

1 **Original Article**

2 **Corresponding author:**

3 Nuria Garatachea, PhD.

4 GENUD (Growth, Exercise, NUtrition and Development) research Group

5 Faculty of Health and Sport Sciences

6 University of Zaragoza

7 Grupo GENUD Edificio SAI 2ª planta, Zaragoza

8 *Phone:* +34 876553755 or 976761000 (Ext. 843754)

9 *Fax:* +34 974238422 / +34 974239384

10 Email: [nugarata@unizar.es](mailto:nugarata@unizar.es)

11 Title: **Validity and reliability of an optoelectronic system to measure movement**

12 **velocity during bench press and half squat in a Smith machine**

13 Short title: **An optoelectronic system to measure movement velocity**

14

15 **Borja Muniz-Pardos<sup>1,2</sup>, Gabriel Lozano-Berges<sup>1,2,3,4,5</sup>, Jorge Marin-Puyalto<sup>1,2,3,4,5</sup>,**

16 **Alex Gonzalez-Agüero<sup>1,2,3,4,5</sup>, German Vicente-Rodriguez<sup>1,2,3,4,5</sup>, Jose A.**

17 **Casajus<sup>1,2,3,4,6</sup>, Nuria Garatachea<sup>1,2,3,4,5,7</sup>**

18 <sup>1</sup> GENUD (Growth, Exercise, NUtrition and Development) Research Group, University  
19 of Zaragoza, Zaragoza, Spain

20 <sup>2</sup> Red española de Investigación en Ejercicio Físico y Salud en Poblaciones Especiales  
21 (EXERNET)

22 <sup>3</sup> Centro de Investigación Biomédica en Red de Fisiopatología de la Obesidad y  
23 Nutrición (CIBER-Obn), Madrid, Spain

24 <sup>4</sup> Instituto Agroalimentario de Aragón -IA2- (CITA-Universidad de Zaragoza),  
25 Zaragoza, Spain

26 <sup>5</sup> Faculty of Health and Sports Science (FCSD, Ronda Misericordia 5, 22001-Huesca,  
27 Spain), Department of Physiatry and Nursing, University of Zaragoza, Spain

28 <sup>6</sup> Faculty of Health Sciences (FCS), Calle Domingo Miral, s/n, 50009, University of  
29 Zaragoza, Zaragoza, Spain

30 <sup>7</sup> Consejo Superior de Deportes (CSD), Madrid, Spain

1 **Abstract**

2 The purpose of this study was to determine the validity and reliability of a camera-based  
3 optoelectronic system to measure movement velocity during bench press (BP) and half  
4 squat (HS) at different load intensities. Twenty-two active males (age:  $28.2 \pm 3.9$  y;  
5 1RM BP:  $77.9 \pm 19.0$  kg; 1RM HS:  $116.6 \pm 22.5$  kg) participated in this study. After an  
6 initial 1RM testing session, participants performed five repetitions for each load (40, 60  
7 and 80% 1RM) and exercise (BP and HS) on a Smith machine in the second testing  
8 session. A third testing session was used for the test-retest reliability study. Time,  
9 displacement and mean propulsive velocity (MPV) were simultaneously determined by  
10 the reference method (T-Force system; T-F) and the Velowin system (VW). In BP,  
11 ordinary least products (OLP) regression analysis revealed low fixed biases for MPV at  
12 40%, time at 60% and displacement at 80% 1RM (intercept=  $0.065 \text{ m}\cdot\text{s}^{-1}$ ,  $-28.02$  ms and  
13  $0.87$  cm, respectively). In HS, low fixed biases were also detected for MPV at 40% and  
14 80% 1RM (intercept=  $-0.040$  and  $0.023 \text{ m}\cdot\text{s}^{-1}$ , respectively), time at 40% and 60% 1RM  
15 (intercept=  $-53.05$  and  $-101.85$  ms, respectively), and displacement at 60% 1RM  
16 (intercept=  $-1.95$  cm). Proportional bias was only observed for MPV at 80% BP. In HS,  
17 there was proportional bias for time and MPV at 40% 1RM, and also for time at 60%  
18 1RM. The reliability test showed low and comparable fixed and proportional biases  
19 between systems across exercises and intensities. VW confirmed to be a valid and  
20 reliable system to measure movement velocity across a wide range of intensities (40-  
21 80% 1RM) for two basic strength exercises through a robust statistical approach. VW  
22 would provide coaches and trainers with a suitable, affordable and easy-to-use  
23 equipment capable of measuring movement velocity in various exercises at different  
24 load intensities.

