Performance in sports

Cable Exit Angles and Measurement Accuracy: Does Cable Angle Influence Velocity Measurements in Linear Position Transducers?

Ángulos de salida del cable y precisión de la medición: ¿Influye el ángulo del cable en las mediciones de velocidad en transductores de posición lineal?

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ABSTRACT

This study analyzes the impact of cable exit angle on the accuracy of velocity measurements in linear position transducers (LPTs). Two models, Vitruve and Chronojump, were evaluated at five cable exit angles (0°, 10°, 30°, 60°, and 90°) using a 2.5 kg mass in free fall. Five measurements were taken per angle, and data were analyzed using MANOVA.

The results showed no significant differences in velocity measurements due to cable exit angle ($p > 0.05$), but there were significant differences between LPT models ($p = 0.005$), with Vitruve recording higher velocities than Chronojump. This challenges the recommendation to limit cable deviation to 2° to avoid friction-related measurement errors.

These findings suggest that cable exit angles within the 0° to 90° range do not compromise the accuracy of velocity measurements in the evaluated models. This may facilitate the implementation of LPTs in training environments by reducing placement restrictions and optimizing their use in velocity-based training (VBT) protocols.

Keywords: cable exit angle, velocity-based training (VBT), velocity measurements, linear position transducers (LPTs).

RESUMEN
Este estudio analiza el impacto del ángulo de salida del cable en la precisión de las mediciones de velocidad en transductores de posición lineal (LPT). Se evaluaron dos modelos, Vitruve y Chronojump, con cinco ángulos de salida (0°, 10°, 30°, 60° y 90°), utilizando una masa de 2,5 kg en caída libre. Se realizaron cinco mediciones por ángulo y los datos fueron analizados mediante MANOVA.
Los resultados no mostraron diferencias significativas en las mediciones de velocidad debido al ángulo de salida del cable ($p > 0,05$), pero sí diferencias entre los modelos de LPT ($p = 0,005$), con Vitruve registrando velocidades más altas que Chronojump. Esto cuestiona la recomendación de limitar la desviación del cable a 2° para evitar errores de fricción.
Estos hallazgos sugieren que el ángulo de salida del cable en el rango de 0° a 90° no compromete la precisión de las mediciones de velocidad en los modelos evaluados. Esto puede facilitar la implementación de LPT en entornos de entrenamiento, reduciendo restricciones en su colocación y optimizando su uso en protocolos de entrenamiento basados en la velocidad (VBT).

Palabras clave: ángulo de salida del cable, entrenamiento basado en la velocidad, medición de velocidad, transductor de posición lineal.

INTRODUCTION

Quantifying velocity in resistance training is crucial for optimizing performance outcomes and minimizing injury risks (González-Badillo & Sánchez-Medina, 2010). Velocity-based training (VBT) has gained popularity as it allows for real-time monitoring and adjustment of training loads based on the movement speed of the athlete (González-Badillo et al., 2022). Accurate measurements of velocity are essential, and various devices, such as linear position transducers (LPTs) and wearable technology, have been developed to facilitate this process (Weakley et al., 2021).

LPTs, commonly used in VBTs, measure the linear displacement of a retractable cable connected to moving load. Although the principles of operation of LPTs are very similar in all manufacturers, there are technical differences between the different models, for (between 100 Hz and 1000 Hz), or the connectivity options to a computer in some cases (through software), or to a mobile phone or tablet (through an app).

LPTs are generally considered accurate (Weakley et al., 2021), although there are some authors who question their reliability in determining force and power variables due to their indirect estimation of these parameters (Cormie et al., 2007), or under low loads due to amplification of signal noise (Crewther et al., 2011; Dorrell et al., 2019). The performance, concordance and reliability of different models of LPT and other devices have also been compared (Courel-Íbañez et al., 2019; Banyard et al., 2017).

