Concurrent Validity and Technological Error-Based Reliability of a Novel Device for Velocity-Based Training

Brief Title: Reliability of a Novel Device for Velocity-Based Training

Wladymir Külkamp[1], Chris Bishop[2], Rafael Kons[3*], Lara Antunes[4] Everton Crivoi Carmo[5], Deborah Hizume-Kunzler[1], Juliano Dal pupo[4]

[1] Center for Health and Sport Sciences, Santa Catarina State University, Florianópolis, Brazil

[2] Faculty of Science and Technology, London Sport Institute, Middlesex University, Allianz Park, Greenlands Lane, London NW4 1RL, United Kingdom

[3] Department of Physical Education, Federal University of Bahia, Brazil

[4] Center of Sports, Federal University of Santa Catarina, Florianópolis, Brazil

[5] Department of Physical Education, SENAC University Center, São Paulo, Brazil

Corresponding author:
Rafael Kons, PhD*
Federal University of Bahia, Department of Education, Faculty of Education
ZIP-CODE: 40110-100
Salvador, Bahia, Brazil, Phone: +55 48 3721-8530
E-mail address: rafakons0310@gmail.com

ORCID:
Wladymir Külkamp: 0000-0002-4113-5791
Chris Bishop: 0000-0002-1505-1287
Rafael Kons: 0000-0003-1615-5464
Everton Crivoi Carmo: 0000-0003-1353-0206
Deborah Hizume-Kunzler: 0000-0002-7954-3192
Juliano Dal Pupo: 0000-0003-4084-9474

Conflict of interest: The author Wladymir Külkamp declares that he is the manufacturer of the Ergonauta I encoder

Abstract

The aim of this study was to verify the concurrent validity and the biological error-free reliability of a novel low-cost commercial encoder (Ergonauta I). Validity protocol involved comparisons with a custom system and other encoder commercially available (Vitruve). Reliability protocols involved inter devices and inter unit comparisons. No participants were recruited, and reliability assessments were performed in a Smith Machine by bar free fall tests. Our results showed a significant bias for mean velocity (MV) estimated by both encoders only in one of the four conditions investigated (bias=0.05 m/s). Regarding sensitivity, the smallest detectable change suggests only values higher than 0.03 m/s must to be considered as real changes in performance, when monitoring MV and mean propulsive velocity (MPV) through Ergonauta I and Vitruve. Between-days intra-device reliability showed Ergonauta I remains highly reliable after one week for most assessments, whereas slightly less sensitive for peak velocity and peak power output.

Key words: Movement velocity; velocity-based training; biomechanics; reliability

Introduction

Velocity-based training (VBT) has often been described as a practical and accurate method for prescribing and monitoring strength training in real-time (Baena-Marín et al, 2022; Weakley et al., 2021a; Weakley et al., 2021b; Külkamp et al., 2021a; Włodarczyk et al., 2021). VBT proposes the use of movement velocity as the main variable to determine the intensity and volume of training, as well as to monitor fatigue and readiness of athletes in a simple but effective manner (Weakley et al., 2021b; Moore, Joseph & Dorrell, 2020; González-Badillo & Sánchez-Medina, 2011). Furthermore, the velocity of movement can also be used to determine the load associated with maximum power output in various exercises (Alt et al., 2020; Pérez-Castilla; García-Ramos, 2021) which is useful for multiple sports.

The existence of an intrinsic and stable relationship between relative loads and movement velocity has been confirmed throughout the scientific literature (García-Ramos et al., 2019; García-Ramos et al., 2017; Pérez Castilla et al., 2017a). Thus, it is reliable to use this relationship for adjustments of load intensity (autoregulation), and comparing expected movement velocity *versus* observed movement velocity (Weakley et al., 2021b; Thompson et al., 2021; Dorell et al., 2020). Moreover, to control the volume of sets and maximize gains in muscle strength or hypertrophy, it is possible to determine the optimal point to interrupt each set by analyzing the gradual decline in mean velocity (MV), rather than relying on a predetermined number of repetitions. This alternative approach offers a way to improve training outcomes. (Galiano et al., 2022; Pareja-Blanco et al., 2020; Weakley et al., 2021b; Pérez-Castilla et al., 2018; Pareja-Blanco et al., 2017b). The use of velocity loss thresholds between 5-20% allows for lower total training volumes compared to traditional resistance training routines, enabling better recovery both within and between sessions, without compromising neuromuscular adaptations, although gains in hypertrophy were more pronounced when higher velocity loss thresholds were applied (Baena-Marín et al., 2022; Włodarczyk et al., 2021; Liao et al., 2021; Weakley et al., 2021; Weakley et al., 2019). Other well-known benefits of VBT are related to the safety and efficient determination of 1RM loads using sub-maximal loads (Morán-Navarro et al, 2021; Külkamp et al., 2021b; González-Badillo & Sánchez-Medina, 2011). As a result, these approaches allow coaches and practitioners to control load and make decisions in real-time.

Currently, there are a number of different commercially available equipment which can be used for VBT purposes, which vary according to the technology used to estimate the movement velocity (e.g., velocity transducers, position transducers and accelerometers), which seems to affect their precision and accuracy (Külkamp et al., 2021b). In the absence of linear velocity transducers (e.g. T-force, Ergotech, Murcia, Spain), the equipment mentioned as the most accurate and precise are linear position transducers, also known as encoders (Weakley et al., 2021a; Villanueva et al., 2021; Mitter et al., 2021; Martínez Cava et al., 2020; Courel-Ibáñez et al., 2019; Pérez-Castilla et al., 2019). Using encoders, movement velocity is estimated according to the rotational speed of their axis, where angular displacements are converted into linear distance measurements, and the time of each reading is then acquired by micro-controlled systems (Harris et al., 2010; Li et al., 2005). VBT suggests that even small variations in velocity can be related to actual changes in an athlete's physical condition (Weakley, 2019b). Depending on the precision and sensitivity of the equipment, this variation may be greater or smaller than the measurement error, which then has implications for how the subsequent data is used in practice. Given the variety of equipment currently available, it is essential to investigate the validity and reliability of each commercially available device. Furthermore, the importance of separating technological and biological error when investigating the reliability of each device has been emphasized (Weakley et al., 2021a; Courel-Ibáñez et al., 2019). According to our knowledge, there is only one scientific paper so far validating a VBT-applied device isolating technological errors (Weakley et al., 2020). The authors showed that the technological variance was around 3.96% and when biological variance was introduced the variance increased to 9.83%.

Thus, the objective of the present study was to verify concurrent validity of a novel low-cost commercial encoder (Ergonauta I) as well as its reliability based exclusively on technological variations (biological error-free). Additionally, we also verified the validity and reliability of another encoder already validated in previous studies (Vitruve) (Pérez-Castilla et al., 2019; Martínez-Cava et al., 2020; Kilgallon et al., 2022). It was hypothesized both encoders would be considered valid with no significant bias in relation to the custom reference system, as well fully reaching accuracy and agreement criteria. Furthermore, they would be considered reliable attending pre-determined criteria for sensitivity and precision.

Materials and Methods

Experimental Design

The study was carried out in three steps. In the first step, concurrent validity, accuracy, and agreement were verified comparing the two encoders (Ergonauta I and Vitruve) with reference measures of range of movement (ROM), concentric phase time (Tcon) and mean velocity (MV). In the second step, the agreement and precision of ROM, mean propulsive velocity (MPV), and peak velocity (PV) measurements of the Ergonauta I and Vitruve encoders (between devices reliability) were verified, as well as agreement and precision of ROM, MV, MPV, PV, and peak power output (PPO) of two units of the Ergonauta I (interunit reliability). In the third and last stage, 7 days after the second stage, these same protocol were performed again with one of the Ergonauta I encoder units (intradevice between-days reliability). In the second and third stages, the tests were carried out from the free fall of the bar on the Smith Machine. The study design is illustrated according to the Figure 1.

To verify the reliability during exercises, biological error was separated of technological errors (Weakley et al., 2021a). Thus, no participants were recruited in the present study, and reliability assessments were performed in a Smith Machine by bar free fall tests from pre-set heights. Five different measurements were used to assess device's reliability: ROM, MV, mean propulsive velocity (MPV), peak of velocity (PV), and peak power output (PPO; exclusively for Ergonauta I). MPV corresponds to the average velocity during the concentric phase until bar acceleration is less than gravity ($-9.81\ m/s^2$) (Sanchez-Medina et al., 2010).

Insert figure 1 here

Equipment and data acquisition

As recently suggested, gold-standard criterion measures should be utilized for validity approaches (Weakley et al., 2021a). However, in the absence of gold-standard measures such as 3D motion capture systems, a Smith Machine (Tonus, Sao Paulo, Brazil) was instrumented to determine standard distances and time interval references in which the bar would be displaced (Figure 2b). The Smith Machine allowed only guided vertical movements and presented a counterweight mechanism that confers to the system (including the bar) a mass equivalent to 10 kg. The frictional force between the bar and the guides (rails) was perceived as negligible. No extra load was applied and no traditional resistance exercises were performed, whereas a researcher moved the bar whenever necessary.