25 **Key words:** strength, technology, kinematics, movement velocity, testing.

26

## 1 **Introduction**

2 The load-velocity relationship assessment has emerged as a method for objectively  
3 monitoring and prescribing resistance training velocity<sup>1-4</sup>. Previous studies suggest that  
4 movement velocity can be used to accurately predict the relative load of basic resistance  
5 exercises commonly included in strength training, such as bench press (BP) or half squat  
6 (HS), among others<sup>5-7</sup>. Thus, the determination of the movement velocity would  
7 eliminate the need for a direct one-repetition maximum (1RM) testing, avoiding the  
8 intrinsic risks of a maximal strength test<sup>6,8,9</sup>. Accurate and reliable assessment of  
9 movement velocity is fundamental to sports testing, training and rehabilitation. Thus,  
10 kinematic systems are becoming increasingly popular as tools for measuring movement  
11 velocity during resistance exercise<sup>10-12</sup>.

12 The linear position transducer is one of the most common systems used for load-velocity  
13 testing<sup>6,13</sup>. This system is characterized by the use of a tethered cable (attached to an  
14 external load) designed to measure time and displacement (distinguishing both eccentric  
15 and concentric phases) and enabling the calculation of movement velocity, which is  
16 essential for strength testing and training<sup>6</sup>.

17 There are currently several commercial linear position transducers (e.g., “T-Force (T-F)”,  
18 “Tendo Weightlifting Analyzer”, “MuscleLab”, “Smart Coach” or “Chronojump”,  
19 among others) helping coaches and researchers to measure movement velocity in  
20 resistance training<sup>13-16</sup>. Nevertheless, most of them use a cable-based system which  
21 might cause some drawbacks, such as the need to attach a cable to the main body part  
22 engaged in the exercise or the great sensitivity of this cable-based system to be damaged  
23 by even small blows. Due to the high cost of traditional linear transducers that have often  
24 been used as the reference method (e.g., the T-F system with a cost of ~ \$3500), its  
25 acquisition may not be feasible for many potential users. This has led to an increasing

1 interest in the development of economical, wireless measurement tools and wearables to  
2 assess kinematic variables to solve the aforementioned difficulties <sup>17,18</sup> and facilitating its  
3 acquisition beyond a few well-funded laboratories or elite sports clubs.

4 Velowin (VW) was developed as an optoelectronic equipment that measures  
5 displacement through an infrared reflector attached to a bar (or any part of the body)  
6 captured by an infrared camera (see Fig. 1). This wireless system would allow the tested  
7 participant to perform a greater range of exercises without bumping a cable that could  
8 render the measurements useless. Any exercise employing a range of motion over the  
9 frontal plane (potentially both vertical- and horizontal-based movements) could be  
10 performed as long as the infrared reflector is positioned in the appropriate plane view for  
11 the camera. Additionally, VW software computes displacement and time to calculate  
12 several kinematic variables.

