Accuracy and reproducibility of a novel device for monitoring resistance training performed at self-selected movement velocity

Short title: **Novel device for monitoring resistance training**

ABSTRACT

Resistance training does not necessarily require repetition failure, whereas Velocity-Based training and “training not to failure” are available alternatives to know the optimal point to interrupt the sets. Nevertheless, Velocity-Based training require exclusively maximal intended velocities and training not to failure currently relies on subjectivity to estimate repetitions in reserve. This study evaluated the accuracy and precision of a linear encoder in estimating the maximum number of repetitions during sets performed until failure at self-selected movement velocity. Fifty-seven males were evaluated in three resistance exercises: close-grip lat pulldown, knee extension, and bench press. Accuracy was evaluated by comparing the mean and median of actual and estimated repetitions using t-tests and Wilcoxon signed-rank tests, respectively. Additionally, the fatigue effect in consecutive sets was analyzed using two-way ANOVA for repeated measures. Levels of agreement were assessed through Bland-Altman analysis, and reproducibility was determined by calculating the Intraclass Correlation Coefficient (ICC). The results showed no significant difference between actual and estimated repetitions ($t_{178} = 0.307$; $p > 0.05$; ES = 0.02; Z = -0.45; $p > 0.05$; ES = -0.02), even in the presence of fatigue between consecutive sets. The reproducibility for estimating maximal repetitions was good ($ICC_{3,2} = 0.88$ [95% CI = 0.83-0.91], $F_{177,177} = 8.07$, $p < 0.001$), with an acceptable degree of agreement. Errors of less than or equal to two repetitions occurred in over 90% of the series for the close-grip lat pulldown and bench press, with knee extension exhibiting a slightly lower frequency. Hence, practitioners and trainers should consider using this linear encoder for the evaluated exercises, especially when failure is not desired under self-selected velocity conditions.

Key Words: Velocity-based training, Resistance training, Movement velocity, Ecological validity, Repetitions, Strength training

INTRODUCTION

Over the years, the regular use of resistance training has been confirmed as an effective strategy for improving and maintaining neuromuscular status[1-4].Typically, resistance training is planned based on the number of sets and repetitions, which vary according to training goals [5]. The repetition *continuum* suggests specific repetition maximum (RM) target zones to achieve more significant gains in certain neuromuscular adaptations (e.g., 4-6 RM for strength *vs.* 8-12 RM for hypertrophy). Training to maximum repetitions involves performing each set until failure. Despite some criticism [7,8], this approach has been widely adopted in resistance training programs.

However, the scientific literature continuously reports that failure is not mandatory to ensure neuromuscular adaptations. Some researchers have shown that interrupting sets before failure can result in similar or even higher adaptations in strength [9-13], power output [10,13], and hypertrophy [9-11] when compared to training to failure, even under non-equalized volume conditions [10]. This approach is known as "training not to failure" (TNF) [10,13].

In recent years, velocity-based training (VBT) has been highlighted as an efficient method for attaining muscle power and strength, and its fundamentals are in line with the concept and adaptive responses of TNF. One of these fundamentals is the control of volume, i.e., the number of repetitions per set, according to the progressive loss of velocity over the sets [14,15,16]. Several studies have reported that training with velocity losses ranging from 5-20% allowed for similar or even greater athletic performance adaptations (e.g., strength [17,18,19], power output [18], jump height [17, 18]), as well as much smaller total training volumes (e.g., <50%) compared with traditional training or when using higher velocity loss approaches (e.g., >30%). However, for velocity loss to be applied as a set-interrupting approach, the traditional VBT approach requires repetitions to always be performed at the maximal intended velocity.

Nevertheless, applying maximum intent is not the only way to perform resistance training. Self-selected movement velocity (MVSS) is used by athletes and non-athletes alike [20,21]. It is not related to explosive movements and does not depend on external control or pacing strategies, therefore being individualized. It was recently suggested that there is an association between perceived effort and the magnitude of MVSS loss during sets performed until failure, as well as specific critical points or thresholds indicating performance transitions [20]. The use of MVSS-based monitoring would expand the VBT method beyond its current scope, allowing for its application in contexts where high velocities are not recommended regarding higher peaks of force generated, such as in non-athletes and rehabilitation patients. Its implementation would also improve the precision of TNF protocols, which currently rely on the subjective judgments of athletes and coaches when determining set interruptions [13,22]. While certain studies have indicated an overall tendency to underestimate by about one repetition [23,24], this tendency can fluctuate based on individual circumstances. Furthermore, the accuracy of estimations can be enhanced when they are provided closer to the point of task failure. Furthermore, it is crucial to solicit feedback from participants throughout each set of repetitions. This process, while somewhat tedious, relies exclusively on individual subjectivity. So far, no equipment has been tested/evaluated for monitoring at MVSS. Ergonauta I stands out as the unique linear encoder capable of anticipatable estimating the maximum number of repetitions executed to concentric failure at MVSS, providing real-time information about the repetitions in reserve.

