-paced running. *International Journal of Exercise Science: Conference Proceedings*, 14(1), Article 27.
- Gilgen-Ammann, R., Schweizer, T., & Wyss, T. (2019). RR interval signal quality of a heart rate monitor and an ECG Holter at rest and during exercise. *European Journal of Applied Physiology*, 119(7), 1525-1532.
- Hansen, K. T., Cronin, J. B., & Newton, M. J. (2011). The reliability of linear position transducer and force plate measurement of explosive force-time variables during a loaded jump squat in elite athletes. *Journal of Strength and Conditioning Research*, 25(5), 1447-1456.
- Hinde, K., White, G., & Armstrong, N. (2021). Wearable devices suitable for monitoring twenty-four hour heart rate variability in military populations. *Sensors*, 21(4), 1061.
- Hoff, J., Kemi, O. J., & Helgerud, J. (2005). Strength and endurance differences between elite and junior elite ice hockey players: The importance of allometric scaling. *International Journal of Sports Medicine*, 26, 537-541.
- Huggins, R. A., Giersch, G. E. W., Belval, L. N., Benjamin, C. L., Curtis, R. M., Sekiguchi, Y., Peltonen, J., & Casa, D. J. (2020). The validity and reliability of Global Positioning System units for measuring distance and velocity during linear and team sport simulated movements. *Journal of Strength and Conditioning Research*, 34(11), 3070-3077.
- Jaric, S., & Markovic, G. (2009). Leg muscles design: the maximum dynamic output hypothesis. *Medicine & Science in Sports & Exercise*, 41(4), 780-787.
- Jiménez-Reyes, P., Samozino, P., Brughelli, M., & Morin, J.-B. (2017). The Efficacy of Personalized Training Utilizing Force-Velocity Profiling during Jumping. *Frontiers in Physiology*, 7, 677.
- Kilgallon, J., Cushion, E., Joffe, S., & Tallent, J. (2022). Reliability and validity of velocity measures and regression methods to predict maximal strength ability in the back-squat using a novel linear position transducer. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*. Advance online publication.
- Król, H., & Gołaś, A. (2017). Effect of Barbell Weight on the Structure of the Flat Bench Press. *Journal of strength and conditioning research*, 31(5), 1321-1337.
- Künstlinger, U., Kramer, W., & Schmidtbleicher, D. (1987). Changes in muscle contractile properties and neural control during human muscular fatigue. *Electroencephalography and Clinical Neurophysiology*, 67(1), 9-21.
- Lake, J., Augustus, S., Austin, K., Comfort, P., McMahon, J., Mundy, P., & Haff, G. G. (2019). The reliability and validity of the bar-mounted PUSH BandTM 2.0