13 VW was launched in 2017 and there are currently three validation studies stating that this  
14 device is valid and reliable to assess movement velocity during free-weight HS and  
15 countermovement jump (CMJ) <sup>19-21</sup>. However, from a profound examination of these  
16 studies, the authors detect some limitations that make the present study necessary. It is  
17 crucial to consider that the VW device is a camera-based system, only able to assess  
18 movement velocity two-dimensionally. This requires the assessed exercise to be strictly  
19 executed in the frontal plane, since any movement performed in the sagittal plane would  
20 be undetected, biasing the measurement. This limitation adds an important error to the  
21 measurement due to the inter-individual variability in the exercise technique, which  
22 would be avoided by restricting the movement pattern (i.e., by using a Smith machine).  
23 In addition to this, the validation of VW using further resistance exercises (e.g., BP)  
24 would be needed to expand the practical application of this system. Finally, there is an  
25 important limitation in the statistical analyses used by two of the three existing studies

1 validating VW<sup>20,21</sup>. While the ‘gold standard’ method to assess movement velocity is the  
2 3-D capture motion system, and not T-F, Model I linear regression analysis (e.g., least  
3 squared regression) should not be used since this statistical method does not assume a  
4 potential error in the reference method (T-F in this case). Instead, Model II regression  
5 analysis [e.g., Ordinary Least Products (OLP) regression] should be used to allow for a  
6 more accurate determination of bias and therefore confirm the real validity of VW<sup>22</sup>.  
7 Hence, the main purpose of this study was to evaluate the validity and reliability of the  
8 VW system to assess time, displacement and mean propulsive velocity (MPV) in two  
9 strength training exercises, BP and HS, over a range of intensities (40, 60 and 80% 1RM)  
10 in a Smith machine. It was hypothesized that VW measurements would be valid and  
11 reliable, in comparison with T-F, irrespective of the load or the exercise performed.

12

## 13 **Material and methods**

### 14 **Experimental approach to the problem**

15 A validation and reliability study was designed to compare time, displacement and MPV  
16 as measured by T-F (used as the ‘gold standard’) and VW during BP and HS exercises  
17 executed at three different intensities (40, 60, 80% 1RM) on a Smith machine. Although  
18 it is not the gold standard method to assess movement velocity, T-F has been widely used  
19 to assess both kinematic and kinetic characteristics in resistance training<sup>6</sup> and has also  
20 been used as a reference method in several validation studies<sup>17,23,24</sup>. Different exercises  
21 and load intensities were selected to test the validity of VW at different velocities and  
22 ranges of displacement. Participants were required to attend the laboratory on three  
23 occasions, separated by at least 48 h between visits. The first session was used to assess  
24 1RM in both exercises for each participant. Validity testing was conducted with all 1232  
25 repetitions performed during second and third testing sessions, as every repetition was

1 measured simultaneously with T-F and VW. Finally, the third session was used for the  
2 reliability test by comparing the data obtained in sessions two and three.

3

#### 4 **Subjects**

5 Twenty-two healthy, active males (mean age:  $28.2 \pm 3.9$  y; height:  $177.8 \pm 7.5$  cm; body  
6 mass:  $74.7 \pm 7.9$  kg; strength training volume:  $151.9 \pm 96.7$  min/week; 1RM BP:  $77.9 \pm$   
7  $19.0$  kg; 1RM HS:  $116.6 \pm 22.5$  kg) voluntarily participated in this study. Participants met  
8 the following inclusion criteria: men from 20 to 35 years old with at least one year of  
9 experience in strength training, specially familiarized with BP and HS exercises.  
10 Participants with musculoskeletal injuries or any medical condition that could alter  
11 performance were excluded. Participants were not allowed to exercise in the 48 h  
12 preceding a test session.

13 Since meaningful changes in muscle function have been observed in females depending  
14 on the menstrual cycle phase (e.g. increase in muscle strength at mid-cycle, when  
15 compared with both follicular and luteal phases <sup>25</sup>), the authors opted not to include  
16 females in the present study.

17 Participants were informed about the protocol of the study, as well as potential risks and  
18 benefits. Prior to data collection, each participant completed and signed an informed  
19 consent form. This study was performed following the Declaration of Helsinki 1964  
20 (revision of Fortaleza 2013) and the protocol was approved by the Ethics Committee of  
21 Clinical Research from the Government of Aragon (CEICA, Spain) [C.I. PI17/0126].