The present study aimed to evaluate the accuracy and precision of a novel device linear encoder that estimates the maximum number of repetitions during sets performed until failure at MVSS and enables real-time control of the optimal interruption point based on the number of repetitions in reserve. We hypothesized that the device's estimates would demonstrate acceptable accuracy and level of agreement for practical applications, along with a high level of reproducibility when compared to actual repetitions.

METHODS

Study Design

To improve ecological validity, this cross-sectional study collected data during actual training sessions, ensuring alignment with real-world contexts. By focusing on data collection during sessions, the study aimed to bridge the gap between controlled experiments and the complexities of practical training environments. The tests were conducted on different days, totaling 12 visits within approximately one month of data collection. Participants were all evaluated at the same training center, using identical equipment and the same evaluator, without controlling for intervening variables like ambient music and flow of people in the environment. To verify the accuracy and precision of the linear encoder, the estimated number of repetitions was compared with the actual and maximum number of repetitions in repeated sets performed until failure in MVSS. Failure was defined as the point during a set where the participant can no longer complete another repetition with proper technique over the entire range of movement.

The study evaluated three exercises: close-grip lat pulldown (LP), knee extension (KE), and bench press (BP). By providing real-time and anticipatory recognition of the total number of repetitions in a set, with adequate accuracy and precision, the linear encoder could improve resistance training monitoring when failure is not desired under self-selected velocity conditions.

Participants

Fifty-seven male (age: 28.62±10.99 years; body mass: 71.91±12.19 kg; stature:1.72±0.08 m) participated as volunteers, selected through non-probabilistic intentional sampling via an interview process. Inclusion criteria adopted involved practicing resistance exercise for at least 6 months (mean of 34.93±18.85 months) with at least two training sessions per week; participants who met these criteria participated in the present study. The adopted exclusion criteria were a recent history of joint or muscle injuries or any health condition that suggested caution in performing maximum efforts. None of the participants reported the use of drugs or medications that could interfere with performance. All selected volunteers signed an informed consent form regarding the risks and benefits of the research. The data collection protocols were previously approved by the local ethics committee (CAAE: 42989615.9.0000.0118).

Procedures

In each visit, only one exercise was evaluated by each participant, implying multiple visits were required to assess a reasonable number of volunteers for each exercise. Initially, all participants underwent an evaluation for body mass, height, and blood pressure level. A standardized warm-up protocol was conducted by all participants before the primary data collection. This protocol included stationary cycling at approximately 60 rpm and free pedaling, followed by three sets with light loads on the exercises that were to be evaluated on that day for all participants. Exercise order was not randomised due to the planned ecological validity design, which depended on individual training routines and allowed for multiple combinations.

For this study, three exercises were selected: BP, LP, and KE. These exercises were chosen based on their widespread use in resistance exercise protocols and their ease of execution, which eliminated the need for familiarization protocols. However, not all participants performed all exercises as data collection was sometimes conducted on days when the evaluated exercises did not correspond to the muscle group that the participant trained on that day.

A standardized procedure was established for performing the exercises. For the BP, due to safety concerns, the exercise was performed using a Smith Machine. Each participant was instructed to keep their back, glutes, and head in constant contact with the bench, as well as both feet on the ground. Each set began with the removal of the bar from the equipment support (without assistance from the evaluator), followed by the eccentric phase of the first repetition. Each consecutive repetition was considered complete when the elbows were fully extended. The grip on the bar (distance between hands) was performed freely. When necessary, the evaluator assisted in returning the bar to the Smith Machine support (in this case, the previous repetition was considered the final one).

Regarding the LP, tests were performed with a V-shaped handle, using the high pulley of equipment exclusively designed for this exercise. The movement began with the concentric phase, which was considered complete when the handle passed the volunteer's chin line. The end of each eccentric phase was considered the moment when the elbows were fully extended.

