# Velocity-Based Training: Differences in Lifting Velocities Between Barbell Velocity Measurement Devices and Center of Mass Velocity Measures with the Alphatek Force Platform System in the Back Squat

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## Abstract

***Introduction:*** Velocity-based strength training (VBST) measurement devices commonly track lifting velocity from the barbell. The Alphatek force platform system is a new device that track lifting velocity from the center of mass (COM) of the person-barbell system ($COM_{pb}$) in the back squat exercise. Therefore, this study aimed to compare the lifting velocities measurements of the $COM_{pb}$ with barbell velocities calculated by traditional VBST devices. ***Methods**:* Twelve healthy and strength-trained participants performed barbell back squats, with data collected concurrently using a linear encoder, an inertial measurement unit (IMU), and the Alphatek force platform system. Additionally, 3D motion capture was used to evaluate the lifting velocity of the $COM_{pb}$. ***Results**:* The study found differences in lifting velocity between the $COM_{pb}$ and the barbell, with increasing differences at higher lifting velocities. The Alphatek force platform system registered lower mean propulsive velocities (MPV) than the linear encoder and the IMU. 3D motion capture showed similar results. ***Discussion:*** The differences in MPV measurements could be attributed to the position of the $COM_{pb}$ relative to the barbell, which changes as a function of load and could be affected by individual anthropometry, technique, and horizontal displacement. ***Conclusion:*** The study suggests that the differences between $COM_{pb}$ and barbell velocity measurements need to be considered in VBST when using devices interchangeably, to accurately prescribe appropriate training loads. Further research is needed to determine whether barbell velocity or $COM_{pb}$ velocity is more suitable for prescribing training and loads.

**Keywords**
Velocity-based strength training, center of mass, barbell, force platform, IMU, linear encoder.

## 1. Introduction

Resistance training is widely considered a key aspect of athletic performance. Velocity-based strength training (VBST) represents a method of resistance training where lifting velocity and the load-velocity relationship is used as the primary measurement for prescribing, managing, and monitoring training load. The load-velocity relationship refers to a linear reduction in lifting velocity with increased external load (Weakly et al., 2021; Martson et al., 2022).

VBST is utilized by coaches and athletes both as a supplement to, or replacement for traditional resistance training methods, like one repetition maximum (1RM) based strength training (García-Ramos, 2023). 1RM-based strength training refers to the method of modulating external resistance as a percentage of a previously tested 1RM in the specific lift. However, often long periods of training and de-training can occur between each 1RM test, reducing its validity. Furthermore, 1RM is a dynamic variable that fluctuates with changes in physiological and psychological status, such as accumulated fatigue and life-related stressors (Suchomel et al., 2021, p. 2053). To overcome some of these challenges, VBST introduces an alternative method of modulating training load in strength training programs and for performance testing. For example, the load-velocity relationship allows for prescribing load according to lifting velocity instead of external mass (Weakly et al., 2021, p. 31). One advantage of VBST is the real-time assessment of performance through velocity tracking, allowing for individualized regulation of training variables on a day-to-day basis. Traditional strength training methods, such as 1RM-based strength training do not naturally incorporate day-to-day modulation of training variables (Guerriero et al., 2018, p. 2). However, VBST necessitates the use of specific equipment and technology to track lifting velocity, which may not be accessible to everyone.

VBST commonly uses linear encoders and inertial measurement unit (IMU) devices to track the lifting velocity in the movement of interest (Fritschi et al., 2021, p. 1). In the back squat exercise, a linear encoder is attached to the barbell through a wire, while an IMU is attached by a magnet directly to the barbell. Thus, both devices track barbell velocity, which has demonstrated acceptable validity and reliability for their intended purpose (Balsalobre-Fernández & Torres-Ronda, 2021; Clemente et al., 2021; Fritschi et al., 2021; Włodarczyk et al., 2021).

Another popular device in the athletic domain is the force platform – which measures the ground reaction forces (GRFs). The force platform has gained popularity among coaches and athletes as they are the only device that can measure the kinetic aspect of sports-related movements (Eythorsdottir, 2022, p. 11), providing a promising tool for coaches and athletes in training and testing. Previously, force platforms were confined to laboratory settings, and were costly, requiring the need for specialized software and hardware knowledge. However, due to today's technological advancement, force platform systems are currently becoming more accessible for field testing as they exist in portable and more affordable forms (Eythorsdottir 2022, p. 2). Concerning VBST, the vertical GRF (vGRF) measured by the force platform is normalized to body mass to obtain acceleration which is further integrated to obtain velocity. Thus, several force platform systems offer "squat assessment" where the velocity of the squat is calculated through the vGRF. Unlike IMUs and linear encoders, force platforms track the center of mass velocity of a person-barbell system ($COM_{pb}$). In addition to velocity, force platform systems have the added benefit of registering other variables like force and power production during various movements, which can be useful metrics in many sports settings.