As a criterion measure of ROM, we used the own natural phenomenon of displacement, according to pre-set distances in the Smith Machine. At the first study stage, two fixed and known distances were used, previously measured with a tape measure (LufkinBrasil® – 3m long, 1 mm resolution). As a criterion measure of Tcon, the GetTickCount function from Windows® was used. This function returns the total milliseconds between events (typically updated every 16 ms at 64 Hz) and is precise enough to measure average velocity in camera-based traffic monitoring systems (Pratama et al., 2016), in addition to measuring the speed of code execution and algorithms (Rayuwat et al., 2019). At the initial and the final points of ROM, limit switches were installed (Figure 2b), to inform the computer system the when the movement begun and ended. Thus, the MV measure was then assessed as an indirect outcome, obtaining the values dividing ROM by Tcon.

Two commercially available rotary encoders were evaluated in the present study. The Ergonauta I (Ergonauta®, Florianópolis, Brazil) presents 400 pulses/revolution, 1mm/pulse resolution, and variable sampling frequency, where pulses are time-stamped with a high resolution (about every 10μs), based on digital pins interruptions checking. Data obtained in real-time by Ergonauta I were transmitted via Bluetooth to a smartphone Zenfone Maxshot – Android® 9 (ASUS®, AsusTek Computer Inc., Taipei, Taiwan). The Vitruve® encoder (Madrid, Spain) has a sampling frequency of 100 Hz, and data collected were transmitted via Bluetooth to a smartphone iPhone 7 Plus – iOS 12.4.1 (Apple®, Inc., USA) (figure 3). Both the equipment are based on the same working principle, where a retractable cable is mechanically fixed to the axis of an electromechanical sensor known as a position transducer. When the retractable cable of this equipment is coupled to the object to be monitored, all variation in displacement is converted into rotation of the transducer axis, which in turn is converted into pulses and finally computed as linear displacement. The time at which each pulse occurs is identified by the micro-controlled system of each device so that the movement velocity and other kinematic and kinetic parameters (e.g. acceleration and PPO) can then be estimated (Li et al., 2005).

Procedures

In the first stage of the study, two different distance measures were used (0.367 m and 0.475 m), which corresponded exactly to the displacement of the bar from the support point to the endpoint (maximum extension) of the guided bar of Smith Machine (figure 2a and 2b). Up and down bar movements were performed by one of the researchers and no traditional exercises were performed. Two speed intervals to be reproduced in the tests were arbitrated a priori (MV > 0.6 m/s and MV < 0.6 m/s). The researcher was instructed to move the bar faster or slower according to the objective in each repetition. Thus, it was possible to establish a set of 4 situations in which the encoders were compared with the reference system: ROM1xVM1; ROMxVM2; ROM2xVM1, and ROM2xVM2. A total of 11 repetitions were performed in each situation, allowing a wide range of MV values, usually observed in VM-based training sessions.

In stages II and III the measures were acquired based on the free fall of the bar from 3 different heights, corresponding to approximately 0.275 m, 0.622 m and 0.967 m. The bar was released from each specific height point and dropped down until it was contained by a rubber step, positioned just below, on a chair (figure 2c). A pulley system was coupled to the smith machine, in order to measure downward movements. A total of

10 repetitions were performed at each height stage. In stage II Ergonauta I and Vitruve were compared, and in stage III two units of Ergonauta I were tested and compared.

In all tests, the retractable cable of devices was attached to the same point of the barbell using a Velcro strep.

Insert Figure 2 here

Statistical Analyses

The normality of data distribution was verified by the Shapiro-Wilk test ($p>0.05$) to guarantee the application of parametric tests. Different tests and statistical procedures were used to verify the validity and reliability. Concurrent validity was determined based on comparisons of means, absolute and relative accuracy, and level of agreement between encoders and criterion measurements, testing each ROMxVM group separately. Comparisons of means were performed through ANOVA oneway (method as factor), applying Welch test correction whenever homogeneity of variance assumption was violated. Tukey's post-hoc was applied for pairwise comparisons when homogeneity of variance was present and Games-Howell when not. The effect size of differences was calculated from planned contrasts "t" values. Absolute accuracy was interpreted as root mean squared error (RMSE), while relative accuracy (accuracy %) was calculated as relative difference between criterion mean values and devices (encoders) mean values. The Lin's concordance correlation coefficient (CCC; Lin, 1989) was used as an overall agreement statistic (exclusively for Tcon and VM). CCC associates the correlation coefficient (Perason's r) between two measures (precision) with the degree of departure of the best-fit line concerning the 45th line passing through the origin (accuracy). Agreement based on CCC was interpreted as almost perfect ($CCC < 0.99$), good ($0.95 \leq CCC \leq 0.99$), moderate ($0.90 < CCC < 0 .95$) or poor ($CCC < 0.90$) (Martins et al, 2014;

McBride, 2005). Additionally, systematic difference (bias), limits of agreement and proportional bias (r≥0.3) (Bland-Altman, 1986) were also used as agreement analysis for the analysis of each ROMxVM group. The encoders should be considered valid if presenting no significant MV bias in relation to the custom reference system, as well accuracy% higher than 90%, CCC ≥ 0.95 and LoA smaller than 10% with respect to the mean bias.

The agreement inter-unit (Ergonauta I 1 vs Ergonauta I 2), and intradevice between days (Ergonauta I 1 vs Ergonauta I 1)] was verified based on systematic bias, LoA and proportional bias (r≥0.3) (Bland-Altman, 1986), as well through mean comparisons. Agreement criteria adopted were non-significant mean differences as well LoA lower than 10% related to average bias. Means comparisons between two different units of Ergonauta I and Vitruve were performed in the stage II via ANOVA one-way (device as factor), whereas in stage III (intradevice Ergonauta I between days) through "t" tests. The precision of the measurements was evaluated considering the Standard Error of Measurement (SEM), presented as Coefficient of variation (CV% = SEM÷mean ×100). As pairwise measurements corresponded always to the same heights of free fall of the bar, SEM was considered to be the own standard deviation (SD) of the measures, alluding to the term "standard deviation within the subject" by Bland-Altman (1996). The sensitivity of devices Ergonauta I and Vitruve was verified from the Smallest Detectable Change (SDC), calculated as √2*SEM*1.96. The SDC indicates the value from which a variation can be considered a real change, that is, a value outside technological error. Criteria for acceptable sensitivity were SDC < 0.07 m/s for MV, MPV and PV (Kilgallon et al., 2022; Martínez Cava et al., 2020) and for PPO SDC < 150w (considering SEM = 50w), and precision criteria was CV < 5% for all measurements.

The effect size (ES) was presented as Cohen's "r", and was interpreted as trivial (ES < 0.1), small (0.1 ≤ ES < 0.3), moderate (0.3 ≤ ES < 0.5), and large (ES ≥ 0.5) (Cohen, 1988). For t-tests a "t-value" conversion to "r-value" was calculated. Statistical analyses were performed using the IBM® SPSS® software platform (version 20) and a custom Microsoft Excel® spreadsheet (Microsoft Office®, version 16). All analysis were performed adopting a significance level of 5%.

Results

The range of velocities investigated ranged from 0.4-0.74 m/s for validity analysis, considering concurrent method. For reliability tests, MV ranged from between 0.56 to 1.02 m/s, considering Ergonauta I estimates. Table 1 show Ergonauta I and Vitruve proved to be valid, except for MV about 0.6 m/s, where a significant systematic bias was observed in relation to the reference system. It should be highlighted that Vitruve did not reach the overall threshold of validity for MV (CCC = 0.944), although the difference was small (Figure 3). LoA of MV were acceptable for both devices (<10%), although small to high heteroscedasticity was observed for MV when compared with the reference system (r = 0.2 – 0.7; table 1), where the bigger the MV, the higher the heteroscedasticity (table 1). Parallel measurements (RMSE and systematic bias) also showed this. Surprisingly, table 3 shows a significant bias observed for ROM between Ergonauta I and the concurrent method, even though the bigger absolute differences were as small as 2 mm. About Vitruve, ROM bias was quite higher, ranging from about 1 cm to 1.5 cm in average. Table 2 and Figure 4 make clear that Ergonauta I and Vitruve have no agreement one each other, regarding ROM, MPV and PV. Moreover, they present proportional bias when compared each other (r>0.3). About inter-units and intra-unit reliability of Ergonauta I, a moderate proportional bias (r = 0.32 – 0.48) was observed only for PV and PPO when comparing two different Ergonauta I units, although non-significant difference was observed in the means. Tables 2 and 3, as well the figure 5 revealed Ergonauta I and Vitruve fully reached the criteria for sensitivity and precision, proving to provide reliable measures under similar conditions as well at different ones.