The accuracy of these devices is critical, as any deviation can result in significant errors in speed measurement, affecting the reliability of training data (Harris et al., 2010). One factor that can affect the accuracy of LPTs is the angle at which the cable exits the device. It is generally recommended that the cable be not deviated more than 2° from the line of action to minimize friction and ensure accurate speed readings (Harris et al., 2010). This recommendation could be the reason why simple, controlled, non-plyometric movement analyses seem to predominate, with the most frequently studied exercises with LPT being those in which the loads move linearly with vertical trajectories on a Smith machine, especially the bench press or the squat (Moreno-Villanueva et al., 2021).

Previous studies have examined the validity and reliability of various VBT devices, including their sensitivity to different attachment points and angles of cable exit (Clemente et al., 2021). For instance, Fritschi et al. (2021) assessed the validity of several VBT devices and found that while the placement of the device does affect measurement validity, the errors introduced were generally small enough to be considered negligible in practical settings. Similarly, Achermann et al. (2023) investigated the accuracy of consumer-grade wearables for VBT and highlighted the importance of proper device placement to ensure reliable data.

Despite these advancements, there is limited research directly addressing the impact of cable exit angles greater than 2° on the accuracy of velocity measurements in LPTs. The T-Force system, a widely used LPT in VBT, explicitly recommends maintaining the cable within this angular limit to avoid measurement errors due to increased friction. This recommendation, however, lacks comprehensive empirical validation.

The objective of this study is to determine whether significant differences arise in the velocity measurements provided by two models of LPTs, Vitruve and Chronojump, when the cable exits the device at various angles. By systematically varying the angle of the cable exit and comparing the velocity readings, this research aims to provide empirical evidence to support or refute the manufacturer's guidelines and enhance the understanding of factors affecting the accuracy of VBT devices. The findings of this study can have a significant impact on VBT practice, helping coaches and athletes select the most accurate devices tailored to their specific needs in practical scenarios.

MATERIALS AND METHODS

Experimental Design

The experiment was designed to assess whether significant differences in the recorded velocity occur when the cable exits the transducer at various angles. The study was conducted using three LPT devices: two Vitruve encoders and one Chronojump encoder. All devices were firmly attached to a horizontal metallic platform to ensure stability and consistency across measurements.

Equipment and Setup

Each encoder was subjected to velocity measurements with the cable exiting the transducer at different angles (0°, 10°, 30°, 60°, and 90°). The angles were precisely set using a manual inclinometer/goniometer to ensure accuracy (BOSCH, GAM-220 MF, ©Robert Bosch GmbH). A known mass (2.5 kg) was used as the load, which was accelerated vertically downward with an approximate acceleration of 9.81 m/s², corresponding to gravity. The load was dropped freely vertically downwards from a height of 0.4 m. To achieve the same load displacement in all measurements, and a vertical trajectory, two support points were used to direct the encoder wire. The support points were polished steel bars with a low coefficient of friction.

Device Calibration and Setup

The Vitruve encoders were attached to the same load to record simultaneous velocity measurements for each angle to verify consistency between devices of the same model. The Chronojump encoder recorded the velocity of the same load under identical conditions but separately, to account for differences in friction and attachment systems between different manufacturers. Although the measurement characteristics (distance traveled, load, and transducer location) were identical, the devices measured different but consecutive events. First, the event was measured with both Vitruve encoders, and immediately afterwards, under the same conditions, the measurement was performed with the Chronojump device. The objective of separating the devices for measurements was to minimize potential interferences in the measurement associated with the resistance in the wire output of each device, as the manufacturers present different resistances at the wire output.

Measurement Protocol

The platform's inclination was adjusted to achieve the desired cable exit angles. For each angle, five velocity measurements were taken to ensure reliability. The known mass of 2.5 Kg was dropped from a fixed height to maintain a consistent initial velocity and acceleration across all trials. The platform and the encoders were configured to ensure the same displacement distance of the load in each trial (see figures 1 and 2). Each measurement was repeated 5 times.

