ORIGINAL SCIENTIFIC PAPER

The use of Loss Velocity and the Rate of Perceived Exertion to Assess Effort Intensity During Sets of Bench Press Exercise Performed until Exhaustion

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Abstract

The objective of the present study was to verify the agreement and correlation between effort intensity determined from the rate of perceived exertion (RPE) and loss velocity in sets performed to exhaustion in the bench press exercise at a self-selected velocity. Thirty-five men and women practitioners of resistance training (33.61±8.16 years; 172.75±11.04 cm of stature; 76.79±15.57 kg of body mass) were evaluated. Participants were familiarized and then performed two sets of bench press performed until exhaustion at a self-selected velocity at 70% and 85% of one-repetition maximum (1RM). Loss velocity was measured by a linear position transducer (Ergonauta® encoder) applied to velocity-based training. A 3-point RPE scale was used to evaluate the perceived exertion of the individuals. The analysis of agreement (Kappa test) and correlation (Spearman test) were applied ($p<0.05$). The results of the study indicated the existence of a moderate degree of agreement ($\kappa = 0.499$; $\kappa = 0.509$ for 70% and 85% of 1RM, respectively), but a strong correlation ($\rho = 0.720$; $\rho = 0.753$ for 70% and 85% of 1RM, respectively) between the effort intensity determined by the Ergonauta and the RPE, at both intensities analyzed (70% and 85% of 1RM). Despite the lack of perfect agreement between methods, loss velocity and RPE seem to demonstrate strong consistency, allowing both to be used for controlling intensity in resistance training. The results of this study should be interpreted in light of individual characteristics, type of exercise, and training objectives.

Keywords: *resistance training, velocity-based training, rate of perceived exertion, movement velocity, bench press, biomechanics*

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LOSS VELOCITY AND RPE IN RESISTANCE TRAINING
http://mjssm.me/?sekcija=article&artid=282

Cite this article: Antunes, L., Külkamp, W., Dal Pupo, J. (2024) The use of Loss Velocity and the Rate of Perceived Exertion to Assess Effort Intensity During Sets of Bench Press Exercise Performed until Exhaustion. *Montenegrin Journal of Sports Science and Medicine*, 20 (2), 57–63. https://doi.org/10.26773/mjssm.240907

Received: 19 June 2024 | Accepted after revision: 20 August 2024 | Early access publication date: 01 September 2024 | Final publication date: 15 September 2024

Conflict of interest: None declared.

Introduction

Movement velocity has been utilized in recent years as a reliable and objective variable for monitoring resistance training (RT) intensity (González-Badillo; Sánchez-Medina, 2010; González-Badillo et al., 2011). The concept of velocity-based training (VBT) in RT is a method in which prescription may be based on two perspectives: intensity control (i.e., lifted weight) through the load-velocity relationship and training volume control through the percentage drop in velocity over a set (González-Badillo et al., 2011). Several studies have demonstrated an inverse and linear relationship between relative loads (% of one maximum repetition - 1RM) and movement velocity, a relationship that remains stable regardless of the improvement or worsening of the assessed individual's physical condition (González-Badillo and Sánchez-Medina, 2010; Conceição et al., 2016; Sánchez-Medina et al., 2017). According to this relationship, it is possible to estimate the expected execution velocity for any relative load, allowing for load control based on a single repetition, eliminating the need for maximum tests (Galiano, 2020; Külkamp, 2021b).

Important to mention that these applications of VBT are conditioned on the exercise being performed at the maximum intended velocity, defined as the intention to move the external resistance (bar, equipment) at the highest possible velocity (Badillo; Medina, 2010; Medina et al., 2014; Conceicao et al., 2016; Loturco et al., 2016; 2017; Moreno et al., 2017). However, the use of ballistic/explosive resistance exercises may not be as suitable for certain populations in RT programs, such as beginners or individuals with some type of musculoskeletal compromise (Lachance; Hortobagyi, 1994), or even for practitioners with specific goals, such as hypertrophy (Scott et al., 2016).