The use of sports technology in testing and training requires equipment that accurately captures the intended concept (validity), and that can consistently reproduce measurements over time (reliability). In addition to validity and reliability, to facilitate broad adaptation of VBST, the technology used must be user-friendly with a "plug and play" feature, that requires minimal preparation time. Alphatek (Alphatek; Stavanger, Norway) has designed a force platform system that provides a user-friendly, "plug and play" approach for VBST, as well as providing instant feedback on lifting velocity in the back squat. Indeed, the Alphatek force platform system checks all the boxes regarding user-friendliness for coaches and athletes in training. However, the user-friendliness of the equipment does not imply that the results it provides are valid or reliable. As the Alphatek force platform system is new, the validity and reliability of their measurements have yet to be established. The Norwegian Olympic Centre conducted a pilot study on the Alphatek force platform system (unpublished). The main findings showed that the Alphatek force platform system registered systematically lower lifting velocities during the back squat exercise in comparison to common measures of barbell velocity (linear encoder and IMUs). Notably, these disparities grew as the lifting velocity increased. These findings demonstrated that the force platform measured a different lifting velocity than that of the barbell – namely the velocity of the $COM_{pb.}$ In contrast, linear encoders and IMUs determine the velocity of a single side of the barbell. From these findings, it has been questioned whether the velocity measures of the $COM_{pb}$ are better suited for VBST than barbell velocity measures. The accuracy of the Alphatek force platform system overall in VBST has also been questioned.

Therefore, this study aimed to investigate (1) the differences in lifting velocity tracked by the Alphatek force platform system and barbell velocity measurement devices during the back squat and (2) the lifting velocity of the Alphatek force platform system compared to three-dimensional (3D) motion capture measures of the $COM_{pb}$. Based on the findings of the Norwegian Olympic Center it was hypothesized that there would be a difference in lifting velocity between the barbell velocity measurement devices and the Alphatek force platform system and that the difference would be greater at higher lifting velocities.

## 2. Material & Methodology

### *2.1 Participants*

Twelve healthy strength-trained participants were recruited for this study, comprising an equal number of males and females, with an average age of 23 ± 3 years. All individuals reported prior experience performing the back squat exercise, although their familiarity with VBST was limited.

### *2.2 Experimental approach*

The primary goal was collecting a broad spectrum of velocities (in the back squat) ranging from approximately 0.2 to 1.4 $ms^{-1}$, concurrently from different measuring devices. To evaluate the measurements of the Alphatek force platform system we used a linear encoder (MuscleLab; Ergotest Innovation AS, Langesund, Norway) as a reference device. Additionally, an IMU (Vmax Pro (2019); Blaumann & Meyer - Sports Technology UG, Germany) was implemented to evaluate the velocity of the barbell.

### *2.3 Set-up and Equipment*

The equipment utilized in this study and their specifications are displayed in Table 1. The data were collected concurrently using the IMU, linear encoder, and the Alphatek force platform system. The IMU was attached by magnet to the right end of the barbell together with the linear encoder, which was attached by a wire as shown in Figure 1.

**Table 1:** Characteristics of devices utilized in this study. Measurement point indicates the specific location of the person-barbell system where the specific devices recorded the velocity.

| Device | Version | Type | Sampling frequency (Hz) | Measurement point |
|---|---|---|---|---|
| Vmaxpro | 2019 | IMU | 1000 | Barbell, end, right |
| Muscle lab | 10.222.103.5244 | Linear encoder | 200 | Barbell, end, right |
| Alphatek | 0.2.8[a] | Force platform | 434 | $COM_{fp}$[b] |
| Qualisys Track Manager | 2022.1 | 3D motion capture | 200 | $COM_{3D}$[c]<br>Barbell, end right |

[a] Represents the firmware version of the device. The other versions of the devices are software. [b] Represents the COM obtained from the Alphatek force platform system. [c] represents the COM obtained from 3D motion capture