*** Insert Table 1 here ***

*** Insert Figure 3 here ***

*** Insert Figure 4 here ***

*** Insert Table 2 here ***

*** Insert Table 3 here ***

*** Insert Figure 5 here ***

Discussion

The aim of the present study was to examine the validity and reliability of a newly available device designed for VBT purposes. An important aspect to highlight was that reliability of encoder was analyzed purely from a technological perspective (biological error-free), using a Smith Machine to measure the free-fall of the bar, as as a novel approach in the absence of a gold standard. As recently suggested (Courel-Ibánez et al., 2019), most of the available studies assessing VBT-applied devices have analyzed reliability disregarding the true source of error (biological or technical). Our data revealed the encoder Ergonauta I reached the pre-defined criteria of accuracy, agreement, sensitivity and precision, which allows practitioners to use it with confidence for VBT monitoring. We also confirmed the validity and reliability of the encoder Vitruve, although with some specific restrictions.

Although results showed a significant bias for MV estimated by Ergonauta I and Vitruve when compared to the reference system, the difference was detected only in one of the four ROM x VEL settings (ROM 1 x VEL 2; table 1). It should be highlighted; however, Ergonauta I and Vitruve must not be used interchangeably, as their measures differ more from each other than when compared to the reference method, for all variables (table 1, table 2 and figure 4, respectively). Surprisingly, despite the significant differences observed in Tcon and ROM estimated by Vitruve (in opposite directions), its MV estimated values did not differ in relation to the reference method here adopted (except for ROM1xVEL2 setting; table 1). It seems reasonable to suppose the non-significant difference is likely due to one error compensating each other leading to a valid MV estimative (i.e., the two errors cancel each other out). Thus, we suggest to avoid using Vitruve for ROM assessments, since our results revealed errors greater than 1-2 cm, on average.

Regarding sensitivity, SDC revealed that only values higher than approximately 0.03 m/s must to be considered as real changes in performance, for both Ergonauta I and Vitruve when monitoring MV and MPV (tables 2 and 3). In practical terms, this value allows practitioners to detect 1RM changes < 5% for most resistance exercises (Garcia-Ramos et al., 2019; Sánchez-Medina et al., 2104; Morán-Navarro et al., 2021). This value of sensitivity (SDC) was similar to the value observed by Martínez Cava et al. (2020) for Vitruve and T-force, but smaller compared to the values presented by Courel-Ibánez et al. (2019). For PV, Vitruve was slightly more sensitive than Ergonauta I (Table 2), although SDC values of Ergonauta I for PV is lower than that observed for other commercial devices (Lorenzetti et al., 2017).

Between-days intra-device reliability showed Ergonauta I remains reliable after one week for ROM, VM and MPV assessments, whereas some proportional bias (heteroscedasticity) was verified for PV and PP (table 3). Even though the observed differences are not overly high from a practical perspective, SDC values revealed that changes in PV and PPO should be considered real if greater to 0.10 m/s and 100 w, respectively, when using Ergonauta I. These results and thresholds for PV and PPO were also observed when comparing two different units of Ergonauta I at stage II (table 2). It seems important to highlight that Courel-Ibánez et al. (2019) observed higher values of SDC for PV in devices considered valid for VBT applications. Lower consistency of PV estimated by encoders has been previously reported (Lorenzetti., et al 2017). Even though PV can provide linear and reliable load-velocity relationships (García-Ramos et al., 2018), MV or MPV should be preferred when using Ergonauta I.

Kilgallon and colleagues (2022) published a recent paper assessing the validity and reliability of Vitruve. They concluded MV, MPV and PV measurements are valid and reliable, suggesting the device can provide reliable load-velocity profiles and repeatable 1-RM predictions. Nevertheless, despite MV and MPV linear models being highly reliable, they displayed poor validity given they were not sensitive enough to replace a direct assessment of 1-RM. The authors observed values of sensitivity (SDC) and precision slightly worse than that observed in our data, for all of variables. As the authors assumed, their results could not separate the errors associated with the Vitruve from those associated with the subjects. In this sense, our work demonstrated that Vitruve was shown to be more reliable when biological variability is not included. Unlike Kilgallon et al. (2022), we did not intend or plan to assess 1-RM estimations with Ergonauta I in the present study. However, it seems reasonable to suppose that if the differences between devices remain similar in a different setting (e.g., during real resistance exercises), it seems likely that estimations of 1-RM would differ as well. Moreover, based on our results, as MV and MPV estimated through Ergonauta I are higher when compared with

Vitruve during the same conditions, it is expected 1-RM values estimated by Ergonauta I will be smaller than Vitruve.

Given the Ergonauta I is only recently commercially available, there is a lack of published empirical research relating to it at present. Only one article published to date, where the Ergonauta I was used as a concurrent device to propose a new method (called Magnet method) for correcting MV estimates of the My Lift application for smartphones, has been published (Külkamp et al., 2021b). The authors showed how close the ROM measurements acquired by Ergonauta I are, compared to a real measurement of distance. As a reference measurement, the authors used a Neodymium magnet sliding over the bar of a Smith Machine during concentric movements of the bar in the bench press exercise. With this approach, the magnet works analogously as a hydraulic dynamometer dead pointer (see Külkamp et al., 2021 for details). Ergonauta I presented almost perfect correlations ($r \geq 0.99$) in relation to the magnet Method and no significant bias regarding ROM (< 1%) and MV (< 1.7%). The authors concluded that when the My Lift app is used in conjunction with the magnet method, it becomes a suitable alternative to monitor velocity during single repetitions (Martínez Cava et al., 2020; Courel-Ibáñez et al., 2019). Our results confirmed the high accuracy of Ergonauta I to estimate ROM when compared to real displacement measurements, in addition to verifying estimates of MV and MPV, when compared with two concurrent systems.

This study presents some limitations which should be acknowledged. The first one concerns the lack of a real "gold standard" method to assess movement velocity (e.g. T-force device or 3D motion capture systems). Although this is always preferred (Weakley et al., 2021a; Martínez Cava et al., 2020; Courel-Ibánez et al., 2019; Lorenzetti et al., 2017), in the absence of these technologies, we decided to get as close as possible to valid and reliable measures. Although MV was indirectly estimated, the ROM measurements provided undoubtedly correspond to the real distance travelled, given this was measured with a tape measure. As such, any error in MV estimations can be attributed to the time measurements (Tcon). Nonetheless, despite the small sampling frequency, maximal errors of about 32 ms can be expected (summing starting and ending points), which would correspond to an addition of 0.015 m/s and 0.04 m/s to the smallest and the highest MV mean values of the reference system (stage I). When looking at table 1, it can be noted that these differences would make Ergonauta I even more accurate, unlike Vitruve. A second limitation corresponds to the small spectrum of velocities investigated, ranging just from about 0.4 m/s to 0.75 m/s in the validity approach and about 0.5 m/s and 1 m/s in reliability assessments. This corresponds to loads of approximately 45-85% 1RM in the bench press (González-Badillo & Sánchez-Medina, 2010). It is well known, that velocities above and below these thresholds are traditionally applied in VBT (García-Ramos et al., 2021; Pérez-Castilla et al., 2020). Thus, some doubt remains about the validity and reliability of Ergonauta I when using lower and higher velocities, which should also be investigated in future studies.

Finally, we can state that this study has important implications for practitioners who seek to utilize VBT technology for training purposes, as it sheds light on the reliability of encoders and provides an alternative approach for assessing VBT outcomes.

Conclusion

Ergonauta I is a valid device for VBT applications when compared with a custom reference system, over the range of velocities investigated. Furthermore, it is a highly reliable equipment, considering its measurements inter and intra-device are consistent enough when biological error is removed. Our data also confirmed the validity and reliability of the encoder Vitruve, although it should not be used interchangeably with the

Ergonauta I. Furthermore, Vitruve is ill advised to be used when measuring ROM in isolation. Since the sensitivity of both encoders was about 0.03 m/s for MV and MPV, they are recommended as suitable devices to monitor performance changes during VBT approaches. We suggest that the Ergonauta I also be tested under real-life conditions (i.e., during traditional resistance exercise) to confirm the appropriateness of such device in practical settings.

References

Alt, T., Knicker, A. J., Severin, J., Horn, D., Nodler, Y. T., & Strüder, H. K. (2020). Peak power assessment of isokinetic knee flexor and extensor tests - pitfalls of a dynamometer-based assessment. *Measurement in Physical Education and Exercise Science*, 24(2), 123-128. doi:10.1080/1091367X.2020.1716237

Baena-Marín, M., Rojas-Jaramillo, A., González-Santamaría, J., Rodríguez-Rosell, D., Petro, J. L., Kreider, R. B., & Bonilla, D. A. (2022). Velocity-Based Resistance Training on 1-RM, Jump and Sprint Performance: A Systematic Review of Clinical Trials. *Sports*, 10(1), 8. https://doi.org/10.3390/sports10010008

Bland, J. M., & Altman, D. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *The lancet*, 327(8476), 307-310.

Cohen, J. (1988). Statistical power analysis for the behavioral sciences. Lawrence Erlbaum Assoc., Hillsdale, NJ. 2nd ed. Lawrence Erlbaum Assoc., Hillsdale, NJ.