In practice, the majority of RT practitioners often perform repetitions at self-selected velocity (SSV), which refers to voluntarily executed repetitions without external control (Nóbrega et al., 2018; Külkamp et al., 2021a). In Nóbrega et al. (2018) study, the effects of repetition duration with self-selected and fixed velocity (cadence 2:2) were compared in a resistance exercise regarding volume, muscle activation, and time under tension per repetition and session. The authors concluded that the duration of repetition at self-selected velocity resulted in greater volume and muscle activation compared to fixed duration in an RT session. Thus, SSV may be considered as a potential alternative to maximum intended velocity for real-time monitoring of resistance exercises, but still needs more investigation, especially in the context of VBT.

A linear position transducer recently introduced to the market (Ergonauta®) allows the determination of three distinct effort zones controlled by the loss of SSV (zone 1 - light or comfortable effort; zone 2 - moderate effort; and zone 3 - heavy effort, where concentric or voluntary failure is imminent) representing the effort throughout a set (Külkamp et al., 2021a, 2021b). This progressive loss of velocity during a set can be interpreted as a sign that neuromuscular function has been impaired; thus, its evaluation can also provide a simple and objective means of quantifying fatigue levels (Izquierdo et al., 2006; Sánchez-Medina; González-Badillo, 2011). Therefore, the use of these effort zones in a set of exercise may limit the amount of induced fatigue and provide better overall control of training volume, according to desired objectives (Külkamp, 2021b; Jovanovic; Flanagan, 2014).

Among the tools for controlling training intensity, the rate of perceived exertion (RPE) has also been widely used in different contexts of physical training (Bjarnason-Wehrens et al., 2004; Williams et al., 2007). As described by Tiggemann et al. (2010), some studies have sought to find relationships between RPE and different RT variables, such as relative intensity (% of 1RM), volume, and movement velocity. According to the authors, RPE seems to be a method related to different RT variables, especially the load. However, more investigations on the relationship between RPE and movement velocity are still necessary. In recent studies (Külkamp, 2017, 2021a), it has been suggested that progressive loss of SSV seems to correspond to changes in RPE, suggesting that SSV loss may be indicative of progressive neuromuscular fatigue.

Considering the growing interest and feasibility of using movement velocity for monitoring RT intensity and the scarcity of studies using SSV as a control variable in VBT, the objective of the present study is to verify the agreement and correlation between effort intensity determined by RPE and loss of SSV, measured by a device in sets performed to exhaustion in the bench press exercise. The main hypothesis of the study is that effort intensity assessed from both methods would show moderate agreement and correlation, given the distinction between the psychometric (RPE) and mathematical (encoder) evaluation methods.

Methods

Participants

Eighteen men and seventeen women practitioners of RT participated in this study (age 33.61±8.16 years, height 172.75±11.04 cm, body mass 76.79±15.57 kg). The selection of participants was non-probabilistic (non-random) and intentional (specific group focus). The inclusion criteria were: experience in RT for at least 6 months; to be familiarized with the bench press exercise; no history of musculoskeletal injuries in the upper limbs. Exclusion criteria were: failure to complete the experimental protocols and engaging in upper limb training sessions (chest, deltoid, and triceps) 48 hours before the tests.

All participants signed the Informed Consent Form before data collection, where they were informed about all procedures used during the research, potential benefits and risks associated with the study, assurance of anonymity, as well as the use of their data in the research and for scientific purposes. The project approved by the Ethics Committee on research involving human subjects at the Federal University of Santa Catarina - Brazil.