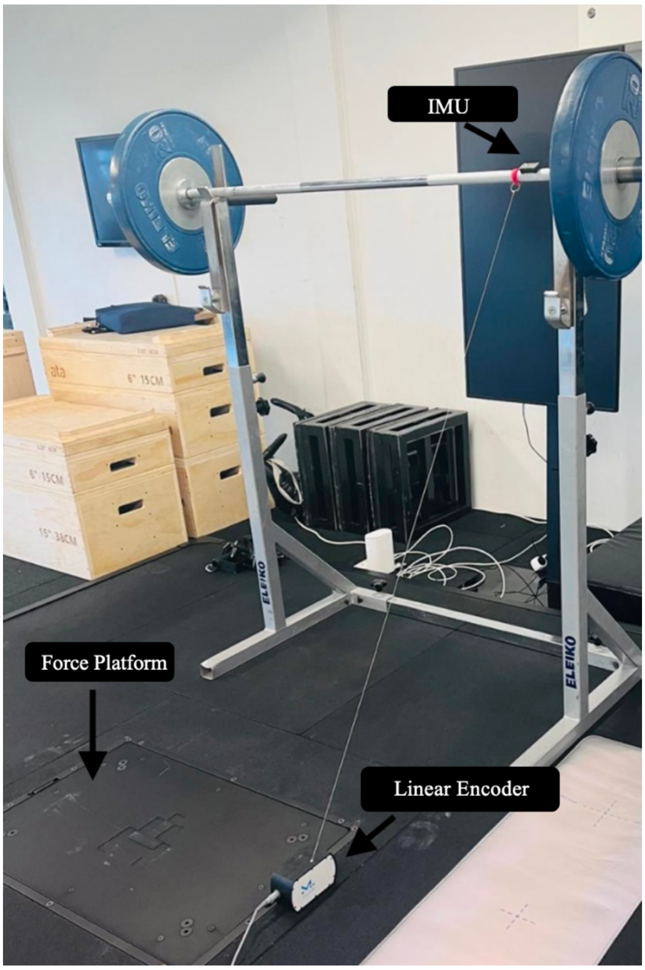


**Figure 1.** Visualization of the setup used for data collection, where the linear encoder and the IMU were attached to the right side of the barbell. The Alphatek platform system is placed on the floor. This photograph was provided by the Norwegian Olympic Center with their consent.

Simultaneously 3D motion capture (Qualisys AB; Gothenburg, Sweden), using 15 infrared cameras, was used on four of the participants for the estimation of the center of mass (COM) of the person applying a similar set-up as explained in Eythorsdottir (2022). For the four participants, 76 reflective markers were placed on anatomical points on the participant's body, in accordance with previous literature (Eythorsdottir, 2022).

### *2.4 Test procedure*

All participants had one test session at the Norwegian School of Sports Science. As there were no requirements of performance in this study, the participants performed a self-directed warm-up routine for about 10 minutes prior to testing. The test procedure consisted of 7 sets of back squats, with progressively higher loads performed for 15, 12, 10, 8, 6, 4, and 2 repetitions. The rest between sets was self-determined by the participants. Participants were also allowed to select the load for each set, with guidance to choose loads that corresponded with one to two repetitions in reserve. Participants were instructed to lift the weight "with the intention of generating the highest possible velocity" or "as explosively as possible" during each repetition. Mean propulsive velocity (MPV), sets, and repetitions were registered concurrently from all the measurement devices for all participants and transferred into an Excel spreadsheet. MPV is defined as the average velocity from the start of the concentric phase until the acceleration of the barbell is lower than gravitational acceleration ($-9.81 m \cdot s^{-1}$) (García-Ramos et al., 2018, p. 1273). The concentric phase refers to the phase of a lift where the lifter moves from the bottom position to the top position of the back squat. In addition, the horizontal displacement of the barbell was recorded from the IMU to distinguish between techniques.

### *2.5 Data Analysis*

All the data were analyzed in Python (version 3.10.6). The 3D motion capture data was analyzed in QTM, and Visual 3D (Visual 3D; C-Motion Inc., Rockville, MD, United States), and the variables of interest were calculated in Python. MPV was measured concurrently from all devices. To pre-process the data of the 3D motion capture, we applied a Savitzky-Golay filter from the SciPy library (version 1.10.1) to smooth the velocity and position data. The filter was implemented with a window length of 30, a polynomial order of 3, and the "nearest" mode for handling the boundaries.

#### *2.5.1 Determination of barbell velocity*

To determine the MPV, linear encoders calculate barbell velocity by differentiating the displacement of the wire by time. IMUs estimate barbell velocity by integrating the acceleration of the bar over time.

*2.5.2 Determination of* $COM_{pb}$ *velocity*

The Alphatek force platform system can determine velocity by integrating the vGRF. Integrating the vGRF for the purpose of computing the movement of the $COM_{pb}$ has previously been referred to as the GRF method (Mapelli et al., 2013, p. 462). In this study, the $COM_{pb}$ calculated by the Alphatek force platform system will be referred to as $COM_{fp.}$ Another commonly used method for estimating COM velocity in the athletic domain is the 3D motion capture. This approach investigated COM kinematics in sports by treating the human body as a system of rigid bodies and calculating the whole-body COM as the weighted average of each segment's COM (Mapelli et al., 2013, p. 462). The 3D motion capture was included in this study to obtain the velocity of the person's COM. Concurrently, the barbell's position was recorded by the 3D motion capture, and this data was subsequently differentiated to obtain the velocity. Then, the person and the barbell were treated as distinct segments. The $COM_{pb}$ was estimated by determining the weighted average of the center of mass of the person and the barbell segments. The $COM_{pb}$ computed with 3D motion capture will be referred to as $COM_{3D}$.