- during bench press with moderate and heavy loads. *Journal of Sports Sciences*, 37(23), 2685-2690.
- Lake, J., Augustus, S., Austin, K., Mundy, P., McMahon, J., Comfort, P., & Haff, G. (2018). The validity of the Push Band 2.0 during vertical jump performance. *Sports*, 6(4), 140.
- Leontijevic, B., Pazin, N., Kukulj, M., Ugarkovic, D., & Jaric, S. (2012). Selective effects of weight and inertia on maximum lifting. *European Journal of Applied Physiology*, 112(5), 1735-1743.
- Merrigan, J., Stovall, J., Stone, J., Stephenson, M., Finomore, V., & Hagen, J. (2022). Validation of Garmin and Polar devices for continuous heart rate monitoring during common training movements in tactical populations. *Measurement in Physical Education and Exercise Science*. Advance online publication.
- Morin, J. B., & Samozino, P. (2016). Interpreting power-force-velocity profiles for individualized and specific training. *International Journal of Sports Physiology and Performance*, 11(2), 267-272.
- Motion X-Rays. (n.d.). Retrieved March 2, 2023, from <https://www.motionxrays.com/>
- Newton, I. (1999). *The Principia*. Translated by I. Bernard Cohen and Anne Whitman. University of California Press, Berkeley.
- Newton, R. U., Murphy, A. J., Humphries, B. J., Wilson, G. J., Kraemer, W. J., & Häkkinen, K. (1997). Influence of load and stretch shortening cycle on the kinematics, kinetics and muscle activation that occurs during explosive upper-body movements. *European Journal of Applied Physiology and Occupational Physiology*, 75, 333-342.
- Nikolaidis, P. T., Fragkiadiakis, E. G., Papadopoulos, E. P., & Karydis, N. V. (2011). Effects of age on vertical jump parameters and anthropometric characteristics in basketball players. *Journal of Strength and Conditioning Research*, 25(10), 2909-2916.
- Olstad, B. H., & Zimmer, C. (2020). Validation of the Polar OH1 and M600 optical heart rate sensors during front crawl swim training. *PLoS ONE*, 15(4), e0231522.
- Perez-Castilla, A., Piepoli, A., Delgado-Garcia, G., Garrido-Blanca, G., & Garcia-Ramos, A. (2019). Reliability and concurrent validity of seven commercially available devices for the assessment of movement velocity at different intensities during the bench press. *Journal of Strength and Conditioning Research*, 33(5), 1258-1265.
- Picerno, P. (2017). Good Practice Rules for the Assessment of the Force-Velocity Relationship in Isoinertial Resistance Exercises. *Asian Journal of Sports Medicine*, 8(3), e15590. <https://doi.org/10.5812/asjasm.15590>
- Polar Verity Sense. (n.d.). Retrieved February 20, 2023, from <https://www.polar.com/us-en/products/accessories/verity-sense>
- Рањеловић, Н., & Савић, З. (2016). Улога и значај школског спорта у процесу васпитања младих. ТЕМЕ: Casopis za Društvene Nauke, 40(4).
- Reid, K. F., & Fielding, R. A. (2011). Skeletal muscle power: a critical determinant of physical functioning in older adults. *Exercise and Sport Sciences Reviews*, 39(1), 12-17.
- Schmidt, R. A., & Lee, T. D. (2019). *Motor control and learning: A behavioral emphasis* (6th ed.). Human Kinetics.
- Speer, K. E., Semple, S., Naumovski, N., & McKune, A. J. (2020). Measuring heart rate variability using commercially available devices in healthy children: A validity and reliability study. *European Journal of Investigation in Health, Psychology and Education*, 10(1), 390-404.
- Spudić, D., Cvitković, R., & Šarabon, N. (2021). Assessment and evaluation of force-velocity variables in flywheel squats: Validity and reliability of force plates, a linear encoder sensor, and a rotary encoder sensor. *Applied Sciences*, 11, 10541.

- Sreckovic, S., Cuk, I., Djuric, S., Nedeljkovic, A., Mirkov, D., & Jaric, S. (2015). Evaluation of force–velocity and power–velocity relationship of arm muscles. *European Journal of Applied Physiology*, *115*(8), 1779-1787.
- Stone, M. H., Sands, W. A., Pierce, K. C., Carlock, J., Cardinale, M., & Newton, R. U. (2005). Relationship of maximum strength to weightlifting performance. *Medicine and Science in Sports and Exercise*, *37*(6), 1037-1043.
- Suchomel, T., Comfort, P., & Lake, J. (2017). Enhancing the force-velocity profile of athletes using weightlifting derivatives. *Strength and Conditioning Journal*, *39*(1), 10-20.
- Suzovic, D., Markovic, G., Pasic, M., & Jaric, S. (2013). Optimum load in various vertical jumps support the maximum dynamic output hypothesis. *International Journal of Sports Medicine*, *34*(11), 1007–1014.
- van den Tillaar, R., & Ettema, G. (2013). A comparison of muscle activity in concentric and counter movement maximum bench press. *Journal of Human Kinetics*, *38*, 63-71.
- van den Tillaar, R., & Ball, N. (2019). Validity and reliability of kinematics measured with PUSH Band vs. linear encoder in bench press and push-ups. *Sports*, *7*(9), 207.
- Wahl, Y., Düking, P., Droszez, A., Wahl, P., & Mester, J. (2017). Criterion-validity of commercially available physical activity tracker to estimate step count, covered distance and energy expenditure during sports conditions. *Frontiers in Physiology*, *8*, 725.
- Weakley, J., Morrison, M., García-Ramos, A., Johnston, R., James, L., & Cole, M. H. (2021). The validity and reliability of commercially available resistance training monitoring devices: A systematic review. *Sports Medicine*, *51*(3), 443-502.
- Whittle, M. W. (2007). Methods of gait analysis. In M. W. Whittle (Ed.), *Gait Analysis (Fourth Edition)* (pp. 137-175). Churchill Livingstone.
- Zhu, W.-H., & Lamarche, T. (2007). Velocity estimation by using position and acceleration sensors. *IEEE Transactions on Industrial Electronics*, *54*(5), 2710–2715.