The KE sets were performed on an extension chair, starting the concentric phase of each repetition with the knees flexed at a 90° angle. Each repetition was considered complete when a knee flexion angle close to or equal to 0° was achieved before the start of the eccentric phase. All equipment used for the exercises were from the Tonus® brand (Brazil).

For each exercise, each participant was asked to perform two sets until voluntary failure, with a 3-minute rest interval between them. Moreover, participants were asked to perform each repetition at a self-selected movement velocity (MVSS), which means that they could perform each repetition at their preferred velocity without any external control or stimulus regarding the execution pace (e.g., metronome). Standardized verbal encouragement was provided to motivate participants to reach the point of failure. Furthermore, following the completion of each set, each participant was prompted to evaluate their perceived level of exertion using the OMNI-RES subjective effort scale. While the primary criterion centered on reaching muscle failure, sets were exclusively selected for further analysis if participants reported exerting a maximal effort (indicated by a rating of 10 on the scale), coupled with an observed inability to maintain proper execution of the repetitions. The loads (kg) used in the tests were the ones predicted in the participants' training logs, which ranged from approximately 45% to 90% of their self-reported individual 1RM loads for the three exercises evaluated.

Data Acquisition:

Throughout all sets and repetitions, movement velocity was monitored using the new linear encoder (Ergonauta®, Florianópolis – Brazil). This device relies on a linear position transducer (incremental encoder) that calculates linear distances based on axis rotation and records the timing of each event through a microcontroller [25]. The average movement velocity during the concentric phase is determined by dividing the movement amplitude for each repetition in this phase by the corresponding elapsed time. No filtering is applied. Upon calculating the average movement velocity values, the equipment employs a unique algorithm that estimates the total number of repetitions that could be performed in self-selected velocity sets to failure, in any resistance exercise. The estimation is based on the identification of a first threshold, which is determined by the progressive decrease in the mean velocity of the concentric phase of each repetition. This threshold marks the end of a zone of effort considered light or comfortable, as well as the entry from the next repetition into a zone of moderate effort. According to the manufacturer of the linear encoder, this threshold occurs whenever a significant drop in MVSS occurs in a repetition corresponding to approximately 65% of the possible repetitions. Thus, when the threshold is identified, the equipment automatically estimates the total number of possible repetitions by dividing the actual number of repetitions by 0.65. For instance, if the threshold is identified in the seventh repetition, then the total number of repetitions is estimated as 7÷0.65, i.e., 11 rounded repetitions. Additionally, the device allows for the identification of a failure zone, where concentric or voluntary failure is imminent. The manufacturer also states that the algorithm used by the device is sensitive to sets between 7 and 15 maximum repetitions, being less precise for repetitions outside these limits.

Statistical analyses

Central tendency and dispersion of continuous variables were reported as mean and standard deviation, whereas discrete variables (e.g., number of repetitions) were presented using median, minimum, and maximum values. To assess reproducibility, level of agreement, and accuracy, we compared the device's estimated number of repetitions with the actual maximum repetitions performed in sets until failure. Reproducibility was determined using Intraclass Correlation Coefficient (ICC) with a Two-way mixed model and absolute agreement from average measure. ICC values less than 0.5 indicate poor reproducibility, values between 0.5 and 0.75 indicate moderate reproducibility, values between 0.75 and 0.9 indicate good reproducibility, and values greater than 0.90 indicate excellent reproducibility [28]. Agreement was assessed using Bland-Altman analysis, considering the magnitude of systematic error (bias), limits of agreement, and the absence of heteroscedasticity as criteria for ensuring adequate agreement.

To assess the accuracy of the linear encoder, we tested the difference between estimated and actual repetitions by comparing means and medians using Student's t-tests and Wilcoxon signed-rank tests, respectively. Furthermore, two-way repeated measures ANOVA was conducted for each exercise individually, to assess the predictive capacity of the linear encoder even in the presence of possible fatigue between sets. The factors considered for ANOVA were the method (estimated vs. actual) and assessment (test vs. retest). The assumption of sphericity could not be tested due to the level of factors being less than three. In case of a significant "F" value, differences were verified using Sidak's post hoc test.

The effect size of differences was calculated by converting "t," "Z," and "F" values to r-values. This standardization allows for a common index, facilitating the interpretation of results [26]. Effect size was interpreted according to Cohen's "r," classified as negligible ($|r| < 0.1$), small ($0.1 \leq |r| < 0.3$), medium ($0.3 \leq |r| < 0.5$), or large ($|r| \geq 0.5$) [27]. Statistical analyses were performed using SPSS for Windows version 20 with a 5% confidence level.