*2.5.3 Statistical analysis*

The linear encoder was used as the reference value, while the Alphatek force platform system and the IMU were compared with the reference value. Linear regression analysis was conducted across all participants between the reference value and the Alphatek force platform system and IMU. Also, mean, standard deviation (±SD), R squared ($R^2$) and slope value ($S_v$) were calculated on the collected data. All values are presented as mean (SD) unless stated otherwise.

## 3. Results

A total of 688 repetitions were collected from the 12 participants performing the back squat exercise. 59 repetitions were excluded due to them not being detected on all devices, resulting in 629 repetitions being analyzed.

The linear encoder demonstrated an average MPV of 0.83 (0.28) $ms^{-1}$ across all the participants. The IMU displayed an average MPV of 0.79 (0.31) $ms^{-1}$, while the Alphatek force platform system exhibited the lowest average MPV of all devices, with 0.64 (0.21) $ms^{-1}$.

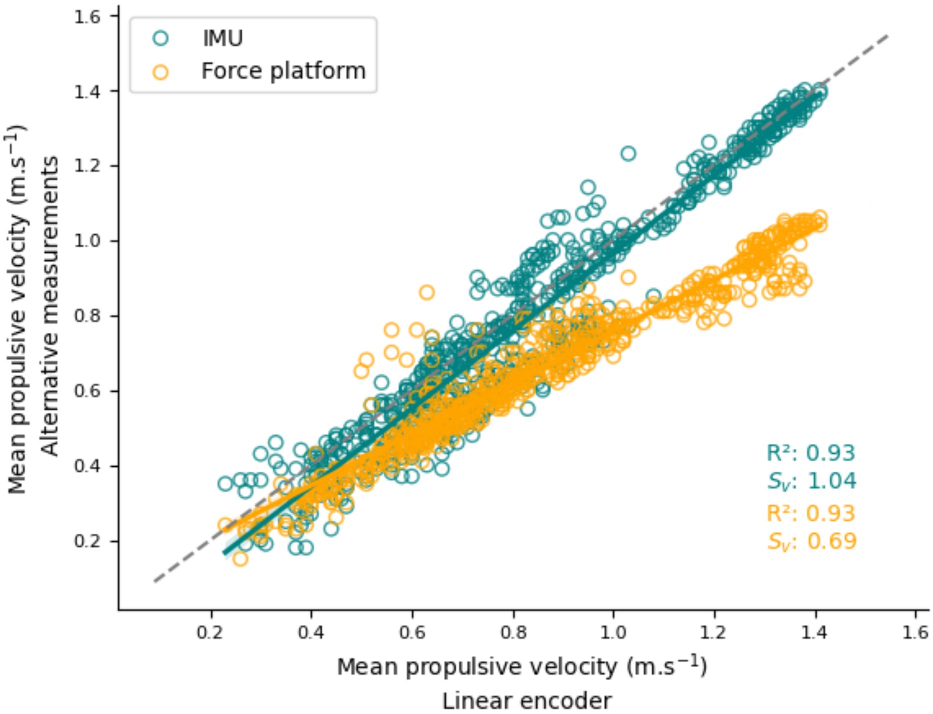


**Figure 2.** MPV ($ms^{-1}$) comparison between devices. Relation between MPV measured with the Alphatek force platform system, IMU, and linear encoder across all participants. The data from the IMU and the force platform are plotted against the linear encoder as the reference value. The dashed line represents the identity line. $S_v$ refers to the slope value of the regression line.

Furthermore, there were increased differences in lifting velocity between the measurements from the Alphatek force platform system, IMU, and the linear encoder (Figure 2). The Alphatek force platform system exhibited a rate of increase of 0.69 according to the regression line in comparison to the linear encoder, highlighting the expanding differences as velocity increased for all participants. The IMU's MPV rate of increase stood at 1.04 according to the regression line and demonstrated a better alignment with the identity line in comparison to the Alphatek force platform system. The $R^2$ values were equal for both the Alphatek force platform system and the IMU across all participants. The Alphatek force platform system presented more outliers compared to the IMU. There was one outlier participant, which is demonstrated in red (Figure 3). When the outlier participant was excluded from the analysis, the R2 for the Alphatek force platform system increased to 0.96. Despite the increasing disparities in lifting velocities between devices, most participants exhibited a robust correlation between the encoder and the Alphatek platform system. The $R^2$ values for individual participants ranged from 0.75 to 0.99, with eight participants achieving an $R^2$ of 0.98 or higher.