## **КОНКУРЕНТНА ВАЛИДНОСТ *MOTION X-RAY* ТЕХНОЛОГИЈЕ КОЈА КОРИСТИ *POLAR VERITY SENSE* ЗА ПРОЦЕНУ БРЗИНЕ, СИЛЕ И СНАГЕ – ПИЛОТ СТУДИЈА**

**Јелена Алексић<sup>1</sup>, Sofia Gkatzaveli<sup>1</sup>, Лазар Тасић<sup>2</sup>, Милош Обреновић<sup>3</sup>,  
Ненад Стојановић<sup>2</sup>, Иван Ћук<sup>1</sup>**

<sup>1</sup>Универзитет у Београду, Факултет спорта и физичког васпитања,  
Београд, Србија

<sup>2</sup>Nissatech Inovation Centre, Ниш, Србија

<sup>3</sup>Nissatech Inovation Centre, Ниш, Србија; Универзитет Унион – Никола Тесла,  
Факултет спорта, Београд, Србија

### **Резиме**

Циљ ове студије је да процени конкурентну валидност коришћењем *Polar Verity Sense* сензора са *Motion X-Ray* технологијом како би се брзина, сила и снага у вежби равног потиска са груди оцениле и упоредиле са златним стандардом (*Qualysis 3D*). Хипотеза истраживања је да ће подаци мерени *Polar Verity Sense* сензором и анализирани помоћу *Motion X-Ray* технологије бити валидни у поређењу са златним



стандардом (тј. *Qualysis 3D*). Ова пилот студија обухвата три мушка рекреативна вежбача старости 28 година, са између пет и десет година искуства и максималним потиском на клупи (1PM) од 100 кг. Поступак тестирања је трајао два дана. Првог дана, 1PM је процењен на Смит машини. После седам дана, учесници су извели две серије од седам понављања равнотиска са груди са 50 кг на истој машини. Прва серија је била пробна, док је друга коришћена за даље анализе. За анализе су коришћени *Polar Verity Sense сензори са Motion X-Ray* технологијом и 3Д кинематичка анализа са *Qualysis* системом. Резултати су показали да није било значајних статистичких разлика између ова два система ( $p < 0,05$ ), док је Пирсонова корелација показала високу и значајну корелацију између њих ( $p > 0,692 < 0,999$ ;  $p < 0,05$ ). Позитивни резултати поређења *Polar Verity Sense* сензора са *Motion X-Ray* технологијом са златим стандардом указују на то да је овај алат валидан за израчунавање силе, брзине и снаге током вежбања. *Polar Verity Sense* са *Motion X-Ray* технологијом је у поређењу са другим сличним инструментима показао сличне и мало боље резултате у погледу валидности прорачуна претходно наведених варијабли. Још један важан статистички резултат је позитивна корелација између резултата маркера и *Polar Verity Sense* сензора, који су постављени на зглоб шаке и на шипку. Ово се објашњава стабилношћу *Polar Verity Sense* сензора током извођења вежбе, што може дати користан увид научницима, који би могли лакше да измере ове варијабли. Што се тиче ограничења студије, ова студија је пилот студија у којој су учествовала три испитаника. Будућа истраживања би могла уврстити више испитаника и различите врсте вежби, укључујући и вежбе са брзим покретима. Упркос ограничењима, ова студија представља веома важан увид у могућности мерења релације сила-брзина које се све чешће користе у спорту, рекреацији и рехабилитацији. Како се технологија развија, алати који се користе и процеси мерења такође показују напредак. То значи да ће научници и практичари, спортисти и рекреативци у наредном периоду имати прилику да мерење својих вежби у тренажном процесу спроводе на јефтинији и лакши начин.