RESULTS

Tables 1, 2, and 3 present the complete set of monitoring parameters recorded by the linear encoder device for each of the three evaluated exercises, during the sets performed to failure. The velocity achieved in the final repetition, along with the relative loss velocity, exhibited relevant variations both between and within sets and differed among exercise types. However, an initial performance transition threshold consistently occurs at around 65% of the total possible repetitions, regardless of the exercise performed and the length of the set. Further analysis revealed that the linear encoder identified this threshold in 98% of the series. The number of repetitions within the moderate effort zone showed few variations, irrespective of the type of exercise and the total number of repetitions performed. The failure zone seems to occur between 77% and

100% of the total possible repetitions, with few variations in the number of repetitions inside. It is important to highlight that, despite there being no difference between the total estimated and actual repetitions in each series, as described below, the linear encoder did not identify the failure zone in some series.

Table 1 near here

Table 2 near here

Table 3 near here

The ICC indicated good reproducibility between actual and estimated repetitions (ICC = 0.88 [95% CI = 0.83-0.91], $F_{177,177} = 8.07$, $p<0.001$). The statistic proposed by Bland-Altman showed an acceptable degree of agreement between actual and estimated repetitions, with a systematic error close to zero and no significant heteroscedasticity ($R^2 = 0.0 – 0.09$). While the limits of agreement were relatively high, only 5% of the estimates fell outside the range of three repetitions when the exercises were analyzed together (Figure 1; panel “ALL”).

Figure 1 near here

Approximately 60% to 75% of all evaluated series demonstrated an estimation error of zero to one repetition, while errors of less than or equal to two repetitions occurred in over 90% of the series for the LP and BP exercises. In the case of the KE exercise, errors of less than or equal to two repetitions were slightly less common, with higher errors being more prevalent as a result (Table 4).

Table 4 near here

Considering all the repetitions performed in the study as a single group, the comparison of means (t178 = 0.307; p>0.05; ES=0.02) and medians (Z = -0.45; p>0.05; ES = -0.02) revealed no significant difference between the maximum repetitions estimated by the linear encoder (mean = 11.65±0.20; [95% CI = 11.25 to 12.05]; median = 12 [6 to 18]) and the actual maximum repetitions (mean = 11.61±0.18; [95% CI = 11.26 to 11.97]; median = 12 [7 to 17]). No significant difference was also observed when comparing the three exercises separately (t_{28-88} = -0.93 to 1.21; p>0.05; ES=0.04 to 0.17;

Z=-0.73 to -1.31; p>0.05; ES= -0.02 to -0.12). In the LP exercise, the estimated repetitions had a mean of 11.35±0.29 [95% CI = 10.77 to 11.93] and a median of 12 (6 to 18), while the actual repetitions had a mean of 11.41±0.25 (95% CI = 10.92 to 11.90) and a median of 11 (7 to 17). In the KE exercise, the estimated means and medians were 13.03±0.29 [95% CI = 12.46 to 13.61] and 14 (8 to 18), respectively, while the actual repetitions had a mean of 12.73±0.28 (95% CI = 12.46 to 13.60) and a median of 13 (8 to 17). Finally, in the BP exercise, the estimated means and medians were 9.54±0.35 [95% CI = 8.82 to 10.24] and 9 (8 to 14), respectively, while the actual repetitions had a mean of 9.78±0.37 (95% CI = 9.03 to 10.54) and a median of 9 (7 to 15).

The repeated measures ANOVA revealed a significant effect of fatigue on the number of repetitions between test and retest series for the LP ($F_{1,26} = 13.06$; $p < 0.05$, ES = 0.58) and BP exercises ($F_{1,9} = 3.24$; $p < 0.05$, ES = 0.51), with a decrease in the mean number of repetitions. However, no significant effect of fatigue was observed for the KE exercise ($F_{1,18} = 1.68$; $p > 0.05$, ES = 0.29). The repeated measures ANOVA also did not reveal any significant effect of the method on the estimated and actual repetitions in any of the exercises, indicating that the linear encoder maintained its predictive capacity. There was no significant interaction effect between the factors used in the ANOVA ($p > 0.05$; ES < 0.3). Therefore, the linear encoder can predict maximum repetitions even with a decrease in the number of repetitions due to neuromuscular fatigue in consecutive sets.