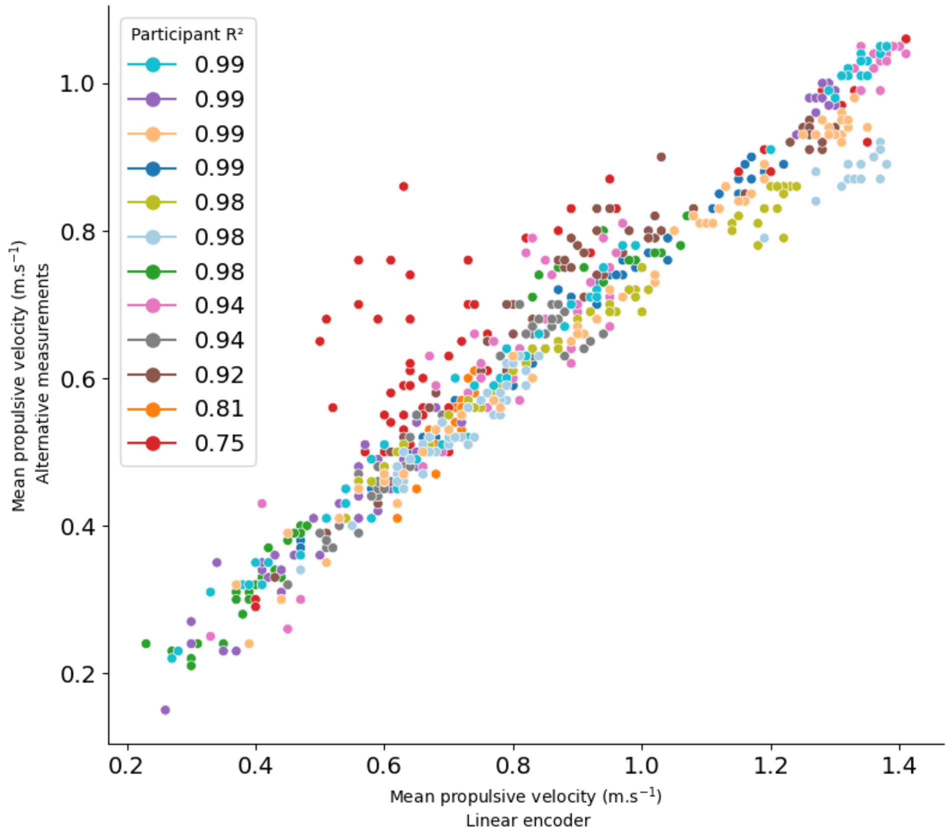


**Figure 3.** MPV (ms-1) comparison between participants. Relation between MPV measured with the Alphatek force platform system and linear encoder across all participants. The force platform data is plotted against the linear encoder as the reference value. Each color represents one participant.

The reference MPV collected from the linear encoder, as well as the related MPV from the Alphatek force platform system along the regression lines for all participants, was calculated (Table 2). These findings demonstrated that, at identical barbell velocity points, the Alphatek force platform system recorded varying lifting velocities among participants. Looking at the SD, the differences between individuals became more pronounced at higher velocities. The range of maximum and minimum values underscored that even when two athletes exhibited the same lifting velocity on the linear encoder (e.g., 1.00 ms-1) they sometimes had different velocities measured on the Alphatek force plate system (e.g., 0.69 and 0.79 ms-1).

**Table 2.** Differences in measured MPV between the linear encoder and the Alphatek force platform system. The encoder is the reference value. These are mean values across all the regression lines of the participants at various barbell velocity points.

| Linear encoder MPV (ms-1) | Alphatek Mean MPV (SD) (ms-1) | Alphatek Min MPV (ms-1) | Alphatek Max MPV (ms-1) |
|---|---|---|---|
| 0.20 | 0.20 (0.03) | 0.16 | 0.25 |

| | | | |
|---|---|---|---|
| 0.30 | 0.27 (0.03) | 0.23 | 0.31 |
| 0.40 | 0.34 (0.02) | 0.31 | 0.38 |
| 0.60 | 0.48 (0.02) | 0.45 | 0.51 |
| 0.80 | 0.62 (0.02) | 0.58 | 0.65 |
| 1.00 | 0.76 (0.03) | 0.69 | 0.79 |
| 1.20 | 0.90 (0.04) | 0.81 | 0.94 |
| 1.40 | 1.03 (0.05) | 0.92 | 1.09 |
| 1.60 | 1.17 (0.06) | 1.04 | 1.25 |

The horizontal displacement also demonstrated an impact on the correlations between MVP across all measurement devices (Figures 4A and 4B). The horizontal displacement varied between 0.7 to 19.8 cm across the participants. The mean (SD) was 6.71 (4.37) cm, and because of this 7 cm was used to distinguish between back squat techniques. A higher $R^2$ for the Alphatek force platform system was found when sorting the dataset by horizontal displacement values less than 7 cm (Figure 4A). As the horizontal displacement is adjusted to exceed 7 cm (Figure 4B), both the correlation and $R^2$ decreased. The slopes of the lines also tended to differ.