22

#### 23 **Procedures**

1 Each participant completed three testing sessions separated by at least 48 h. The first  
2 session was used for personal data compilation, body composition measurements and  
3 indirect 1RM test in BP and HS, according to Brzycki equation <sup>26</sup> shown in Eq. (1):

$$4 \quad 1RM = 100 * (\text{Weight (kg)} / 102.78 - 2.78 \cdot \text{number of repetitions}). \quad (1)$$

6  
7 Since this equation is valid for estimating 1RM when the number of repetitions is lower  
8 than 10, the weights used during all indirect 1RM tests were calculated to reach less than  
9 10 repetitions. In addition, this equation has been previously shown to be highly accurate  
10 with resistance-trained middle-aged men <sup>27</sup>. Tests were performed with the assistance of  
11 two researchers to guarantee the safety of the participants.

12 During the second testing session, each participant performed five repetitions at  
13 maximum velocity for each load (40, 60 and 80% 1RM; following this incremental order)  
14 and exercise (BP and HS; in a randomized order) in a Smith machine, with a rest period  
15 between sets of at least 3 min. The re-test was performed in the third testing session,  
16 replicating the protocol from the second testing session, but swapping the exercise order.

17 Prior to each testing session, participants performed a warm-up that consisted of 5 min of  
18 low intensity cycling (Ergoline cycle ergometer, Ergoline GmbH, Bitz, Deutschland), 5  
19 min of upper- and lower-body joint mobilizations and a set of 10 repetitions with 50% of  
20 the load used in the first attempt, for both exercises. BP exercise began with both arms in  
21 full extension with the hands grasping the barbell at a width approximately 5 cm wider  
22 than shoulder width. During eccentric action, participants took down the barbell at  
23 moderate velocity until approximately 5 cm over the chest. Adjustable safety catchers  
24 were used to control this distance. From this position, concentric action was performed at  
25 maximal voluntary velocity. For HS exercise, eccentric action was performed at moderate

1 velocity from the position with hips and knees in full extension to 90° of knee flexion. A  
2 goniometer was used to accurately measure this knee angle, and the displacement of the  
3 bar was recorded for each individual to detect potentially incomplete repetitions during  
4 all HS tests. From this point, concentric action was also performed at maximal voluntary  
5 velocity. A pause of approximately 1.5 s between the concentric and eccentric phases was  
6 included in both BP and HS exercises. The distance covered during eccentric phase in HS  
7 was measured prior to the first testing session by the T-F system. This distance was the  
8 same in the three testing sessions. During all repetitions, participants were encouraged to  
9 perform the propulsive phase of the movement as rapidly as possible.

#### 11 **Measurement equipment and data acquisition**

12 A Smith machine (Impulse IT Smith Machine, Midlothian, Scotland) was used for  
13 performing all test conditions. Displacement, time and MPV were simultaneously  
14 measured with a T-F system (T-Force Dynamic Measurement System®, Ergotech,  
15 Murcia, Spain) and VW (Velowin, DeporTEC, Murcia, Spain). T-F (sample frequency of  
16 1000 Hz) consists of a linear velocity transducer extension cable; however, VW (sample  
17 frequency of 500 Hz) is an optoelectronic linear position transducer system that does not  
18 use a cable. Both methods automatically calculate the above-mentioned variables and  
19 provide instantaneous velocity and displacement feedback. Following VW manufacturer  
20 guidelines, “two reflective circles in line” calibration was applied each day prior to the  
21 start of each testing session. This calibration is the most accurate and consists of placing  
22 two reflective circles separated by 500 mm beside the barbell at the same plane of the  
23 reflective used during testing. In each calibration, inclination angle was approximately  
24 90° being the mean of mm per pixel  $1.459 \pm 0.032$  mm/px. The camera was positioned  
25 perpendicularly with respect to the plane of the marker movement, and was set high



1 enough to encompass the tallest participant performing the HS and also the lowest point  
2 of the barbell during BP.