DISCUSSION

The results confirmed our hypothesis regarding the accuracy, agreement, and reproducibility of the devices, revealing no significant or practically relevant differences between the linear encoder estimates and the maximum number of repetitions achievable in series performed to failure for any of the evaluated exercises. The equipment's predictive capacity was confirmed in consecutive series, even when fatigue was present and the number of repetitions was reduced. Based on the presented results, the Ergonauta I appears suitable for monitoring resistance training based on self-selected velocity.

While there are other available and reliable linear transducers in the fitness market, their validity is restricted to maximal intended velocity applications [25]. Additionally, they lack the capability to independently estimate repetitions in reserve [29]. Thus, Ergonauta I holds a distinct advantage as the only transducer capable of real-time estimation of the number of repetitions achievable in a set performed until exhaustion at MVSS. This feature could be beneficial for athletes and practitioners engaged in resistance training routines where high velocities are not recommended, even though a reduced yet effective volume of sets is necessary. Additionally, practitioners and trainers can also use the prescription based on the effort zones suggested by linear encoder, although caution should be taken for the KE exercise.

Moreover, our data confirms the findings of Külkamp and colleagues [20] that relying solely on MVSS to determine the duration of resistance exercise series, both in absolute and relative terms, is not recommended due to variations observed between exercises and participants. While the linear encoder utilizes the progressive drop of MVSS as a parameter, it is not used in isolation, but rather embedded within an algorithm that mathematically evaluates velocity loss when combined with concurrent parameters. This algorithm proved to be effective in estimating the maximum number of repetitions possible in a series performed to failure in maximal voluntary activation, based on the detection of an initial threshold of significant speed loss (65% of the total maximum repetitions).

Two independently conducted studies also previously suggested the occurrence of a performance transition threshold when repetitions reach approximately 65% of the maximum possible. Sanchez-Medina and González-Badillo [30] identified this threshold from an abrupt elevation in ammonia levels, whereas Tillaar et al. [31] applied an electromyographic signal analysis. In both studies, the authors suggested that the reduction of high-energy phosphagens was responsible for the change in performance. However, in these studies, repetitions were performed at maximum intended velocity.

In contrast to the mentioned studies [30, 31], that used biological parameters, the transition threshold observed and investigated in the present study was determined mathematically through an algorithm. However, the results are similar, even though the repetitions were performed in MVSS in the present study and in maximum intended velocity in the other two studies. Perhaps time to under tension could be used as a possible explanation for the similarity in the point of occurrence of this initial transition threshold, both in MVSS and at maximum velocity. At maximum velocity, the duration of each repetition is shorter, generating less time under tension. However, the intensity is higher, leading to greater use of high-energy phosphagens in each repetition and, therefore, greater fatigue [32]. On the other hand, at MVSS, although a lower intensity is experienced in the initial repetitions, since the velocity is not maximal [20], the time under tension is longer, possibly generating greater fatigue [33,34]. Thus, if these two premises are true, one phenomenon could compensate for the other, leading to a common point of performance transition regardless of the movement velocity regime used. However, this hypothesis needs to be adequately investigated.

We believe that the main limitation of the present study concerns the lack of standardization of the relative load (%1RM) used in the sets. Although the total number of possible repetitions with the same relative load may vary between different participants and types of exercise [35,36], this could have allowed for more participants who performed a certain number of repetitions in a specific exercise, unlike what was observed in some sets. Additionally, although it is our understanding that BP performance may be facilitated by the Smith Machine, we acknowledge that the absence of familiarization with this exercise can be interpreted as another limitation.

Finally, we propose future studies to compare the effort zones provided by the equipment with biological or psychometric markers. It would also be valuable to explore the feasibility of reproducing similar results in sets performed at maximum intended velocity, and extend the research to include other exercises and populations, such as females and the elderly.

CONCLUSION

The linear encoder estimates were found to be both accurate and precise, taking into account the specific margins of error for each exercise investigated (LP, KE, and BP). Therefore, interrupting sets based on the maximum number of repetitions estimated by the new linear encoder can be applied in non-failure training or VBT approaches at self-selected movement velocity. These conclusions should be interpreted within the study's limitations and taking into account potential individual variations.

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Figure Legends:

Figure 1. Agreement between actual repetitions (repActual) and estimated repetitions (repEstim) considering all exercises combined (ALL) and separately for lat pulldown (LP), knee extension (KE) and bench press (BP).