Figure 1.
Initial position of the encoders during the experiment

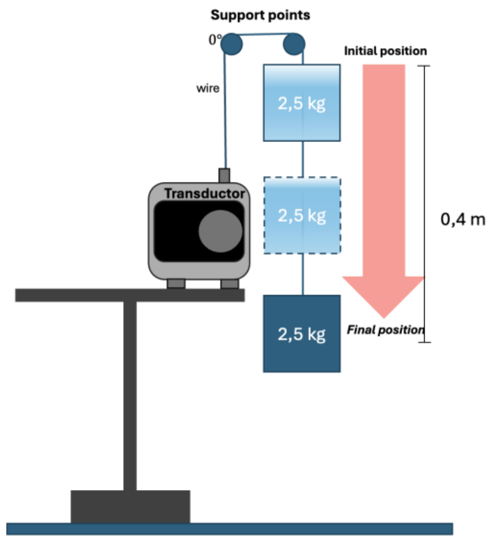
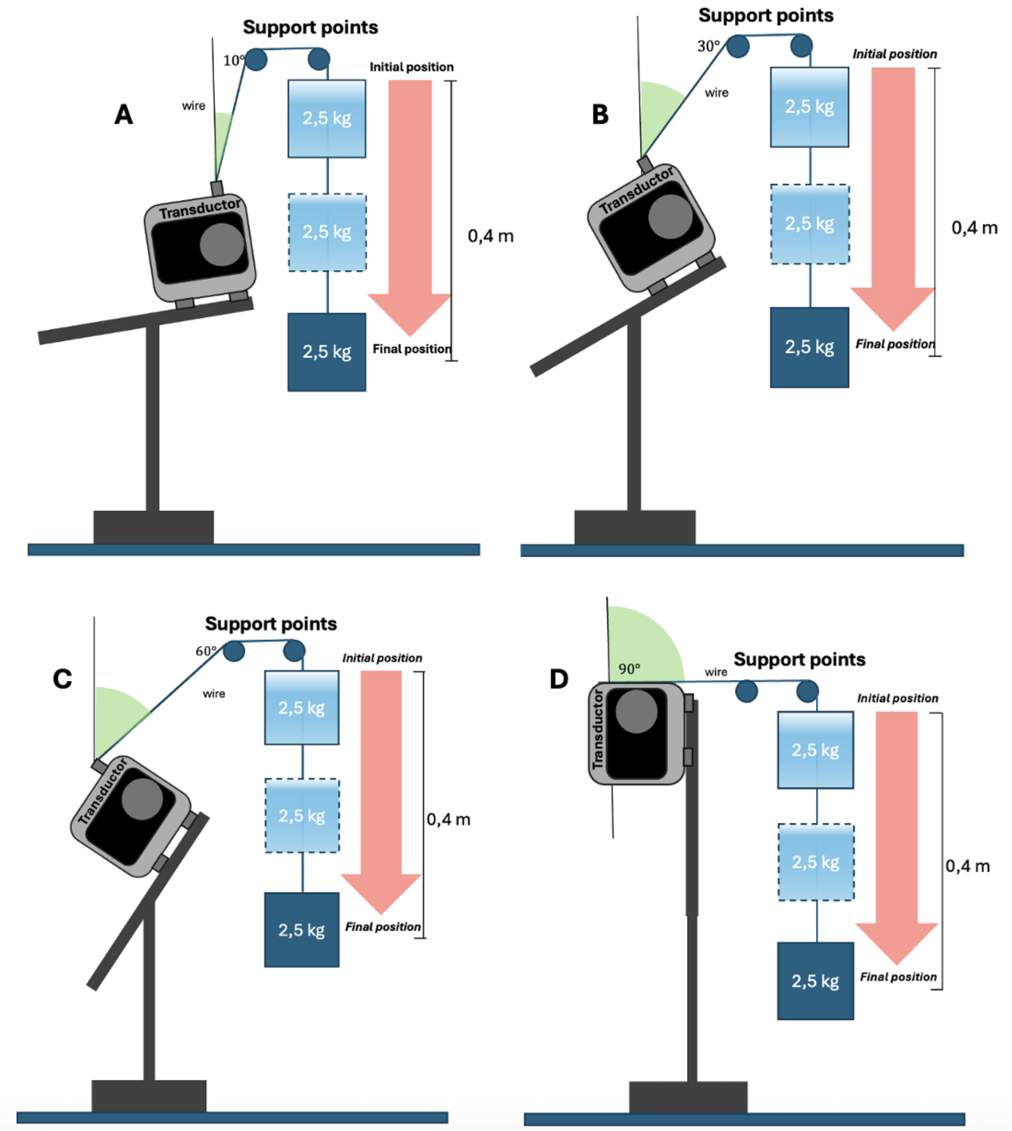