3 The T-F system has been previously used as a reference method to validate other systems  
4 <sup>24</sup>. Therefore, it was also used for this validity study with the same purpose. Additionally,  
5 this system has been widely used among researchers and trainers to assess kinetic and  
6 kinematic variables in strength exercises <sup>13,28,29</sup>.

7

8 [INSERT FIGURE 1]

9

## 10 **Data analysis**

11 The Statistical Package for the Social Science (SPSS; version 24.0 for Mac OS X, SPSS  
12 Inc., Chicago, IL, USA) and the statistical software R (version 3.5.1) were used for all  
13 statistical analyses. The authors separated the data analysis by load intensity and exercise  
14 since analysis of variance (ANOVA) tests indicated a significant influence of exercise  
15 type, intensity and their interaction ( $\eta_p^2=0.473, 0.043$  and  $0.022$ , respectively; all  $p<0.01$ ).

16 Time, displacement and MPV for each load intensity and exercise were computed and  
17 statistically analyzed. Bland Altman plots were performed to reveal the agreement  
18 between VW and T-F in BP and HS, since this is the approach typically used to test  
19 agreement between methods and helps comparing with previous validity studies <sup>30</sup>.

20 However, because fixed and proportional bias cannot be determined through this analysis,  
21 OLP regression analysis was performed by computing the equations provided by  
22 Ludbrook in R <sup>31</sup>. Validity was determined following the presence and degree of bias  
23 between methods. The degree of fixed bias was deduced from the y-intercept 95% of the  
24 confidence intervals (CIs). If the CIs for the intercept include the value of zero, then there  
25 is no fixed bias. Proportional biases were assessed from the 95% CIs for the slope. If the

1 CIs for the slope include the value of 1.0, then there is no proportional bias. OLP  
2 regression analysis produces different errors, intercepts and slopes than least squares  
3 regression because error is assumed for both VW and T-F. In addition, test-retest  
4 reliability for MPV was also determined through OLP regression analysis following the  
5 same procedures described above.

6

## 7 **Results**

### 8 **Concurrent validity**

9 From a total of 1320 repetitions registered, 88 were excluded due to inappropriate  
10 exercise technique or error in the measurement by either T-F or VW. As seen in Fig. 2,  
11 the box plots graphically show the distribution of the values obtained for all variables,  
12 intensities and exercises for both T-F and VW (Table 1 shows the corresponding  
13 numerical values). Table 1 summarizes the differences observed between both systems.  
14 When examining the agreement between devices in measuring MPV in BP and HS, a  
15 small mean difference across the full range of intensities was observed, as depicted in  
16 Fig. 3.

17 [INSERT FIGURE 2]

18

19 [INSERT TABLE 1]

20

21 [INSERT FIGURE 3]

22

23 In BP, fixed biases were detected for MPV at 40%, time at 60% and displacement at 80%  
24 1RM (intercept=  $0.065 \text{ m}\cdot\text{s}^{-1}$ ,  $-28.02 \text{ ms}$  and  $0.87 \text{ cm}$ , respectively). In HS, fixed bias  
25 were also observed for MPV at 40% and 80% 1RM (intercept=  $-0.040$  and  $0.023 \text{ m}\cdot\text{s}^{-1}$ ,

1 respectively), time at 40% and 60% 1RM (intercept= -53.05 and -101.85 ms,  
2 respectively) and, finally, displacement at 60% 1RM (intercept= -1.95 cm). Proportional  
3 biases were identified for MPV at 80% 1RM in BP (slope= 1.03). In HS, it was observed  
4 proportional biases for time at 40% and 60% 1RM (slope= 1.05 and 1.10, respectively),  
5 and also for MPV at 40% 1RM (slope= 1.06). Fig. 4 shows the OLP regression plots for  
6 MPV during both exercises at the different intensities.