Table 1. Characteristics of sets performed to exhaustion in the lat pulldown

n	**%1RM**	**lastMV (m/s)** x̄ (sd)	**Velocity Loss (%)** x̄ (sd)	**Thr1** md (↓-↑)	**Z3** md (↓-↑)	**repPred** md (↓-↑)	**repActual** md (↓-↑)	**Error** md (↓-↑)	**repZ1** md (↓-↑)	**repZ2** md (↓-↑)	**repZ3** md (↓-↑)	**%Rep _Trh1** x̄ (sd)	**%Rep _Thr2** x̄ (sd)
3	48-90	0.37 (0.18)	43 (17)	4 (4-5)	6 (0-6)	6 (6-8)	7	1 (1-1)	4 (4-5)	2 (1-3)	2 (0-2)	57.14 (-)	85.71 (-)
7		0.38 (0.10)	47 (9)	5 (4-7)	8 (0-8)	8 (6-11)	8	1 (0-3)	5 (4-7)	2 (1-3)	1 (0-1)	67.86 (12.20)	100 (-)
7		0.44 (0.16)	38 (11)	6 (5-8)	9 (0-9)	9 (8-9)	9	0 (0-1)	6 (5-8)	2 (0-4)	1 (0-2)	68.25 (9.99)	97.78 (4.97)
18		0.40 (0.12)	43 (11)	6 (5-9)	9 (0-10)	9 (8-12)	10	1.5 (0-2)	6 (5-9)	2 (0-4)	1.5 (0-2)	65.56 (12.93)	95 (5.16)
10		0.48 (0.14)	31 (4)	8 (6-9)	10 (0-11)	12 (9-14)	11	1 (0-3)	8 (6-9)	2 (1-3)	2 (0-2)	70 (9.63)	94.32 (4.71)
15		0.42 (0.11)	39 (4)	8 (6-9)	12 (0-12)	12 (9-14)	12	0 (0-3)	8 (6-9)	3 (1-5)	1 (0-3)	65.56 (6.95)	96.15 (5.50)
13		0.37 (0.10)	46 (12)	8 (6-10)	11 (0-13)	12 (9-15)	13	2 (1-4)	8 (6-10)	2 (1-4)	3 (0-4)	60.36 (9.85)	85.89 (8.57)
5		0.33 (0.12)	52 (13)	9 (8-10)	13 (11-14)	14 (12-15)	14	1 (0-2)	9 (8-10)	3 (2-4)	2 (1-4)	62.86 (5.97)	91.43 (9.31)
7		0.43 (0.09)	34 (6)	11 (9-12)	14 (12-15)	17 (14-18)	15	2 (0-3)	11 (9-12)	2 (1-4)	2 (1-4)	70.48 (6.51)	91.43 (6.34)
1		0.5(-)	37 (-)	10 (-)	15 (-)	15 (-)	16	1 (-)	10 (-)	4 (-)	2 (-)	62.5 (-)	93.75 (-)
2		0.36 (0.03)	42 (6)	11 (10-12)	14 (13-15)	16.5 (15-18)	17	1.5 (1-2)	11 (10-12)	2 (2-2)	4 (3-5)	64.71 (8.32)	82.35 (8.31)
88		**0.38 (0.11)**	**41.09 (6.07)**					**1 (0-4)**		**2 (0-5)**	**2 (0-5)**	**65.78 (9.94)**	**93.14 (7.32)**

n = number of sets monitored; lastMV = last rep movement velocity; rep = repetition; Thr1 = rep correspondent to the first threshold; Z3 = rep correspondent to beginning of failure zone; repPred = predicted repetitions; repZ1= number of reps inside the light effort zone; repZ2 = number of reps inside the moderate effort zone; repZ3 = number of reps inside the failure zone; %repThr1 = relative repetition concerning the first threshold; %repThr2 = relative repetition at the onset of the failure zone; x̄ (sd) = mean (standard deviation); md (↓-↑) = median (minimum- maximum).