**(A)** **(B)**

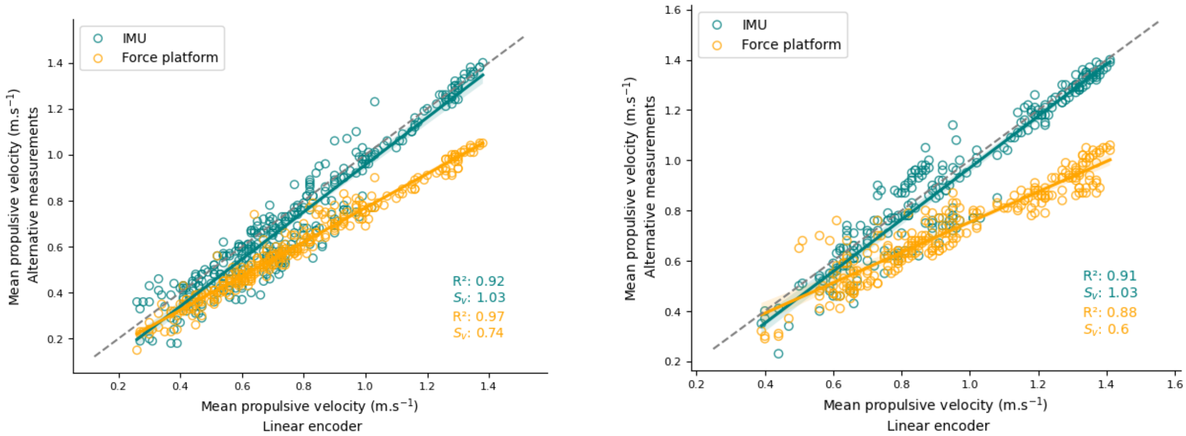


**Figure 4.** MPV (ms-1) sorted by horizontal displacement of the barbell. The horizontal displacement was registered by the IMU. All repetitions are measured with the Alphatek force platform system, IMU, and linear encoder across all participants. (A): Horizontal displacement < 7 cm. (B): Horizontal displacement > 7 cm. The linear encoder is the reference value. The dashed line represents the identity line. $S_v$ refers to the slope value of the regression line.

The $COM_{3D}$ data showed an MPV of 0.6 (0.28) $ms^{-1}$, and the $COM_{fp}$ showed an MPV of 0.54 (0.26) $ms^{-1}$, and 0.68 (0.32) for barbell velocity. The linear encoder showed an MPV of 0.69 (0.35) $ms^{-1}$ (Figure 5).

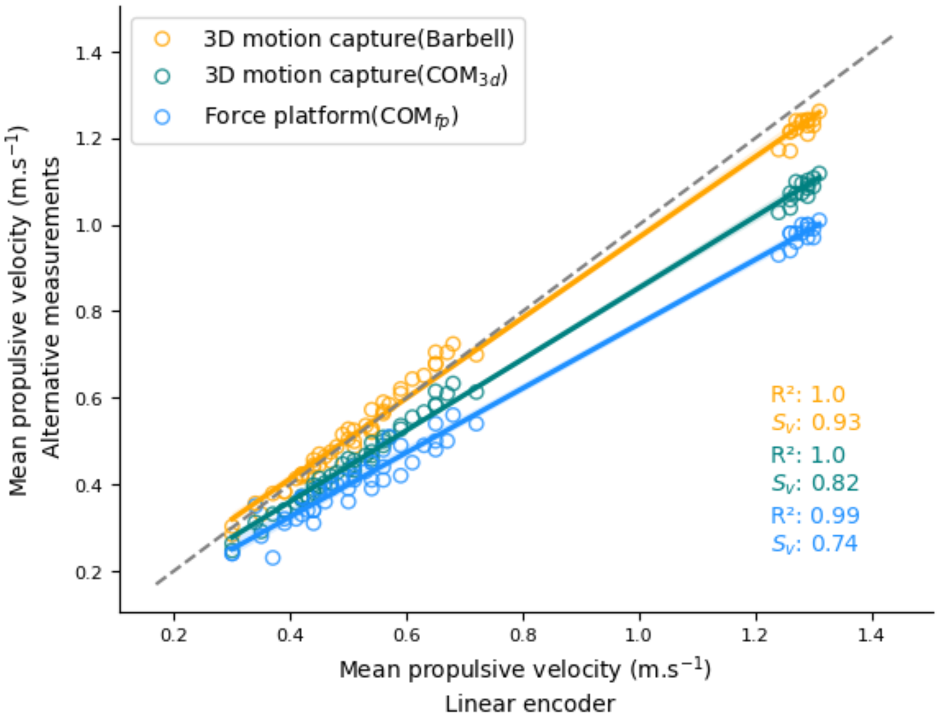


**Figure 5.** MPV (ms-1) comparison between 3D motion capture and Alphatek platform system. Relation between the Alphatek force platform system, linear encoder, and 3D motion capture across 2 participants. The linear encoder is the reference value. The dashed line represents the identity line.