Courel-Ibáñez, J., Martínez-Cava, A., Morán-Navarro, R., Escribano-Peñas, P., Chavarren-Cabrero, J., González-Badillo, J. J., & Pallarés, J. G. (2019). Reproducibility and repeatability of five different technologies for bar velocity measurement in resistance training. *Annals of Biomedical Engineering*, 47(7), 1523-1538. https://doi.org/10.1007/s10439-019-02265-6

Galiano, C., Pareja-Blanco, F., Hidalgo de Mora, J., & Sáez de Villarreal, E. (2022). Low-velocity loss induces similar strength gains to moderate-velocity loss during resistance training. *Journal of Strength & Conditioning Research*, 36(2), 340-345. https://doi.org/10.1519/jsc.0000000000003487

García-Ramos, A., Pestaña-Melero, F. L., Pérez-Castilla, A., Rojas, F. J., & Haff, G. G. (2017). Differences in the Load-Velocity Profile Between Four Bench Press Variants. *International Journal of Sports Physiology and Performance*. 13(3):326-331. https://doi.org/10.1123/ijspp.2017-0158

García-Ramos, A., Suzovic, D., & Pérez-Castilla, A. (2021). The load-velocity profiles of three upper-body pushing exercises in men and women. *Sports Biomechanics*, 20(6), 693-705. https://doi.org/10.1080/14763141.2019.1597155

García-Ramos, A., Pestaña-Melero, F. L., Pérez-Castilla, A., Rojas, F. J., & Haff, G. G. (2018). Mean velocity vs. mean propulsive velocity vs. peak velocity: which variable determines bench press relative load with higher reliability?. *The Journal* *of Strength & Conditioning Research*, 32(5), 1273-1279. https://doi.org/10.1519/jsc.0000000000001998

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.

González-Badillo, J. J., Marques, M. C., & Sánchez-Medina, L. (2011). The importance of movement velocity as a measure to control resistance training intensity. *Journal of Human Kinetics*, 29, 15-19. https://doi.org/10.2478%2Fv10078-011-0053-6

González-Badillo, J. J., & Sánchez-Medina, L. (2010). Movement velocity as a measure of loading intensity in resistance training. *International Journal Of Sports Medicine*, 31(05), 347-352. https://doi.org/10.1055/s-0030-1248333

Harris, N. K., Cronin, J., Taylor, K. L., Boris, J., & Sheppard, J. (2010). Understanding position transducer technology for strength and conditioning practitioners. *Strength & Conditioning Journal*, 32(4), 66-79. http://dx.doi.org/10.1519/SSC.0b013e3181eb341b

Hori, N., Newton, R. U., Kawamori, N., McGuigan, M. R., Kraemer, W. J., & Nosaka, K. (2009). Reliability of performance measurements derived from ground reaction force data during countermovement jump and the influence of sampling frequency. *Journal of Strength & Conditioning Research*, 23(3), 874-882. https://doi.org/10.1519/jsc.0b013e3181a00ca2

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*, “ahead of print” https://doi.org/10.1177/17543371221093189

Külkamp, W., Feunteun, Y., & Junior, N. B. (2021). Concurrent validity and reliability of self-selected movement velocity for resistance training monitoring in close grip pull-down and knee extension. *Science & Sports*, 36(6), 460-469. https://doi.org/10.1016/j.scispo.2020.06.012

Külkamp, W., Rosa-Junior, J. L., Ache-Dias, J., & Carminatti, L. J. (2021). An effective, low-cost method to improve the movement velocity measurement of a smartphone app during the bench press exercise. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology*. Ahead of print https://doi.org/10.1177/17543371211058089

Li, Yuhua & Gu, Fengshou & Harris, Georgina & Ball, Andrew & Bennett, Nick & Travis, Ken. (2005). The measurement of instantaneous angular speed. Mechanical Systems and Signal Processing. *Mechanical Systems and Signal Processing*, 19. 786-805. https://doi.org/10.1016/j.ymssp.2004.04.003

Lawrence, I., & Lin, K. (1989). A concordance correlation coefficient to evaluate reproducibility. *Biometrics*, 255-268.

Lorenzetti, S., Lamparter, T., & Lüthy, F. (2017). Validity and reliability of simple measurement device to assess the velocity of the barbell during squats. *BMC Research Notes*, 10(1), 1-5. https://doi.org/10.1186/s13104-017-3012-z

Loturco, I., Kobal, R., Moraes, J. E., Kitamura, K., Cal Abad, C. C., Pereira, L. A., & Nakamura, F. Y. (2017). Predicting the maximum dynamic strength in bench press: the high precision of the bar velocity approach. *Journal of Strength and Conditioning Research*, 31(4), 1127-1131. https://doi.org/10.1519/jsc.0000000000001670

Martínez Cava, Alejandro & Belmonte, Alejandro & Courel Ibáñez, Javier & Morán-Navarro, Ricardo & González-Badillo, Juan & Pallarés, Jesús. (2020). Reliability of technologies to measure the barbell velocity: Implications for monitoring resistance training. *Plos One*. 15. e0232465. https://doi.org/10.1371/journal.pone.0232465

Martins, W. P., & Nastri, C. O. (2014). Interpreting reproducibility results for ultrasound measurements. Ultrasound in obstetrics & gynecology: *the official journal of the International Society of Ultrasound in Obstetrics and Gynecology*, 43(4), 479-480. https://doi.org/10.1002/uog.13320

McBride, G. B. (2019). A proposal for strength-of-agreement criteria for Lin’s concordance correlation coefficient. NIWA Client Report: HAM2005-062; National Institute of Water & Atmospheric Research: Hamilton, New Zeeland, May 2005.

Mitter, B., Hölbling, D., Bauer, P., Stöckl, M., Baca, A., & Tschan, H. (2021). Concurrent validity of field-based diagnostic technology monitoring movement velocity in powerlifting exercises. *The Journal of Strength & Conditioning Research*, 35(8), 2170-2178. https://doi.org/10.1519/jsc.0000000000003143

Moore, Joseph & Dorrell, Harry. (2020). Guidelines and Resources for Prescribing Load using Velocity Based Training. *IUSCA Journal*. 1. https://doi.org/10.47206/iuscaj.v1i1.4.

Morán-Navarro, R., Martínez-Cava, A., Escribano-Peñas, P., & Courel-Ibáñez, J. (2021). Load-velocity relationship of the deadlift exercise. *European Journal of Sport Science,* 21(5), 678-684. https://doi.org/10.1080/17461391.2020.1785017

Moreno Villanueva, Adrian & Pino Ortega, Jose & Rico-González, Markel. (2021). Validity and reliability of linear position transducers and linear velocity transducers: a systematic review. *Sports Biomechanics*. "ahead of print" https://doi.org/10.1080/14763141.2021.1988136

Pareja-Blanco, F., Alcazar, J., Cornejo-Daza, P. J., Sánchez-Valdepeñas, J., Rodriguez-Lopez, C., Hidalgo-de Mora, J., ... & Ortega-Becerra, M. (2020). Effects of velocity loss in the bench press exercise on strength gains, neuromuscular adaptations, and muscle hypertrophy. *Scandinavian Journal of Medicine & Science in Sports,* 30(11), 2154-2166. https://doi.org/10.1111/sms.13775

Pareja-Blanco, F., Rodríguez-Rosell, D., Sánchez-Medina, L., Sanchis-Moysi, J., Dorado, C., Mora-Custodio, R., ... & González-Badillo, J. J. (2017). Effects of velocity loss during resistance training on athletic performance, strength gains and muscle adaptations. *Scandinavian Journal of Medicine & Science In Sports,* 27(7), 724-735. https://doi.org/10.1111/sms.12678

Pérez Castilla, Alejandro & García Ramos, Amador & Padial, Paulino & Morales-Artacho, Antonio & Feriche, Belen. (2017). Load-Velocity Relationship in Variations of the Half-Squat Exercise: Influence of Execution Technique. *The Journal of Strength and Conditioning Research*. 34(4), 1024-103. https://doi.org/10.1519/jsc.0000000000002072

Pérez-Castilla, A., García-Ramos, A., Padial, P., Morales-Artacho, A. J., & Feriche, B. (2018). Effect of different velocity loss thresholds during a power-oriented resistance training program on the mechanical capacities of lower-body muscles. *Journal of Sports Sciences*, 36(12), 1331-1339. https://doi.org/10.1080/02640414.2017.1376900

Pérez-Castilla, A., Piepoli, A., Delgado-García, G., Garrido-Blanca, G., & García-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 & Conditioning Research*, 33(5), 1258-1265. https://doi.org/10.1519/jsc.0000000000003118

Pérez-Castilla, & García-Ramos, A. (2021). Force-velocity vs. power-velocity relationships: which method provides the maximum power and optimal velocity with higher reliability during the leg cycle-ergometer and bench press throw exercises? *Measurement in Physical Education and Exercise Science*, 25(4), 294–305. https://doi.org/10.1080/1091367X.2021.1878184

Pratama, Y., Nugraha, I. B., & Samosir, E. T. (2016). Vehicle Counting and Classification for Traffic Data Acquisition. *Jurnal Teknologi*, 78(6-3). http://dx.doi.org/10.11113/jt.v78.8932

Rayuwati, & Mustapa, Mahmud & Taliang, Askar & Iskandar, Akbar. (2019). Comparison of Encoding and Decoding Methods for Binary Files. Journal of Physics: Conference Series. 1364. 012024. https://doi.org/10.1088/1742-6596/1364/1/012024.