Design and procedures

This is an analytical descriptive study with a cross-sectional design. The study was conducted on two non-consecutive days. On the 1st day was performed the anthropometric measurements (height and body mass), estimation of 1RM load based on the velocity of a single repetition (using predictive equations), and the familiarization with movement and the 3-point RPE scale. Subsequently, two sets of bench press exercise to concentric failure were conducted at 70% or 85% of 1RM (randomly determined). On the 2nd day two sets of bench press exercise were performed at one of the intensities (70% or 85% of 1RM). A 10-minute interval was given between sets, and there was a minimum of 48 hours between assessment sessions.

All tests were preceded by a warm-up protocol, consisting of 5 minutes of vertical ergometer cycling (elevation series lifecycle®) at a light intensity and self-selected cadence, along with a set of 15 repetitions of the bench press exercise (40% of 1RM). The sets performed at 70% and 85% of 1RM were performed out to exhaustion, considering concentric failure. During the sets, individuals were instructed to perform the concentric and eccentric phases of the exercise at a self-selected velocity (freely, but not the slowest or fastest possible). The concentric phase was considered when the subject completed full elbow extension and the eccentric phase was when the bar touched the chest or reached at least a 90º angle at the elbow. The positioning of individuals was standardized as follows: a flat bench positioned so that the bar's trajectory coincided with the subject's chest line, both feet on the ground, and grip width adjusted so that the wrist was aligned with the elbow (90º angle).

Estimation of 1RM based on predictive equations

Two equations based on movement velocity were used to estimate 1RM for for males (1) and females (2) (Torrejón, 2019). These equations were selected based on the results of a pilot study, which revealed lower estimation errors compared to other equations available in the literature. A test consisting of two repetitions at the maximum intended velocity of the bench press exercise in the Smith machine was performed to determine movement velocity. A third attempt was made if there was a difference greater than 10% between the previous repetitions, ensuring greater reliability for the measure. A 15-second interval was given between repetitions. It was used a load typically used for warm-up in the participant's training routine, allowing velocity values between 0.6 m/s and 1.0 m/s, measured by using a linear encoder (Ergonauta®). The repetition with the highest velocity was used for analysis. Ultimately, the acquired values were used to estimate individuals' maximum dynamic load (1RM) and subsequently for calculating loads corresponding to 70% and 85% of 1RM.

Movement Velocity= -0,0165*%1RM+1,81 (Equation 1)
Movement Velocity= -0,0148*%1RM+1,72 (Equation 2)

Movement velocity acquisition and determination of intensity zones

Linear velocity during the bench press exercise was assessed using a position transducer (Ergonauta®, Florianópolis, Brazil), consisting of an incremental encoder (400 pulses per revolution), retractable cable, and an acquisition system. The Ergonauta has a resolution of 1mm/pulse and variable sampling frequency, where pulses are marked at high resolution (approximately every 10μs) (Külkamp, 2021b). Real-time data obtained by the Ergonauta were transmitted via Bluetooth to the Samsung Galaxy S6 Lite Android® 10 Tablet (Samsung®, Suwon, South Korea). The validity, reliability, and sensitivity of the Ergonauta encoder were recently confirmed (Külkamp et al., 2023).

The device determines three distinct effort zones (Figure 1), based on the identification of two transition thresholds. The first threshold marks the end of the zone considered light or comfortable effort (green color) and the beginning of the second zone, considered moderate effort (yellow color). According to the manufacturer, the first threshold occurs when there is a significant drop in SSV in the repetition corresponding to approximately 65% of the total possible repetitions. Finally, the device allows the identification of a third zone (failure zone - red color), considered heavy effort, where concentric or voluntary failure is imminent (Külkamp et al., 2021a).

In a recent study, Külkamp (2021a) concluded that, regardless of the type of resistance exercise and the number of repetitions performed, these thresholds behave very similarly, reaching approximately the same point within the sets. The study also concluded that these effort zones appear to correspond to changes in the intensity of perceived effort.