Figure 2.

Encoders positions with wire exit angles of 10° (A), 30° (B), 60° (C), and 90° (D)



Data Analysis

The recorded velocity data were analyzed to compare the performance of the Vitruve (1 and 2) and Chronojump encoders at different cable exit angles. The data normality assumptions were confirmed by Shapiro-Wilk's test. Statistical analyses were performed to determine if the differences in the measured velocities were significant at each angle. A multivariate analysis of variance (MANOVA) was conducted to evaluate the impact of the cable exit angle and the type of encoder on the velocity measurements. Following the MANOVA, univariate ANOVAs were conducted to examine the effects of each factor individually. Statistical analyses were carried out with the statistical software IBM SPSS for Windows, version 25.0 (IBM Corp., Armonk, NY, USA) and NSCC Software (https://www.ncss.com/). Significance was set by p-values less than 0.05.

RESULTS

The analysis aimed to identify if any significant discrepancies in velocity measurements could be attributed to the different cable exit angles. This would provide empirical evidence regarding the recommendation to maintain the cable within a 2° angular limit to ensure accurate velocity readings. The velocity measurements obtained from the Vitruve 1, Vitruve 2, and Chronojump encoders at various cable exit angles (0°, 10°, 30°, 60°, and 90°) are summarized in Table 1. No statistically significant differences were observed in any of the angles analyzed ($p<0.05$). On the contrary, statistically significant differences were observed among the 3 different encoders ($p=0.005$) (see table 2).

Table 1.
Mean Velocity Measurements (Standard Deviation) by Encoder and Cable Exit Angle

	Cable Exit Angle (º)				
Encoder	**0°**	**10°**	**30°**	**60°**	**90°**
VT 1	0.90 (0.032)	0.93 (0.032)	0.91 (0.032)	0.87 (0.032)	0.91 (0.032)
VT 2	0.91 (0.032)	0.88 (0.032)	0.89 (0.032)	0.92 (0.032)	0.98 (0.032)
CJ	0.88 (0.032)	0.87 (0.032)	0.90 (0.032)	0.82 (0.032)	0.79 (0.032)

VT: Vitruve encoder, CJ: Chronojump encoder

Table 2.
Relationship between exit angle and velocity

Effect	**Value**	**F-Value**	**p-Value**
Encoder (A)	0.839	5.76	0.005*
Angle (B)	0.971	0.44	0.778
Encoder*Angle (AB)	0.806	1.81	0.093

*statistically significant

When the different devices were analyzed, results showed statistically significant differences according to the type of encoder on the velocity measurements, with both Vitruve encoder (1 and 2) generally showing higher velocity readings compared to Chronojump. Nevertheless, the main aim of the present study was not to assess the validity or reproductivity of the three devices as that topic has been already studied. Therefore, these results were not included.