## 4. Discussion

The study aimed to investigate the differences in lifting velocity measured by the Alphatek force platform system and the barbell velocity measurement devices during the back squat. We also aimed to evaluate the lifting velocity of the Alphatek force platform system by comparing it to 3D motion capture measures of the COM. Supporting our hypothesis, the main findings of this study were that a difference in lifting velocity between the barbell and the $COM_{fp}$ was greater with increased lifting velocity (Figure 2). The Alphatek force platform system also measured lower values than the linear encoder and the IMU.

### *4.1 $COM_{pb}$ and barbell velocity comparison*

The observed increased differences in measured MPV at higher lifting velocities (Figure 2) could likely be attributed to the position of the $COM_{pb}$, compared to the position of the barbell. While the position of the barbell remains constant regardless of the load, the position of the $COM_{pb}$ will move, as a function of the load on the barbell. With heavy loads, the $COM_{pb}$ is positioned closer to the barbell, as more of the system's total mass is concentrated around this area, resulting in more similar velocities. With lighter loads, the $COM_{pb}$ will be closer to the hip joint and hence further away from the barbell, resulting in bigger differences between barbell velocity and the $COM_{pb}$ velocity. Additionally, as the load of the barbell increases, its contribution to the overall $COM_{pb}$ velocity becomes more significant. These factors, including the position of the $COM_{pb}$ and the barbell's contribution to the $COM_{pb}$ velocity, explain why greater differences in lifting velocities between the force platform versus the IMU and linear encoder were observed at higher velocities (light weight), and why the velocities registered by the different equipment became more similar at lower velocities (heavy weight). Looking at the $R^2$ values, for most of the participants (Figure 3) the differences between the barbell and the $COM_{pb}$ appear systematic, however, for a few participants the differences appear more random. This could be because of technique (e.g., for the red participant in Figure 3), or because of few data points (e.g., for the orange participant in Figure 3).

The comparison of the velocity of $COM_{pb}$ and that of the barbell reveals varying patterns of association among participants (Figure 3). Each color-coded participant demonstrates a unique trend, although some participants demonstrate more similar patterns than others. A quantitative analysis of these patterns (Table 2) demonstrates that each participant possesses a unique slope. These findings could be a result of the fact that each participant has a unique anthropometry. The distribution of the mass among body segments and the barbell affects the position of the $COM_{fp}$ and therefore there will be individual velocity $COM_{fp}$ points, hence affecting the rate of increase. In contrast, the velocity of the barbell alone represents a single point of the system, without accounting for the mass contribution from different body segments. Hence, the $COM_{pb}$ velocity measured by the force platform accounts for anthropometric variations, while the IMU and linear encoder do not.

### *4.2 Horizontal displacement*

It seems evident that the rate of increase of the regression line is affected by variations in horizontal displacement between participants (Figures 4A and 4B). The results showed a distinct difference in the rate of increase and $R^2$ when the values were sorted by their displacement in the horizontal direction. For those who had most of their movement in the vertical direction (horizontal displacement < 7 cm, Figure 4A) the $R^2$ was higher. This could be because the Alphatek force platform system only measures vGRF and does not take into account the movements in the horizontal direction.

The different slopes in $COM_{pb}$ velocity and barbell velocity could also be a result of each participant's technique, as this could result in different velocity contributions from the body segments. Individuals exhibiting a horizontal displacement < 7 cm may display a more balanced distribution of workload between the hip and knee joints, leading to equal velocity contributions to the overall velocity of the $COM_{pb}$ from these segments. Conversely, individuals utilizing back squat techniques with a horizontal displacement > 7 cm (Figure 4B) are prone to greater dependence on the hip joint, resulting in varying velocity contributions from the knee and upper body segments.

### *4.3 $COM_{3D}$ and $COM_{fp}$ comparisons*

The $COM_{3D}$ velocity was also lower than the barbell velocity obtained from the linear encoder, and the disparities grew as velocity increased (Figure 5). Note that there were also variations between the $COM_{fp}$ and the $COM_{3D}$ velocities. At the point where the curve intersects the *y*-axis, the velocities from the $COM_{fp}$ and $COM_{3D}$ were equal; however, due to distinct slopes, these differences would also expand as velocities increase. In addition, there were differences between the linear encoder and the barbell velocity collected from the 3D motion capture system.

A potential reason for the increased velocity differences at higher velocities when comparing the $COM_{3D}$ with the $COM_{fp}$ may be linked to the 3D motion capture method as it depends on estimating the mass of individual body segments, which can be subject to incorrect sources or estimations.

At lower velocities, the $COM_{pb}$ (Figure 5) is primarily influenced by the load and velocity of the barbell segment, as its contribution to the overall velocity is considerably greater. Conversely, at higher velocities, the contribution of body segments plays a more significant role in the total $COM_{pb}$, and inaccurate estimation of each segment can result in increased variations in the $COM_{pb}$'s total velocity. However, the complete explanation remains unclear.