Sanchez-Medina, L., Perez, C. E., & Gonzalez-Badillo, J. J. (2010). Importance of the propulsive phase in strength assessment. *International Journal Of Sports Medicine*, 31(02), 123-129. https://doi.org/10.1055/s-0029-1242815

Sánchez-Medina, L., González-Badillo, J. J., Pérez, C. E., & Pallarés, J. G. (2014). Velocity-and power-load relationships of the bench pull vs. bench press exercises. *International Journal of Sports Medicine*, 35(03), 209-216. https://doi.org/10.1055/s-0033-1351252

Thompson, Steve & Rogerson, David & Ruddock, Alan & Greig, Leon & Dorrell, Harry & Barnes, Andrew. (2021). A Novel Approach to 1RM Prediction Using the Load-Velocity Profile: A Comparison of Models. *Sports*. 9. 88. https://doi.org/10.3390/sports9070088.

Weakley, J., Chalkley, D., Johnston, R., García-Ramos, A., Townshend, A., Dorrell, H., ... & Cole, M. (2020a). Criterion validity, and interunit and between-day reliability of the FLEX for measuring barbell velocity during commonly used resistance training exercises. *The Journal of Strength & Conditioning Research*, 34(6), 1519-1524. https://doi.org/10.1519/jsc.0000000000003592

Weakley, J., McLaren, S., Ramirez-Lopez, C., García-Ramos, A., Dalton-Barron, N., Banyard, H., ... & Jones, B. (2020b). Application of velocity loss thresholds during free-weight resistance training: Responses and reproducibility of perceptual, metabolic, and neuromuscular outcomes. *Journal of Sports Sciences*, 38(5), 477-485. https://doi.org/10.1080/02640414.2019.1706831

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. https://doi.org/10.1007/s40279-020-01382-w

Weakley, J., Mann, B., Banyard, H., McLaren, S., Scott, T., & Garcia-Ramos, A. (2021). Velocity-based training: From theory to application. *Strength & Conditioning Journal*, 43(2), 31-49. http://dx.doi.org/10.1519/SSC.0000000000000560

Włodarczyk, M., Adamus, P., Zieliński, J., & Kantanista, A. (2021). Effects of Velocity-Based Training on Strength and Power in Elite Athletes A Systematic Review. *International Journal of Environmental Research and Public Health*, 18(10), 5257. https://doi.org/10.3390/ijerph18105257.

Figure Legends:

Figure 1. Schematic of study design

Figure 2. Instrumented Smith machine

Figure 3. Level of agreement between technologies based on the Lin's concordance correlation coefficient (CCC). Each encoder device was compared with the reference system. Tcon = concentric time. MV=mean concentric velocity. SEE = standard error of estimative.

Figure 4. Level of agreement between Ergonauta I A and Vitruve based on Bland-Altman graphs.

Figure 5. Level of agreement between Ergonauta I's devices based on Bland-Altman graphs. Left panels correspond to interunit reliability (stage II). Panels on the right correspond to between days intra-device reliability (stage III).

Table 1. Parameters of validity and agreement of encoders Ergonauta I and Virtuve when compared with the reference system

	ROM 1 x VEL 1			ROM 1 x VEL 2			ROM 2 x VEL 1			ROM 2 x VEL 2		
	RS	**Ergo**	**Vitruve**	**RS**	**Ergo**	**Vitruve**	**RS**	**Ergo**	**Vitruve**	**RS**	**Ergo**	**Vitruve**
ROM												
mean	0.367	0.366	0.375	0.367	0.366	0.377	0.475	0.477	0.491	0.475	0.477	0.492
(SD)	(0)	(0.001)	(0.001)*‡	(0)	(0.001)	(0.002)*‡	(0)	(0.001)*‡	(0.001)*‡	(0)	(0.001)*‡	(0.001)*‡
accuracy %	100	99.83	97.72	100	99.75	97.2	100	99.66	96.56	100	99.54	96.36
RMSE	------	0.001	0.008	------	0.001	0.01	------	0.002	0.016	------	0.002	0.017
Syst. bias	------	-0.001	0.008	------	-0.001	0.01	------	0.002	0.016	------	0.002	0.017
LoA	------	±0.002	±0.002	------	±0.002	±0.003	------	±0.001	0.002	------	±0.001	±0.002
Prop. Bias (r)	------	0.224* |	0.485*†	------	0.196* |	0.216* |	------	0.089	0.313*†	------	0.092	0
Tcon												
mean	0.915 (0.079)	0.869	0.991	0.587	0.546	0.657	0.900	0.847	0.991	0.646	0.60	0.0716
(SD)		(0.094)	(0.101)**‡	(0.02)	(0.02)*‡	(0.024)*‡	(0.058)	(0.071)	(0.070)*‡	(0.054)	(0.05)	(0.056)*†
accuracy %	------	95.05	91.69	------	92.9	88.16	------	94.10	89.89	------	92.82	89.16
RMSE	------	0.054	0.079	------	0.043	0.070	------	0.056	0.093	------	0.048	0.073
Syst. Bias	------	-0.045	0.076	------	-0.042	0.07	------	-0.053	0.091	------	-0.046	0.07
LoA	------	±0.062	±0.048	------	±0.023	±0.017	------	±0.038	±0.039	------	±0.024	±0.044
Prop. Bias (r)	------	0.053	0.153* |	------	0.104* |	0.196	------	0.46*†	0.278* |	------	0.527*‡	0.486*†
MV												
mean	0.404 (0.037)	0.425	0.382	0.626	0.672	0.575	0.530	0.566	0.498 (0.034)**‡	0.74	0.801	0.691
(SD)		(0.044)	(0.036)**†	(0.024)	(0.025)*‡	(0.022)*‡	(0.033)	(0.046)		(0.064)	(0.073)	(0.051)**‡
accuracy %	------	94.78	94.47	------	92.63	91.91		93.1	94.02	------	91.66	93.38
RMSE	------	0.025	0.024	------	0.048	0.051	------	0.039	0.033	------	0.064	0.054
Syst. Bias	------	0.021	-0.022	------	0.046	-0.051	------	0.037	-0.032	------	0.062	-0.049
LoA	------	±0.028	0.016	------	±0.026	±0.015	------	±0.029	±0.016	------	±0.036	±0.05
Prop. Bias (r)	------	0.203*| |	0.228*|	------	0.202*|	0.344*†	------	0.549*‡	0.017*|	------	0.722*‡	0.184*|

*statistically different from GS ($p<0.05$);**statistically different from Ergonauta I ($p<0.05$); |: small effect size; †: moderate effect size; ‡: large effect size

Syst. Bias = systematic bias; Prop. Bias = proportional bias; LoA = limits of agreement; RS = reference system; Ergo = Ergonauta I

Table 2. Inter device (inter-unit) reliability parameters of Ergonauta I.