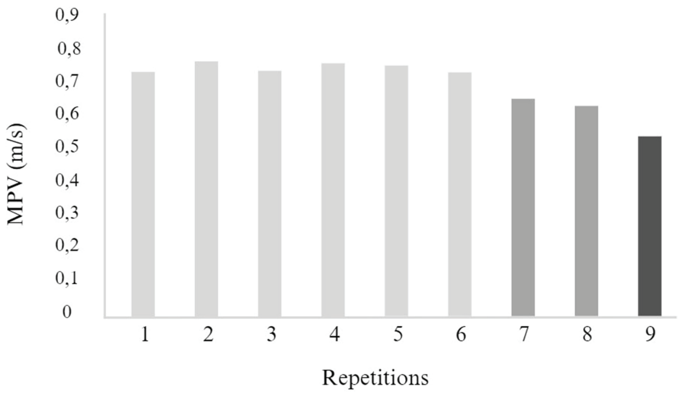

Figure 1. Illustration of a representative set showing the three effort zones determined by the Ergonauta (the colors used in the figure are in gray scale and are representative, with light gray representing the color green, medium gray representing yellow and dark gray representing red.)

RPE scale

A 3-point RPE scale (Figure 2) was used during the tests to assess the effort perceived by individuals. Visual descriptors of the scale were displayed and explained to the participants: Zone 1 (green), was associated with a sensation of "light/comfortable" effort; Zone 2 (yellow) was associated with a sensation of "moderate" effort; and Zone 3 (red) was associated with a sensation of "heavy/intense" effort. Then, the participants were instructed to report, repetition by repetition, one of the colors of the scale (green, yellow or red) at the end of the concentric phase of the movement, based on their perceived of effort, until concentric failure was reached.

The scores on the 3-point RPE scale are interval in nature and were developed based on scores from zero to 10 of the OMNI-Resistance Exercise scale (OMNI-RES) (Robertson et al., 2003). According to the study of Külkamp (2021a), which compared the three effort zones of the Ergonauta with the

OMNI-RES scale (Robertson et al., 2003), Zone 1 was associated with RPE values ≤6, Zone 2 with RPE values of 7 and 8, and Zone 3 with RPE values ≥9. Thus, three scores were determined on the scale to be used in the present study (3-point RPE scale), aiming to resemble the three effort zones present in the Ergonauta device.

Figure 2. 3-point adapted Rating of Perceived Exertion (RPE) scale. Scale adapted from the OMNI-RES scale by Robertson et al. (2003) (the colors used in the figure are in gray scale and are representative, with light gray representing the color green, medium gray representing yellow and dark gray representing red.)

Statistical analysis

The data were presented using descriptive statistics (mean and standard deviation). The Kappa concordance coefficient and Spearman correlation were employed to assess the agreement and correlation of effort zones determined by the Ergonauta and based on RPE. The Landis and Koch's classification (1977) was considered for Kappa test: $\kappa < 0$: no concordance, $\kappa = 0\text{-}0.2$: minimal concordance, $\kappa = 0.21\text{-}0.4$: reasonable concordance, $\kappa = 0.41\text{-}0.6$: moderate concordance, $\kappa = 0.61\text{-}0.8$: substantial concordance, $\kappa = 0.81\text{-}1$: perfect concordance. For Spearman correlation test it was used the Mukaka's classification (2012): $\rho = \pm 0$ to ± 0.19: very weak correlation, $\rho = \pm 0.2$ to ± 0.39: weak correlation, $\rho = \pm 0.4$ to ± 0.69: moderate correlation, $\rho = \pm 0.7$ to ± 0.89: strong correlation, $\rho = \pm 0.9$ to ± 1: very strong correlation. Only the sets that met all the previously established criteria in the study, particularly regarding exercise execution, were included in the analysis. A significance level of $p \leq 0.05$ was adopted for all inferential analyses. The SPSS software was used for statistical analyses.

Results

Table 1 presents the mean and standard deviation of age, height, body mass, and the load used during the tests (70%1RM and 85%1RM) for all subjects, separated by gender.