7 [INSERT FIGURE 4]

8

### 9 **Test-retest reliability**

10 The test-retest reliability results for MPV in both exercises and across all intensities are  
11 provided in Table 2. In BP, fixed biases for MPV at 60% and 80% 1RM as measured with  
12 T-F were detected (intercept= 0.082 and 0.081 m·s<sup>-1</sup>, respectively), whereas VW only  
13 showed fixed bias for MPV at 80% 1RM (intercept= 0.058). In HS, only VW presented  
14 fixed bias for MPV at 80% 1RM (intercept= -0.092). In relation to the assessment of  
15 heteroscedasticity in the reliability test (Table 2), T-F presented proportional biases for  
16 MPV at 60% and 80% 1RM in BP (slope= 0.86 and 0.81, respectively), whereas VW  
17 presented heteroscedasticity for MPV at 80% 1RM during BP and 80% 1RM during HS  
18 (slope= 0.87 and 1.21, respectively).

19

20 [INSERT TABLE 2]

21

### 22 **Discussion**

23 The main findings of the present study confirmed that VW is a valid and reliable device  
24 to measure movement velocity during HS in a Smith machine across different intensities,  
25 and also revealed that VW is also valid and reliable to be used during BP. To the best of

1 the authors' knowledge, this is the first study testing VW using OLP regression analysis  
2 over a range of intensities. Most of the previous validity studies not using the true gold  
3 standard method employed a combination of Bland-Altman and least squared linear  
4 regression analysis to determine bias and agreement between systems <sup>17,24,32</sup>. However,  
5 the use of these methods to determine the magnitude of bias, as determined by the slope  
6 of the linear correlation, assign all bias to the dependent variable (VW in this case) <sup>22</sup>.  
7 When not using the true gold standard for the comparison, the selection of OLP regression  
8 analysis seems more appropriate since it also assumes potential error in the reference  
9 method, allowing for a more accurate determination of fixed and proportional bias <sup>22,31,33</sup>.  
10  
11 Recent studies examined the validity and reliability of VW during free-weight HS over a  
12 range of intensities <sup>19,20</sup>. Similar to the present study, García-Ramos et al. <sup>20</sup> used the T-F  
13 system as the reference method, finding a low fixed bias in MPV between devices during  
14 HS (fixed bias= 0.02 by García-Ramos vs. fixed bias range= -0.04 to 0.02 in the present  
15 study). García-Ramos et al. <sup>20</sup> found a significant proportional bias in the assessment of  
16 MPV during HS, observing an underestimation of MPV with increasing MPV, as  
17 assessed by VW. In the present study, proportional bias was also observed in the  
18 assessment of MPV during HS, but only at 80% 1RM and in the opposite direction (i.e.,  
19 VW overestimated MPV with increasing MPV). Notably, García-Ramos et al. <sup>20</sup>  
20 determined bias through the Bland-Altman method, which could potentially distort the  
21 results of this validity test.

22

23 It is worth noting the presence of fixed bias in the displacement during 80% 1RM BP.  
24 Since the camera was positioned at the same distance and height for both exercises to  
25 encompass the vertical movement developed during each exercise, a slight parallax error

1 might have influenced the measurement in this case. Notably, the presence of proportional  
2 bias for MPV was only at 80% 1RM BP and 40% 1RM HS. This might be because  
3 participants performing the 80% 1RM BP were sometimes unable to fully extend the arms  
4 during all repetitions, whereas during the 40% 1RM, HS participants easily completed  
5 the whole movement, even performing a small countermovement at the end of the  
6 concentric phase. It is possible that the two different filters interpreting kinematics might  
7 have affected the precise moment of starting and finishing the concentric phase, thus  
8 increasing heteroscedasticity between systems in these cases. However, it should be  
9 considered that assessments conducted in sports science are commonly characterized by  
10 the presence of heteroscedasticity <sup>34</sup>.