DISCUSSION

The aim of the present study was to confirm the influence of the cable's exit angle in different encoders to the measurement's accuracy. Commonly, it was established that exit angles higher than 2º might influence the measured velocity from these devices due to the friction with the encoder case. Typical exercises often used in training sessions require that the bar or dumbbells move in different directions that are not always vertical. This fact may reduce the utility of encoders in field training or could result in difficulties placing the device in a position the allows the cable to exit with 0º. This study proved that the cable exit angle does not influence the measured velocity, for the models studied, since there is no physical interference between the cable and the support. The information might be of great help to coaches, researchers and athletes that used encoders in their training sessions. Although this matter was not the main aim of the present study, the fact that the experimental protocol was performed with three different devices allowed a parallel study. Vitruve encoder has been validated previously (Perez-Castilla et al., 2019; Perez-Castilla et al., 2019B; Held et al., 2021) as well as used in experimental studies as a validated device (Rodríguez-Rodríguez et al., 2023). Nevertheless, results indicate a statistically significant effect of the type of encoder on the velocity measurements. Results showed that both Vitruve encoders measured higher velocities than the Chronojump encoder. Although no significant differences were observed in the reported speed at the exit angle among the three devices studied, the differences in the design of their casings may influence the recorded measurements. Both Vitruve devices share the same casing, with a similar cable exit port. Conversely, in the case of the Chronojump, the cable exit is different. These differences may result in varying measurements between different models of devices but not between the same models. However, the cable exit angle did not have a significant impact on the velocity measurements. Additionally, no significant interaction effect between the encoder type and the cable exit angle was observed.

One critical factor influencing the accuracy of LPTs is the friction generated between the cable and the device during measurement. When the cable exits the transducer at an angle greater than the recommended 2°, increased friction can occur, potentially leading to errors in velocity readings. This frictional force can impede the smooth movement of the cable, causing fluctuations in the measured displacement and thus affecting the precision of the data recorded. As the cable rubs against the transducer housing, the resistance introduced can vary with the angle and speed of movement, leading to inconsistent measurements. Studies such as Harris et al. (2010) emphasize the importance of maintaining minimal deviation in cable exit angles to reduce these frictional effects and ensure the reliability of velocity-based training data. Understanding and mitigating the impact of cable friction is essential for enhancing the accuracy of LPTs and, by extension, the effectiveness of velocity-based training (VBT) methodologies.

A consistent solution to minimize friction at the cable exit is to modify the housing so that the cable exits through a notch rather than a circular hole, allowing for an angled exit without generating friction between the cable and the housing.

These findings suggest that while the type of encoder used can influence the accuracy of velocity measurements in velocity-based training (VBT), the cable exit angle within the tested range (0° to 90°) does not significantly affect the measurements. This contradicts the general recommendation to maintain the cable within a 2° deviation from the line of action to minimize measurement errors due to friction.

Further research should investigate the potential effects of other factors, such as different load magnitudes and varying movement speeds, on the accuracy of velocity measurements by linear position transducers (LPTs) and include more devices.

The methodology described ensures a comprehensive evaluation of the impact of cable exit angles on the accuracy of velocity measurements by LPTs, contributing valuable insights to the application of VBT in resistance training. According to the results obtained in the present study, the cable exit angle should not be a factor to consider regarding accuracy of velocity measures. The results will help validate or question the current guidelines provided by LPT manufacturers and enhance the reliability of velocity-based assessments in sports science.

DECLARATION OF INTEREST STATEMENT

The authors declare there are no conflicts of interest regarding this manuscript's publication. No financial, personal, or other relationships with other people or organizations have influenced the work reported in this paper. The authors have no relevant financial or non-financial interests to disclose that could be perceived as potential conflicts of interest.

STATEMENT OF ETHICS

This study did not involve human, animal, or plant subjects. All experiments were conducted using electronic devices and inanimate objects (linear position transducers and weights), with no intervention of living beings. Informed consent was not required for this research study.

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