Table 1. Age, Height, Body Mass, and Load of the Subjects

	n	Age (years)	Height (m)	Body Mass (kg)	Load (kg) 70%1RM	Load (kg) 85%1RM
Male	18	33.11±7.53	1.80±6.93	86.89±12.44	66±19.16	73.7±19.13
Female	17	34.18±9.02	1.64±8.17	65.5±9.97	22.97±8.20	26.21±9.55
Total	35	33.61±8.16	1.73±11.04	76.79±15.57	44.47±26.14	50.64±28.30

In Tables 2 and 3 are presented the level of agreement between the effort intensity zones determined by the Ergonauta (Zone 1 = light; Zone 2 = moderate; Zone 3 = heavy) and the effort zones based on RPE (green = light/comfortable; yellow = moderate; red = heavy/intense) for relative loads of 70% and 85% of 1RM, respectively. The Kappa test indicated a moderate agreement between the intensity zones determined by the Ergonauta and the effort zones based on RPE at both intensities ($\kappa = 0.499$; $\kappa = 0.509$ for 70% and 85% of 1RM, respectively).

Table 2. Level of Agreement Between the Intensity Zones Determined by Ergonauta and the Effort Zones Based on RPE at 70% of 1RM

		Ergonauta		
		Zone 1	Zone 2	Zone 3
RPE	Zone 1	68.59%	6.91%	0.72%
	Zone 2	21.65%	34.39%	16.57%
	Zone 3	2.03%	17.54%	58.38%

Table 3. Level of Agreement Between the Intensity Zones Determined by Ergonauta and the Effort Zones Based on RPE at 85% of 1RM

		Ergonauta		
		Zone 1	Zone 2	Zone 3
RPE	Zone 1	69.25%	2.10%	0.00%
	Zone 2	24.05%	36.08%	7.33%
	Zone 3	4.06%	25.18%	59.23%

The correlation analysis (Spearman test) indicated that at both intensities (70%1RM and 85%1RM), there was a strong correlation between the intensity zones determined by the Ergonauta and the effort zones based on RPE (ρ = 0.720; ρ = 0.753 for 70% and 85% of 1RM, respectively; p<0.0001).

Lastly, in Table 4 is presented the frequency (absolute and relative) of the agreement between the effort zones of RPE and determined by the Ergonauta for each repetition over the sets.

Table 4. Magnitude and Relative Frequency of the Agreement Differences Between the Zones Reported by the Subjects and Those Determined by Ergonauta in the Total Number of Repetitions Analyzed in the Study

70%1RM (n= 669 reps)				85%1RM (n= 739 reps)			
Difference	F	F (%)	∑%	Difference	F	F (%)	∑%
0	459	68.60		0	508	68.74	
1	196	29.30	97.9	1	210	28.42	97.16
2	14	2.1	100	2	21	2.84	100

Note. f: frequency; f(%): relative frequency; ∑%: sum of relative frequencies

Discussion

There has been a growing interest in the use of the movement velocity for monitoring RT intensity. However, there is still a lack of studies showing the possibilities of application and the relationship with the variables of RT. In this context, in the present study we aimed to verify if the loss velocity and the rate of perceived exertion show the same effort intensity during sets of bench press exercise performed until exhaustion.

The main results showed a moderate degree of agreement, but a strong correlation between the intensity of effort determined by the Ergonauta and the RPE at both analyzed intensities (70%1RM and 85%1RM). Despite not being broadly concordant, the strong relationship between the methods allows us to say that both can discriminate the intensity of individuals in a similar way during bench press sets. Notwithstanding both parameters may reflect the intensity training, it is important to highlight that RPE is a psychometric and subjective measure (Hackett et al., 2018) while the Ergonauta device provides a mathematical determination of effort intensity based on the progressive loss of self-selected movement velocity. Thus, a non-perfect agreement between them could be expected.