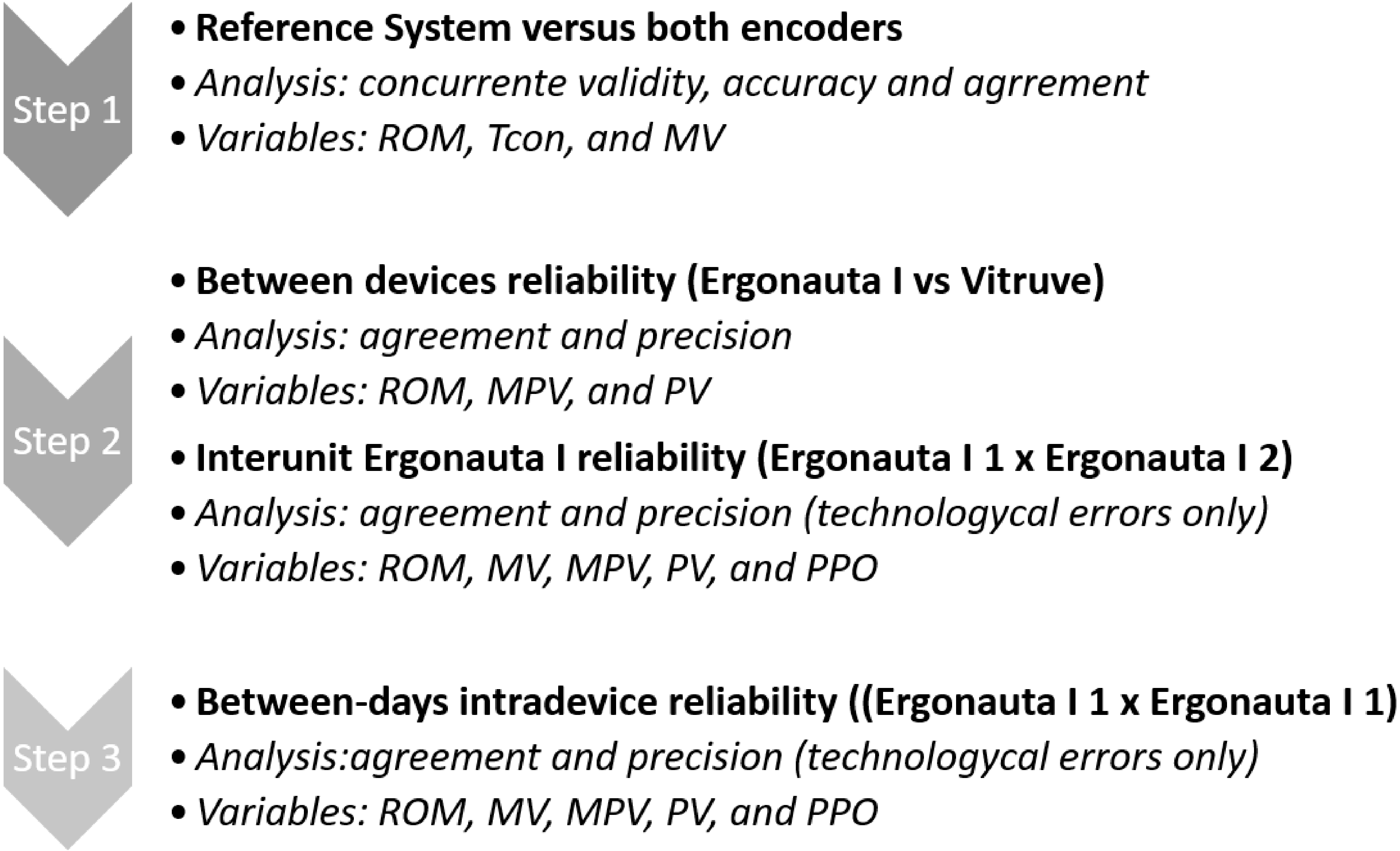
	ROM 1			ROM 2			ROM 3			Average	
	Ergo A	**Ergo B**	**Vitruve**	**Ergo A**	**Ergo B**	**Vitruve**	**Ergo A**	**Ergo B**	**Vitruve**	**Ergo**	**Vitruve**
ROM											
mean	0.278	0.280	0.285	0.627	0.626	0.640	0.974	0.976	0.989		
(SD)	(0.002)	(0.002)	(0.003)**‡	(0.002)	(0.001)	(0.002)**‡	(0.003)	(0.005)	(0.001) **‡		
SDC	0.006	0.006	0.008	0.006	0.003	0.006	0.008	0.014	0.003	0.007	0.006
CV%	0.719	0.714	1.053	0.319	0.160	0.313	0.308	0.512	0.101	0.455	0.489
MPV											
mean	0.558	0.565	0.513	0.810	0.807	0.773	1.003	0.999	0.965		
(SD)	(0.009)	(0.006)	(0.008)**‡	(0.013)	(0.013)	(0.009)**‡	(0.015)	(0.013)	(0.010)**‡		
SDC	0.025	0.017	0.022	0.036	0.036	0.025	0.042	0.036	0.028	0.032	0.025
CV%	1.613	1.062	1.559	1.605	1.611	1.035	1.496	1.301	1.036	1.448	1.210
MV											
mean	0.563	0.573		0.815	0.813		1.014	1.021			
(SD)	(0.009)	(0.008)	------	(0.013)	(0.013)	------	(0.011)	(0.010)	------		
SDC	0.025	0.022	------	0.036	0.036	------	0.030	0.028	------	0.030	------
CV%	1.599	1.396	------	1.595	1.599	------	1.085	0.979	------	1.376	------
PV											
mean	1.011	1.027	0.986	1.581	1.574	1.453	1.943	2.014	1.803		
(SD)	(0.013)	(0.011)	(0.013)**‡	(0.037)	(0.053)	(0.038)**‡	(0.03)	(0.059)	(0.012)**‡		
SDC	0.036	0.030	0.036	0.103	0.147	0.105	0.083	0.164	0.033	0.094	0.058
CV%	1.286	1.071	1.318	2.340	3.367	2.615	1.544	2.929	0.666	2.090	1.533
PPO											
mean	979.7	980.5		1528.4	1571.3		1875.5	1954.7			
(SD)	(38.716)	(10.501)	------	(42.834)	(59.046)	------	(33.237)	(66.47)	------		
SDC	107.315	29.107	------	118.730	163.667	------	92.128	184.245	------	115.866	------
CV%	3.952	1.071	------	2.803	3.892	------	1.772	3.401	------	2.815	------

**statistically different from Ergonauta I (p<0.05); |: small effect size ; †: moderate ES; ‡: large effect size; Ergo = Ergonauta

Table 3. Between-days (Intra-unit) reliability parameters of Ergonauta I.

	ROM 1		**ROM 2**		**ROM 3**		**Average**
	Ergo A	**Ergo A**	**Ergo A**	**Ergo A**	**Ergo A**	**Ergo A**	**Ergo A**
ROM							
mean (SD)	0.278 (0.002)	0.276 (0.002)	0.627 (0.002)	0.623 (0.002)	0.974 (0.003)	0.970 (0.003)	
SDC	0.006	0.006	0.006	0.006	0.008	0.008	0.006
CV%	0.719	0.725	0.319	0.321	0.308	0.309	0.450
MPV							
mean (SD)	0.558 (0.009)	0.554 (0.006)	0.810 (0.013)	0.809 (0.010)	1.003 (0.015)	0.999 (0.011)	
SDC	0.025	0.017	0.036	0.028	0.042	0.030	0.030
CV%	1.613	1.083	1.605	1.236	1.496	1.101	1.356
MV							
mean (SD)	0.563 (0.009)	0.564 (0.007)	0.815 (0.013)	0.811 (0.010)	1.014 (0.011)	1.007 (0.008)	
SDC	0.025	0.019	0.036	0.028	0.030	0.022	0.027
CV%	1.599	1.241	1.595	1.233	1.085	0.794	1.258
PV							
mean (SD)	1.011 (0.013)	1.055 (0.020)	1.581 (0.037)	1.613 (0.021)	1.943 (0.03)	2.008 (0.050)	
SDC	0.036	0.055	0.103	0.058	0.083	0.139	0.079
CV%	1.286	1.896	2.340	1.302	1.544	2.490	1.810
PPO							
mean (SD)	979.7 (38.716)	1017.2 (20.601)	1528.4 (42.834)	1558.6 (24.149)	1875.5 (33.237)	1953.8 (64.116)	
SDC	107.315	57.103	118.730	66.938	92.128	177.720	103.322
CV%	3.952	2.025	2.803	1.549	1.772	3.282	2.564

Ergo = Ergonauta



Step 1

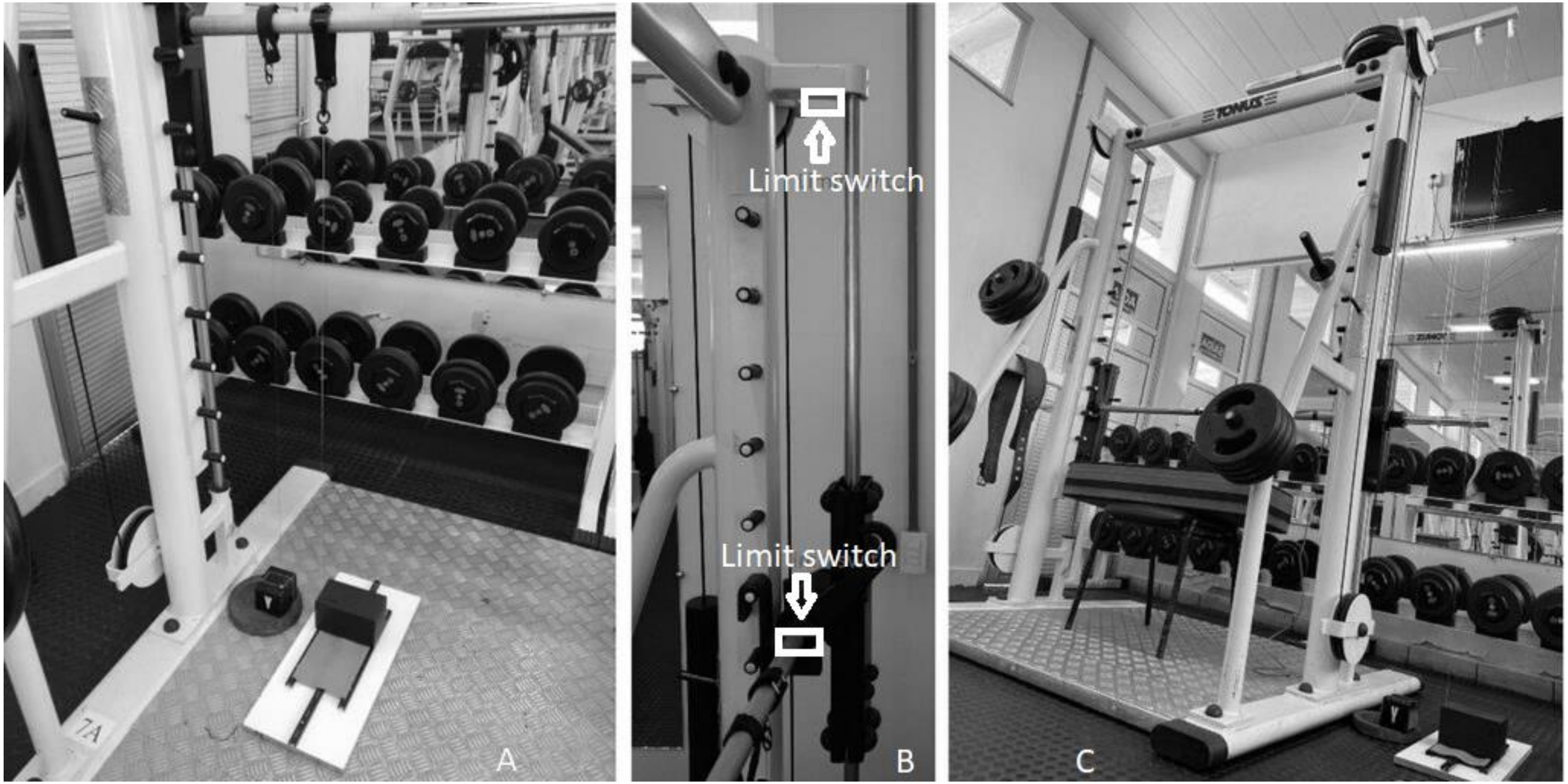
- **Reference System versus both encoders**
- *Analysis: concurrente validity, accuracy and agrrement*
- *Variables: ROM, Tcon, and MV*