### *4.4 Practical Applications*

It is important to recognize that barbell velocity and COM velocity are two different measurements of lifting velocity. Coaches and athletes should consider this if using IMUs or linear encoders interchangeably with force platforms for VBST. The significance of the differences between COM and barbell velocity lies in whether they are random or systematic for the individual. If the differences in velocity measurements between devices are systematic, coaches may more effectively provide the correct training loads. If a certain percentage of drop in velocity is used, it is important to determine if this drop is consistent regardless of the velocity being measured (i.e., the barbell velocity vs. the $COM_{pb}$ velocity). Conversely, unsystematic differences increase the risk of prescribing the wrong training loads, potentially leading to injuries and negatively affecting performance. If these differences are consistent, coaches may switch between or from a linear encoder to the force plate without it affecting the use of VBST. However, if there is a variation in the velocity drop, it is crucial to understand these differences to accurately prescribe the appropriate training loads for athletes.

In this study, we present a table that correlates the velocity of the barbell with the velocity of the $COM_{pb}$ (Table 2). This table offers valuable insights into the relationship between the barbell's velocity and the $COM_{pb}$ velocity. As a result, coaches and athletes can use this information as a reference when transitioning from barbell velocity to $COM_{pb}$ velocity in VBST. It's important to highlight that for each barbell velocity point, the corresponding $COM_{pb}$ velocities vary based on the individual participants (Table 2). Note that even if two athletes display the same barbell velocity, the $COM_{pb}$ velocity can differ between the two. Consequently, our findings reveal that different athletes can achieve equal barbell velocity but have distinct $COM_{pb}$ velocities. This discrepancy in barbell velocity and $COM_{pb}$ velocity among participants suggests that athletes may be prescribed the same training loads based on barbell velocity but require different training loads based on $COM_{pb}$ velocity.

The similarities in barbell velocity and differences in $COM_{pb}$ velocity between individuals may be because barbell velocity represents only a part of the entire system where an individual performs muscular work (the person-barbell system) or the portion of work acting on the bar. In contrast, the $COM_{pb}$ velocity accounts for the total work applied to the person-barbell system. Further research is needed to determine whether barbell velocity or $COM_{pb}$ velocity is more suitable for prescribing training and loads.

*4.5 Strengths and limitations*

To the best of our knowledge, this is the first study to examine the differences between $COM_{pb}$ and barbell lifting velocities. Our work reveals new understanding in this previously unexplored area and sets the stage for further research. The test protocol covered a wide range of repetitions enabling us to observe participants reaching similar velocities at different loads. Furthermore, the diverse participant population, which includes individuals with varying anthropometric attributes, physical capabilities, and techniques, as well as both women and men, strengthens the overall understandability of the results. However, it is important to acknowledge the limitations of our study. It cannot be definitively stated whether the 3D motion capture or the Alphatek force platform system is more accurate for measuring the velocity of the $COM_{pb}$. It should be noted that the force platform is considered by many authors as the "gold standard" for calculating the center of mass motion (Gutierrez-Farewik et al., 2006; Mapelli et al.; 2013, McKinon et al.; 2004, Crowe et al.; 1995, Whittle, 1997). However, the Alphatek force platform system's accuracy remains unconfirmed as it has not yet been validated against another force platform, thus necessitating a comparison to other established force platform systems to determine its validity. For instance, the Norwegian Olympic Center conducted an unpublished study where they compared the Alphatek force platform system with the Vald force platform system (Vald performance; Pty Ltd, Newstead QLD, Australia. The Alphatek force platform system displayed lower velocities in comparison. Therefore, these findings may call into question the validity of the Alphatek force platform system, and a thorough validation study is crucial to assess its reliability and accuracy. In addition, it is important to note that the sampling frequency of the devices utilized in this study differed (Table 1). This could affect our results, but the level of impact is not clear. However, the differences in sampling frequency could have been beneficial, because, in real-world scenarios, sampling frequencies will vary across devices.

5. **Conclusion**

The results of our study suggest that the $COM_{fp}$ exhibited lower velocities compared to standard VBST devices, namely the linear encoder and the IMU. Notably these differences increased at higher lifting velocities. Similar trends were observed for the $COM_{3D}$, which also exhibited lower values compared to the barbell velocity with similar increases at higher velocities. Hence consistent patterns were observed for the $COM_{pb}$. In addition, the result of our study suggests that the velocity of the $COM_{pb}$ is more influenced by the load on the barbell, anthropometric factors, and individual techniques than barbell velocity. However, the extent of the impact remains unclear and warrants further investigation. The findings in this study indicate that when using different devices interchangeably in VBST, the differences between the $COM_{pb}$ and barbell velocity measurements must be considered to accurately prescribe appropriate training loads. Additionally, the relationship between $COM_{pb}$ velocity and barbell velocity varies among individuals, highlighting the importance of understanding these differences for optimal training prescription. Further research is needed to determine whether $COM_{pb}$ velocity or barbell velocity is more suitable for prescribing training and loads.

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