Some studies have suggested that monitoring movement velocity during RT allows for a precise estimation of how many repetitions are left in reserve in a given exercise set, corresponding to the concept of 'effort level' (González-Badillo; Marques, and Sánchez-Medina, 2011; González-Badillo et al., 2016; Pareja-Blanco et al., 2017; González-Badillo; Sánchez-Medina, 2011). Halperin et al. (2022) and Hackett et al. (2018) investigated the accuracy in predicting/estimating repetitions to failure in RT. The authors concluded that prediction accuracy might be better if predictions are made closer to failure, in sets with lower repetition volume, and when using heavier loads. Some of these results coincide with those found in the present study, where better agreement values were found in Zone 3 (failure zone) compared to Zone 2 (transition zone), as well as slightly higher agreement values at the higher intensity (85%1RM). In Halperin et al.'s (2022) study, the authors suggest that this occurs because performing more repetitions allows a wide range of errors compared to sets with a lower repetition volume.

Due to its feasibility, RPE is certainly one of the most used metrics for controlling the intensity in physical training. However, the method presents some limitations and particularities. According to Hackett et al. (2018), RPE seems unable to discriminate momentary failure and is a subjective measure for which accuracy cannot be quantified. Some researchers reported in their studies lower RPE values than the maximum during sets performed to volitional fatigue, indicating an incompatibility between RPE and maximal effort (Shimano et al., 2006; Pritchett et al., 2009). In addition, according to Borg (2000), regardless of the RPE method used, not all individuals will provide reliable and valid ratings. The author also reported that about 5 to 15% of these individuals may have difficulties understanding instructions and requests, as well as difficulties in verbal and mathematical understanding.

Another point to consider is that the previously mentioned study (Hackett et al., 2018), like the majority of studies related to RPE and RT, uses 10-point scales, such as the OMNI-RES scale (Robertson et al., 2003), and Borg's CR10 (Borg, 1982). In the present study we used of an adapted scale (from the OMNI-RES scale) with only 3 points, which, in addition to resembling the three effort zones present in the Ergonauta device, possibly facilitated subjects' understanding of perceived effort during the bench press. This suggests that the use of scales with fewer levels (points) may facilitate interpretation and classification of the effort by the individuals. Furthermore, Hackett et al. (2018) believe that with repeated applications and user experience with the scales, it is likely that individuals' reliability and accuracy will improve over time. According to Balsalobre-Fernández et al. (2021), subjective scales should be considered together with velocity measurements to obtain a more accurate estimate of relative load (%1RM).

Conclusion

Based on our results, it can be concluded that there is a moderate degree of agreement but a strong correlation between the intensity of effort determined by the Ergonauta and the RPE at both analyzed intensities (70%1RM and 85%1RM). Despite not being broadly concordant, the strong relationship between the methods allows us to say that both can discriminate the intensity of individuals in a similar way during bench press sets. It is important to emphasize that the results of this study should be interpreted according to the individual characteristics, context, exercise, periodization, and objectives at hand. It is recommended to undergo multiple sessions of familiarization with the technique, device operation, and the RPE scale, regardless of the individual's training level.

Funding

This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001.

Conflict of Interest

The author Wladymir Külkamp declares that he is the manufacturer of the Ergonauta I encoder.

References

Balsalobre-Fernández, C., Muñoz-López, M., Marchante, D., & García-Ramos, A. (2021). Repetitions in Reserve and Rate of Perceived Exertion Increase the Prediction Capabilities of the Load-Velocity Relationship. *Journal of strength and conditioning research*, *35*(3), 724–730. https://doi.org/10.1519/JSC.0000000000002818

Bjarnason-Wehrens, B., Mayer-Berger, W., Meister, E. R., Baum, K., Hambrecht, R., Gielen, S., & German Federation for Cardiovascular Prevention and Rehabilitation (2004). Recommendations for resistance exercise in cardiac rehabilitation. Recommendations of the German Federation for Cardiovascular Prevention and Rehabilitation. *European journal of cardiovascular prevention and rehabilitation: official journal of the European Society of Cardiology, Working Groups on Epidemiology & Prevention and Cardiac Rehabilitation and Exercise Physiology*, *11*(4), 352–361. https://doi.org/10.1097/01.hjr.0000137692.36013.27