Table 2. Characteristics of sets performed to exhaustion in the knee extension

n	**%1RM**	**lastMV (m/s)** x̄ (sd)	**Velocity Loss (%)** x̄ (sd)	**Thr1** md (↓-↑)	**Z3** md (↓-↑)	**repPred** md (↓-↑)	**repActual** md (↓-↑)	**Error** md (↓-↑)	**repZ1** md (↓-↑)	**repZ2** md (↓-↑)	**repZ3** md (↓-↑)	**%Rep _Trh1** x̄ (sd)	**%Rep _Thr2** x̄ (sd)
3	59-81	0.43 (0.10)	36 (8)	6 (5-6)	8 (0-8)	9 (8-9)	8	1 (0-1)	6 (5-6)	2 (1-2)	1 (0-1)	70.83 (7.22)	100 (-)
2		0.48 (0.05)	34 (2)	6 (6-6)	9 (0-9)	9 (9-9)	9	0 (0-0)	7 (5-6)	2.5 (2-3)	1 (0-1)	66.67 (0)	100 (-)
4		0.54(0.11)	30 (6)	7 (6-9)	10 (0-9)	10.5 (9-14)	10	1.5 (1-4)	7 (6-9)	2 (1-4)	1 (0-1)	72.5 (15)	100 (-)
9		0.55(0.08)	27 (4)	9 (8-10)	11 (0-11)	14 (12-15)	11	3 (1-4)	9 (8-10)	2 (1-3)	1 (0-1)	78.79 (6.43)	100 (-)
11		0.56(0.12)	29 (4)	8 (7-9)	11.5 (0-12)	12 (11-14)	12	1 (0-2)	8 (7-9)	3 (2-5)	2 (0-2)	66.67 (7.45)	95.83 (4.45)
9		0.53(0.07)	27 (3)	9 (7-11)	13 (0-13)	14 (11-17)	13	1 (1-4)	9 (7-11)	3 (1-5)	1 (0-3)	69.23 (9.42)	96.70 (6.05)
5		0.55(0.06)	26 (3)	9 (9-12)	13.5 (0-14)	14 (14-18)	14	0 (0-4)	9 (9-12)	4 (1-5)	1.5 (0-2)	70 (9.31)	96.43 (5.05)
16		0.61(0.10)	28 (4)	9 (7-12)	14 (0-15)	14 (11-18)	15	1.5 (0-4)	9 (7-12)	5 (1-7)	2 (0-3)	60 (9.11)	95 (5.03)
2		0.61(0.11)	26 (2)	10.5 (10-11)	16 (0-15)	16 (15-17)	16	1 (1-1)	10.5 (10-11)	4.5 (4-5)	1 (1-1)	65.62 (4.42)	100 (-)
1		0.66 (-)	26 (-)	9 (-)	17 (-)	14 (-)	17	3 (-)	9 (-)	7 (-)	1 (-)	52.94 (-)	100 (-)
62		**0.56 (0.10)**	**28.9 (3.51)**					**1 (0-4)**		**3 (1-7)**	**1 (0-3)**	**67.67 (10.28)**	**98.39 (2.11)**

n = number of sets monitored; lastMV = last rep movement velocity; rep = repetition; Thr1 = rep correspondent to the first threshold; Z3 = rep correspondent to beginning of failure zone; repPred = predicted repetitions; repZ1= number of reps inside the light effort zone; repZ2 = number of reps inside the moderate effort zone; repZ3 = number of reps inside the failure zone; %repThr1 = relative repetition concerning the first threshold; %repThr2 = relative repetition at the onset of the failure zone; x̄ (sd) = mean (standard deviation); md (↓-↑) = median (minimum- maximum).