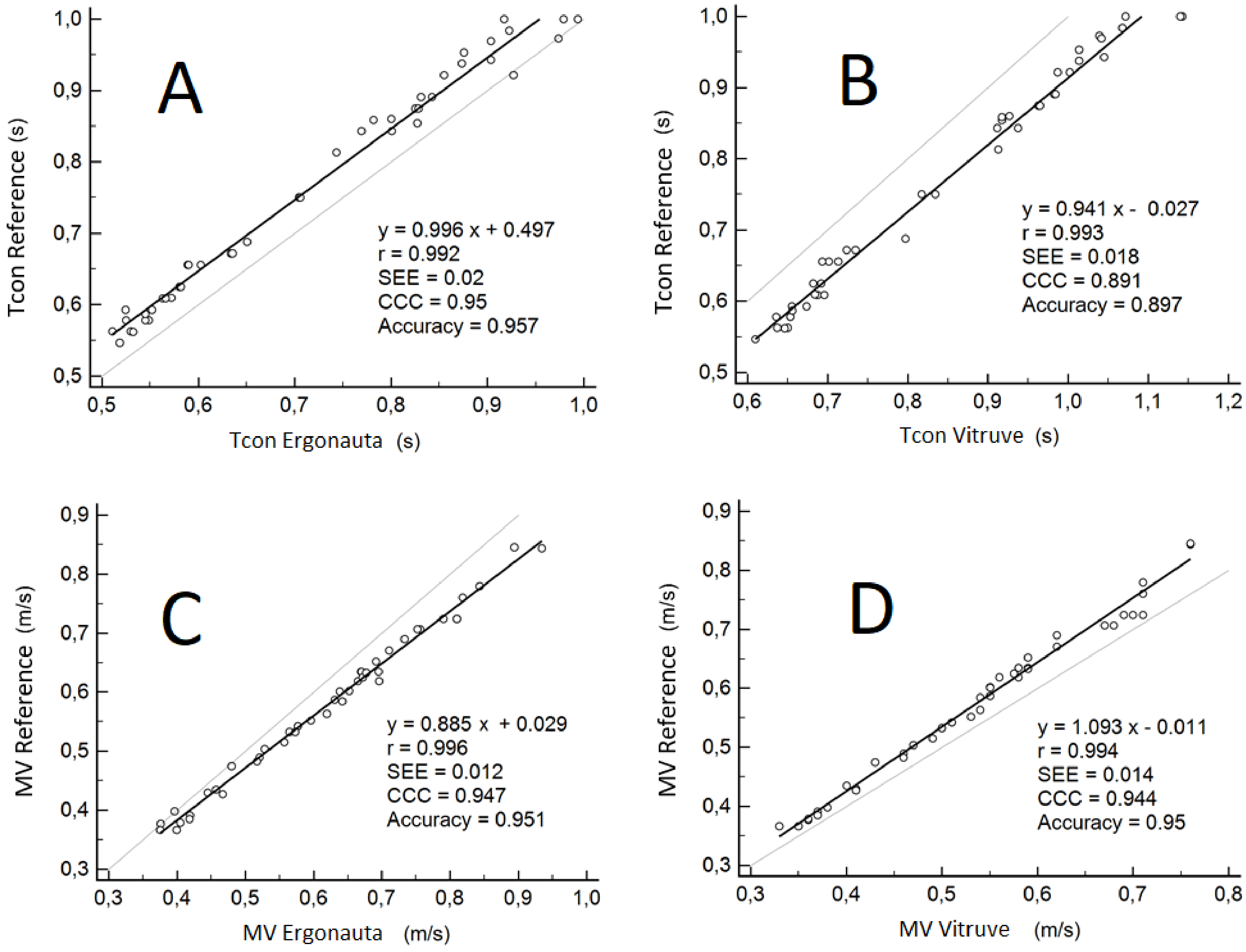
Step 2

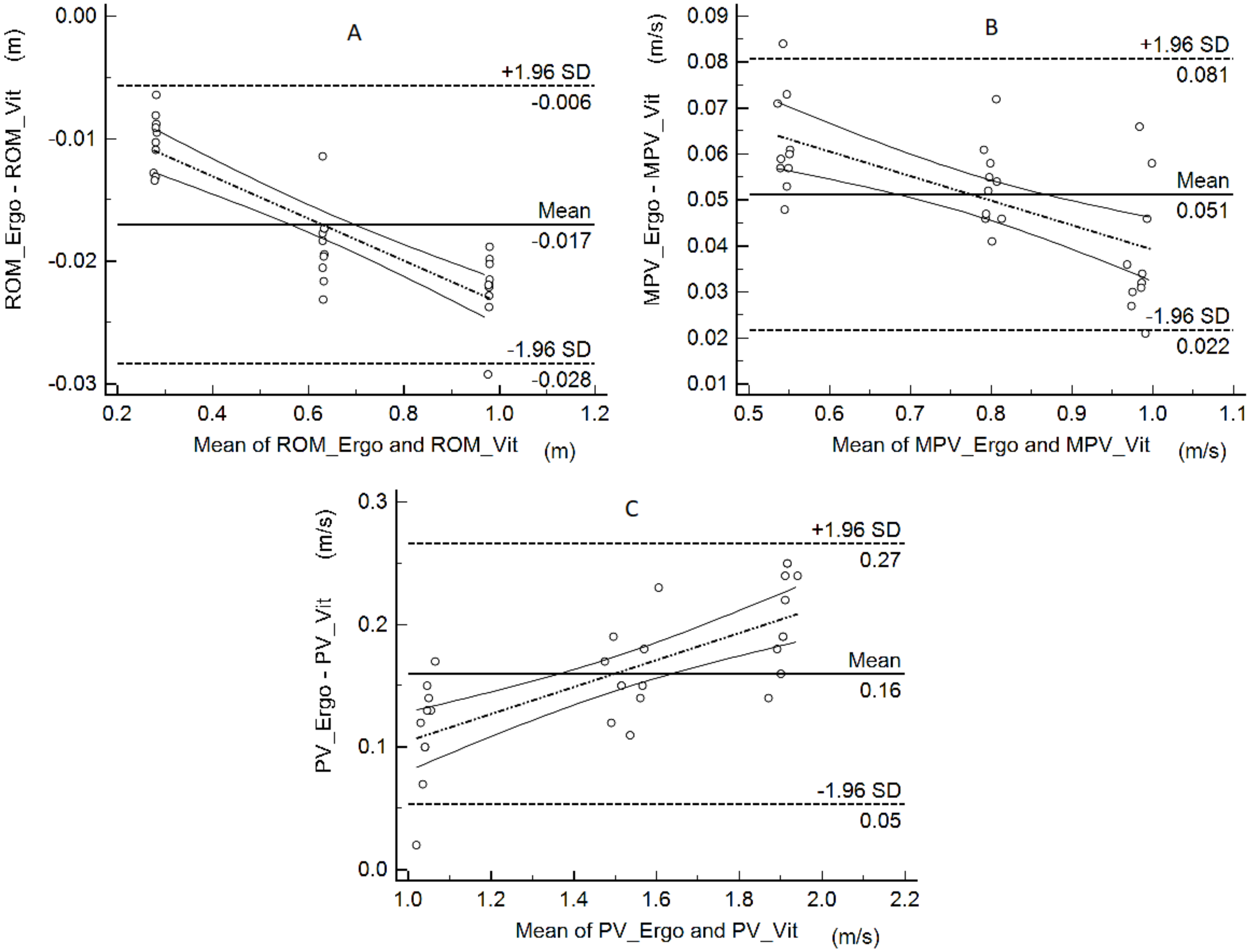
- **Between devices reliability (Ergonauta I vs Vitruve)**
- *Analysis: agreement and precision*
- *Variables: ROM, MPV, and PV*
- **Interunit Ergonauta I reliability (Ergonauta I 1 x Ergonauta I 2)**
- *Analysis: agreement and precision (technologycal errors only)*
- *Variables: ROM, MV, MPV, PV, and PPO*