Borg, G. (2000). *Borg scales for pain and perceived exertion* [in portuguese]. Manole

Conceição, F., Fernandes, J., Lewis, M., Gonzaléz-Badillo, J. J., & Jimenéz-Reyes, P. (2016). Movement velocity as a measure of exercise intensity in three lower limb exercises. *Journal of sports sciences*, *34*(12), 1099–1106. https://doi.org/10.1080/02640414.2015.1090010

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 and conditioning research, *36*(2), 340–345.

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*(5), 347–352. https://doi.org/10.1055/s-0030-1248333

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*, *29A*, 15–19. https://doi.org/10.2478/v10078-011-0053-6

González-Badillo, J. J., Rodríguez-Rosell, D., Sánchez-Medina, L., Ribas, J., López-López, C., Mora-Custodio, R., Yañez-García, J. M., & Pareja-Blanco, F. (2016). Short-term Recovery Following Resistance Exercise Leading or not to Failure. *International journal of sports medicine*, *37*(4), 295–304. https://doi.org/10.1055/s-0035-1564254

Hackett, D. A., Cobley, S. P., & Halaki, M. (2018). Estimation of Repetitions to Failure for Monitoring Resistance Exercise Intensity: Building a Case for Application. *Journal of strength and conditioning research*, *32*(5), 1352–1359. https://doi.org/10.1519/JSC.0000000000002419

Halperin, I., Malleron, T., Har-Nir, I., Androulakis-Korakakis, P., Wolf, M., Fisher, J., & Steele, J. (2022). Accuracy in Predicting Repetitions to Task Failure in Resistance Exercise: A Scoping Review and Exploratory Meta-analysis. *Sports medicine (Auckland, N.Z.)*, *52*(2), 377–390. https://doi.org/10.1007/s40279-021-01559-x

Izquierdo, M., Ibañez, J., González-Badillo, J. J., Häkkinen, K., Ratamess, N. A., Kraemer, W. J., French, D. N., Eslava, J., Altadill, A., Asiain, X., & Gorostiaga, E. M. (2006). Differential effects of strength training leading to failure versus not to failure on hormonal responses, strength, and muscle power gains. *Journal of applied physiology (Bethesda, Md. : 1985)*, *100*(5), 1647–1656. https://doi.org/10.1152/japplphysiol.01400.2005

Külkamp, W. (2017). *Monitoring resistance exercises at self-selected velocity: proposed method for quantifying training intensity* [Unpublished doctoral thesis] [in portuguese]. Santa Catarina State University

Külkamp, W., Feunteun, Y., & Junior, N. B. (2021a). 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. (2021b). 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

Külkamp, W., Bishop, C., Kons, R., Antunes, L., Carmo, E. C., Hizume-Kunzler, D., Dal Pupo, J. (2023). Concurrent Validity and Technological Error-Based Reliability of a Novel Device for Velocity-Based Training. *Measurement in Physical Education and Exercise Science.* DOI: 10.1080/1091367X.2023.2207570

Lachance, P.F., & Hortobágyi, T. (1994). Influence of Cadence on Muscular Performance During Push-up and Pull-up Exercise. *Journal of Strength and Conditioning Research, 8*, 76–79.

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, *33*(1), 159–174.

Mukaka M. M. (2012). Statistics corner: A guide to appropriate use of correlation coefficient in medical research. *Malawi medical journal : the journal of Medical Association of Malawi*, *24*(3), 69–71.