11

12 In addition to this study, Laza-Cagigas et al. <sup>19</sup> recently performed a comprehensive  
13 validity study of VW using the gold standard method to assess both movement velocity  
14 and force production (3D motion capture system and force platform, respectively) during  
15 free-weight HS. Although these authors did not examine MPV, they did not find neither  
16 fixed nor proportional bias in mean velocity (intercept= -0.04 and slope=1.01). Laza-  
17 Cagigas et al. <sup>19</sup> also reported the presence of fixed bias in the measurement of  
18 displacement, but remarkably higher than the present study (fixed bias= -10.24 cm by  
19 Laza-Cagigas vs. a fixed bias at 60% 1RM HS of -1.95 cm in the present study). Although  
20 Laza-Cagigas et al. <sup>19</sup> appropriately used the gold standard method to test the validity of  
21 VW, not preventing the movement from horizontal oscillations (i.e., using free-weights)  
22 when comparing a 3D device and a 2D device (i.e., VW), could alter the accuracy in the  
23 evaluation of vertical velocity as measured by VW. This additional bias could potentially  
24 explain the greater error in the measurement of displacement observed in their study.

1 Peña García-Orea et al.<sup>21</sup> also performed a validity study of VW during a loaded CMJ in  
2 a Smith Machine over a range of intensities, revealing that VW was a valid and reliable  
3 tool to measure CMJ velocity, when compared to T-F. However, these authors reported  
4 the absolute values for mean and peak velocity from each device and the concordance  
5 correlation coefficient instead of reporting fixed or proportional bias between devices<sup>35</sup>.  
6 This makes the comparison with the current results challenging.

7 While the present study also shows the degree of bias across load intensities between VW  
8 and T-F, some of the aforementioned studies did not report the specific error across  
9 different loads<sup>19,21</sup>. The study by García-Ramos et al.<sup>20</sup> found no main effects of variable  
10 x load interaction across different intensities during free-weight HS. Thus, the  
11 comprehensive examination of the bias at different load intensities and exercises reinforce  
12 preceding studies and expand the utility of VW since most athletes develop their strength  
13 training varying load intensities depending on the periodization plan<sup>36</sup>.

14 Previous research examined the validity of similar instruments that also focus on the  
15 measurement of movement velocity. The PUSH band<sup>17</sup> found larger systematic bias in  
16 the assessment of mean velocity during HS ( $0.11 \text{ m}\cdot\text{s}^{-1}$  by PUSH vs. a range of  $-0.04$  to  
17  $0.02 \text{ m}\cdot\text{s}^{-1}$  by VW in the present study). Similarly, previous research<sup>37</sup> carried out a  
18 similar investigation studying the validity of a video analysis software (Kinovea) for  
19 quantifying movement velocity during the BP exercise at different intensities, also  
20 reporting larger systematic bias for MPV than the present study (range from  $-0.43 \text{ m}\cdot\text{s}^{-1}$   
21 to  $-0.16 \text{ m}\cdot\text{s}^{-1}$  for Kinovea vs.  $0.01 \text{ m}\cdot\text{s}^{-1}$  to  $0.07 \text{ m}\cdot\text{s}^{-1}$  for VW).

22 Regarding the test-retest reliability study, both fixed and proportional biases seemed to  
23 follow the same pattern (i.e., variables with meaningful fixed biases were accompanied  
24 by proportional biases). Although these biases were small, the necessity to perform a  
25 manual calibration procedure could also be a source of error in the measurement,

1 potentially affecting the accuracy from one day or exercise to another. The results of the  
2 present study agree with Peña García-Orea et al.<sup>21</sup> in that a simpler calibration process  
3 would facilitate the usability of VW and could also increase the accuracy between testing  
4 sessions.