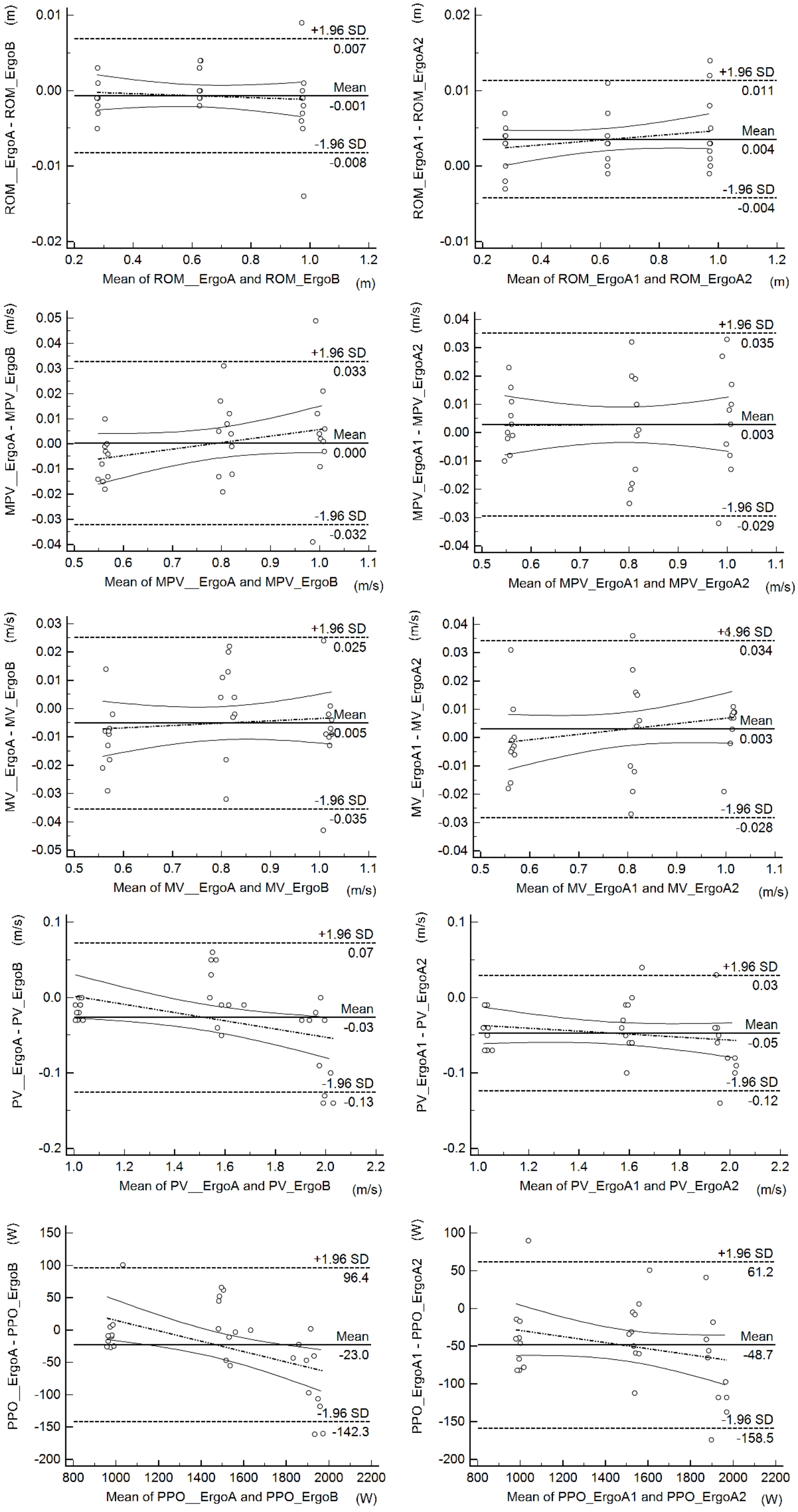
Step 3

- **Between-days intradevice reliability ((Ergonauta I 1 x Ergonauta I 1)**
- *Analysis:agreement and precision (technologycal errors only)*
- *Variables: ROM, MV, MPV, PV, and PPO*


7A
A
Limit switch
Limit switch
B
TONUS
C


A
y = 0.996 x + 0.497
r = 0.992
SEE = 0.02
CCC = 0.95
Accuracy = 0.957
Tcon Reference (s)
Tcon Ergonauta (s)
1,0
0,9
0,8
0,7
0,6
0,5
0,5
0,6
0,7
0,8
0,9
1,0
B
y = 0.941 x - 0.027
r = 0.993
SEE = 0.018
CCC = 0.891
Accuracy = 0.897
Tcon Reference (s)
Tcon Vitruve (s)
1,0
0,9
0,8
0,7
0,6
0,5
0,6
0,7
0,8
0,9
1,0
1,1
1,2
C
y = 0.885 x + 0.029
r = 0.996
SEE = 0.012
CCC = 0.947
Accuracy = 0.951
MV Reference (m/s)
MV Ergonauta (m/s)
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,3
0,4
0,5
0,6
0,7
0,8
0,9
1,0
D
y = 1.093 x - 0.011
r = 0.994
SEE = 0.014
CCC = 0.944
Accuracy = 0.95
MV Reference (m/s)
MV Vitruve (m/s)
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,3
0,4
0,5
0,6
0,7
0,8


A
+1.96 SD
-0.006
Mean
-0.017
-1.96 SD
-0.028
ROM_Ergo - ROM_Vit (m)
0.00
-0.01
-0.02
-0.03
0.2
0.4
0.6
0.8
1.0
1.2
Mean of ROM_Ergo and ROM_Vit (m)
B
+1.96 SD
0.081
Mean
0.051
-1.96 SD
0.022
MPV_Ergo - MPV_Vit (m/s)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.5
0.6
0.7
0.8
0.9
1.0
1.1
Mean of MPV_Ergo and MPV_Vit (m/s)
C
+1.96 SD
0.27
Mean
0.16
-1.96 SD
0.05
PV_Ergo - PV_Vit (m/s)
0.3
0.2
0.1
0.0
1.0
1.2
1.4
1.6
1.8
2.0
2.2
Mean of PV_Ergo and PV_Vit (m/s)


ROM__ErgoA - ROM_ErgoB (m)
Mean of ROM__ErgoA and ROM_ErgoB (m)
+1.96 SD
0.007
Mean
-0.001
-1.96 SD
-0.008
ROM_ErgoA1 - ROM_ErgoA2 (m)
Mean of ROM_ErgoA1 and ROM_ErgoA2 (m)
+1.96 SD
0.011
Mean
0.004
-1.96 SD
-0.004
MPV__ErgoA - MPV_ErgoB (m/s)
Mean of MPV__ErgoA and MPV_ErgoB (m/s)
+1.96 SD
0.033
Mean
0.000
-1.96 SD
-0.032
MPV_ErgoA1 - MPV_ErgoA2 (m/s)
Mean of MPV_ErgoA1 and MPV_ErgoA2 (m/s)
+1.96 SD
0.035
Mean
0.003
-1.96 SD
-0.029
MV__ErgoA - MV_ErgoB (m/s)
Mean of MV__ErgoA and MV_ErgoB (m/s)
+1.96 SD
0.025
Mean
-0.005
-1.96 SD
-0.035
MV_ErgoA1 - MV_ErgoA2 (m/s)
Mean of MV_ErgoA1 and MV_ErgoA2 (m/s)
+1.96 SD
0.034
Mean
0.003
-1.96 SD
-0.028
PV__ErgoA - PV_ErgoB (m/s)
Mean of PV__ErgoA and PV_ErgoB (m/s)
+1.96 SD
0.07
Mean
-0.03
-1.96 SD
-0.13
PV_ErgoA1 - PV_ErgoA2 (m/s)
Mean of PV_ErgoA1 and PV_ErgoA2 (m/s)
+1.96 SD
0.03
Mean
-0.05
-1.96 SD
-0.12
PPO__ErgoA - PPO_ErgoB (W)
Mean of PPO__ErgoA and PPO_ErgoB (W)
+1.96 SD
96.4
Mean
-23.0
-1.96 SD
-142.3
PPO_ErgoA1 - PPO_ErgoA2 (W)
Mean of PPO_ErgoA1 and PPO_ErgoA2 (W)
+1.96 SD
61.2
Mean
-48.7
-1.96 SD
-158.5