Nóbrega, S. R., Barroso, R., Ugrinowitsch, C., da Costa, J. L. F., Alvarez, I. F., Barcelos, C., & Libardi, C. A. (2018). Self-selected vs. Fixed Repetition Duration: Effects on Number of Repetitions and Muscle Activation in Resistance-Trained Men. *Journal of strength and conditioning research*, *32*(9), 2419–2424. https://doi.org/10.1519/JSC.0000000000002493

Pareja-Blanco, F., Rodríguez-Rosell, D., Sánchez-Medina, L., Ribas-Serna, J., López-López, C., Mora-Custodio, R., Yáñez-García, J. M., & González-Badillo, J. J. (2017a). Acute and delayed response to resistance exercise leading or not leading to muscle failure. *Clinical physiology and functional imaging*, *37*(6), 630–639. https://doi.org/10.1111/cpf.12348

Pritchett, R. C., Green J. M., Wickwire, P. J., Kovacs, M. S. (2009). Acute and session RPE responses during RT: Bouts to failure at 60% and 90% of 1RM. *South African Journal of Sports Medicine*, *21*(1), 232-26.

Robertson, R. J., Goss, F. L., Rutkowski, J., Lenz, B., Dixon, C., Timmer, J., Frazee, K., Dube, J., & Andreacci, J. (2003). Concurrent validation of the OMNI perceived exertion scale for resistance exercise. *Medicine and science in sports* *and exercise*, *35*(2), 333–341. https://doi.org/10.1249/01.MSS.0000048831.15016.2A

Sánchez-Medina, L., & González-Badillo, J. J. (2011). Velocity loss as an indicator of neuromuscular fatigue during resistance training. *Medicine and science in sports and exercise*, *43*(9), 1725–1734. https://doi.org/10.1249/MSS.0b013e318213f880

Sánchez-Medina, L., Pallarés, J. G., Pérez, C. E., Morán-Navarro, R., & González-Badillo, J. J. (2017). Estimation of Relative Load From Bar Velocity in the Full Back Squat Exercise. *Sports medicine international open*, *1*(2), E80–E88. https://doi.org/10.1055/s-0043-102933

Scott, B. R., Duthie, G. M., Thornton, H. R., & Dascombe, B. J. (2016). Training Monitoring for Resistance Exercise: Theory and Applications. *Sports medicine (Auckland, N.Z.)*, *46*(5), 687–698. https://doi.org/10.1007/s40279-015-0454-0

Shimano, T., Kraemer, W. J., Spiering, B. A., Volek, J. S., Hatfield, D. L., Silvestre, R., Vingren, J. L., Fragala, M. S., Maresh, C. M., Fleck, S. J., Newton, R. U., Spreuwenberg, L. P., & Häkkinen, K. (2006). Relationship between the number of repetitions and selected percentages of one repetition maximum in free weight exercises in trained and untrained men. *Journal of strength and conditioning research*, *20*(4), 819–823. https://doi.org/10.1519/R-18195.1

Tiggemann, C. L., Pinto, R. S., Kruel, L. F. M. (2010). A Percepção de Esforço no Treinamento de Força. *Revista Brasileira de Medicina do Esporte*, *16*(4), 301-309. https://doi.org/10.1590/S1517-86922010000400014

Torrejón, A., Balsalobre-Fernández, C., Haff, G. G., & García-Ramos, A. (2019). The load-velocity profile differs more between men and women than between individuals with different strength levels. *Sports biomechanics*, *18*(3), 245–255. https://doi.org/10.1080/14763141.2018.1433872

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

Williams, M. A., Haskell, W. L., Ades, P. A., Amsterdam, E. A., Bittner, V., Franklin, B. A., Gulanick, M., Laing, S. T., Stewart, K. J. (2007). Resistance exercise in individuals with and without cardiovascular disease: 2007 update: a scientific statement from the American Heart Association Council on Clinical Cardiology and Council on Nutrition, Physical Activity, and Metabolism. *Circulation*, *116*(5), 572–584. https://doi.org/10.1161/CIRCULATIONAHA.107.185214