5 Based on a robust statistical analysis, the results from the present study confirm that an  
6 affordable and comfortable system (VW) can be utilized to measure movement velocity  
7 during the BP and HS exercises at different intensities in a Smith machine. As far as the  
8 limitations of a 2D camera-based instrument are concerned, the accuracy of the  
9 measurements depends on whether the movement is performed on the frontal plane.  
10 Consequently, if the exercises were performed away from the vertical vector, the  
11 measurements might be distorted<sup>37</sup>. In the current study, all measurements were  
12 performed on a Smith machine to avoid these risks. Sports practitioners and specialists  
13 should consider this source of error and, as previously reported, the experience of the  
14 lifters could be determinant when the use of the Smith machine is not possible<sup>37</sup>. Another  
15 important limitation of this system is that it requires a nearby camera and laptop, which  
16 would take up floor space and might complicate simultaneous trainings. This should be  
17 considered by the coach or sports specialist to adequately organize the testing procedures  
18 in advance.

19 Importantly, certain limitations should be considered when interpreting the results of the  
20 present study. In particular, a wider variety of exercises and intensities are needed to  
21 provide further validation of the VW system. For example, the VW system has shown to  
22 be valid and reliable over vertical-based movements (squat, countermovement jump and  
23 BP), although its efficacy on horizontal-based movements (e.g., ball throwing, running  
24 or ball kicking) is still unknown. Finally, as only males were recruited for this study, the  
25 results cannot be directly applied to female athletes. This study reinforces the validity and

1 reliability of VW and expands its use to a wider range of intensities (from 40% to 80%  
2 1RM) and exercises (BP and HS) in a Smith machine.

3

#### 4 **Conclusion**

5 The VW system has proven to be a valid and reliable tool in comparison with T-F when  
6 measuring time, displacement and MPV across different exercises and load intensities.

7 Besides, it seems operational, easy-to-use and comfortable since it does not require a  
8 cable to perform strength exercises, as long as they are performed in the vertical plane.

9 Notably, the use of VW could help coaches and trainers in the assessment of the load-  
10 velocity relationship, especially in field situations thanks to the portability of this camera-  
11 based system. Nevertheless, the coach should also consider that the inherent limitation in  
12 a 2D instrument might affect the accuracy of exercises performed out of the vertical plane.

13 The economical cost of VW in comparison with the reference method (T-F) would allow  
14 a wider range of coaches or sports clubs to afford this equipment.

15

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17 The authors declare no conflict of interests with respect to the publication of the present  
18 study.

19

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22



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1 Table 1. Concurrent validity of T-Force vs. Velowin. Values of Time (ms), Displ (cm)  
2 and MPV ( $\text{m}\cdot\text{s}^{-1}$ ).  
3  
4 Table 2. Test-retest reliability of MPV ( $\text{m}\cdot\text{s}^{-1}$ ) measured by Velowin and T-Force.  
5  
6 Figure 1. Measurement scheme of the optoelectronic Velowin system.  
7  
8 Figure 2. Time, displacement, and Mean Propulsive Velocity (MPV) obtained in bench  
9 press and half squat exercises by T-Force (T-F) and Velowin (VW) systems. The boxes  
10 represent the median values with the 25<sup>th</sup> percentile and 75<sup>th</sup> percentiles, with the lower  
11 and upper error bars indicating the minimum and maximum values, respectively (black  
12 dots represent the outliers).  
13  
14 Figure 3. Comparison of Mean Propulsive Velocity (MPV) between T-Force (T-F) and  
15 Velowin (VW) in bench press and half squat. The center line determines the mean  
16 difference between systems, whereas the dashed lines represent the 95% limits of  
17 agreement (standard error  $\pm 1.96 \times$  standard deviation).  
18  
19 Figure 4. Ordinary Least Products regression plots of the relation between the Mean  
20 Propulsive Velocity (MPV) determined by T-Force (T-F) and Velowin (VW) at different  
21 intensities and exercises. Regression and confidence intervals lines are displayed.