Table 3. Characteristics of sets performed to exhaustion in the bench press

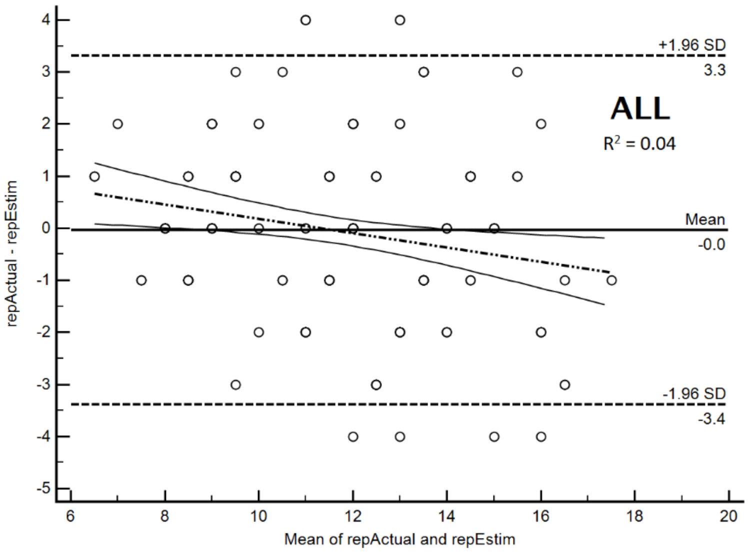
n	**%1RM**	**lastMV (m/s)** x̄ (sd)	**Velocity Loss (%)** x̄ (sd)	**Thr1** md (↓-↑)	**Z3** md (↓-↑)	**repPred** md (↓-↑)	**repActual** md (↓-↑)	**Error** md (↓-↑)	**repZ1** md (↓-↑)	**repZ2** md (↓-↑)	**repZ3** md (↓-↑)	**%Rep _Trh1** x̄ (sd)	**%Rep _Thr2** x̄ (sd)
1	44-76	0.19 (-)	39 (-)	5 (-)	7 (-)	8 (-)	7	1 (-)	5 (-)	1 (-)	1 (-)	71.43 (-0)	100 (-)
8		0.17 (0.05)	50 (13)	5 (5-6)	8 (7-8)	8 (8-9)	8	0 (0-1)	5 (5-6)	1.5 (1-2)	1 (1-2)	67.18 (6.47)	98.44 (4.42)
6		0.16 (0.04)	54 (15)	5.5 (5-7)	8.5 (8-9)	8.5 (8-11)	9	1 (0-2)	5.5 (5-7)	2 (1-3)	1.5 (1-2)	62.96 (9.07)	94.44 (6.09)
5		0.17 (0.06)	53 (11)	6 (5-8)	9 (8-10)	9 (8-12)	10	1 (1-2)	6 (5-8)	2 (1-2)	2 (1-3)	64 (11.40)	90 (7.07)
2		0.13 (0.01)	66 (0)	6 (5-7)	9 (9-9)	9.5 (8-11)	11	1.5 (0-3)	6 (5-7)	2 (1-3)	(3-3)	54.54 (12.86)	81.81 (0.00)
3		0.26 (0.03)	37 (2)	8 (7-9)	11 (11-12)	12 (11-14)	12	1 (0-2)	8 (7-9)	3 (1-3)	2 (1-2)	66.67 (8.33)	94.44 (4.81)
2		0.18 (0.05)	65 (13)	6.5 (6-7)	10 (10-10)	10 (9-11)	13	3 (2-4)	6.5 (6-7)	2.5 (2-3)	4 (4-4)	50 (5.44)	76.92 (0.00)
1		0.25 (-)	47 (-)	9 (-)	12 (-)	14 (-)	15	1 (-)	9 (-)	2 (-)	4 (-)	60 (-)	80 (-)
28		**0.18 (0.05)**	**51.37 (10.62)**					**1 (0-4)**		**2 (1-3)**	**2 (1-4)**	**63.42 (9.22)**	**92.32 (8.25)**

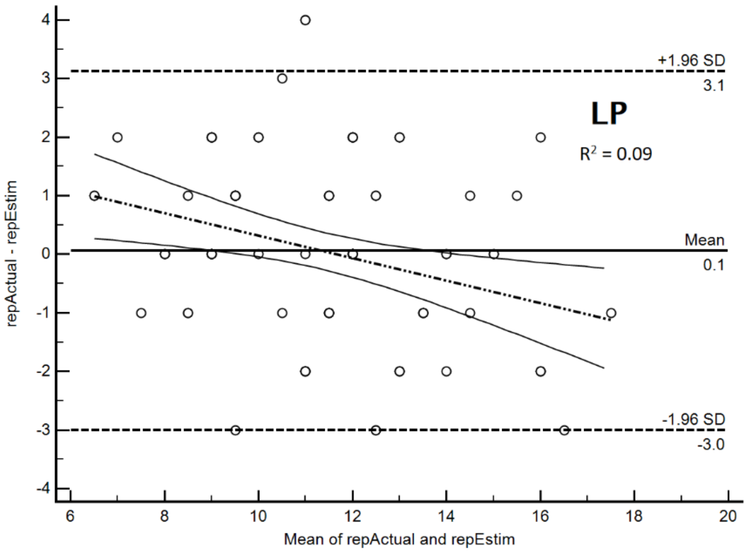
n = number of sets monitored; lastMV = last rep movement velocity; rep = repetition; Thr1 = rep correspondent to the first threshold; Z3 = rep correspondent to beginning of failure zone; repPred = predicted repetitions; repZ1= number of reps inside the light effort zone; repZ2 = number of reps inside the moderate effort zone; repZ3 = number of reps inside the failure zone; %repThr1 = relative repetition concerning the first threshold; %repThr2 = relative repetition at the onset of the failure zone; x̄ (sd) = mean (standard deviation); md (↓-↑) = median (minimum- maximum).

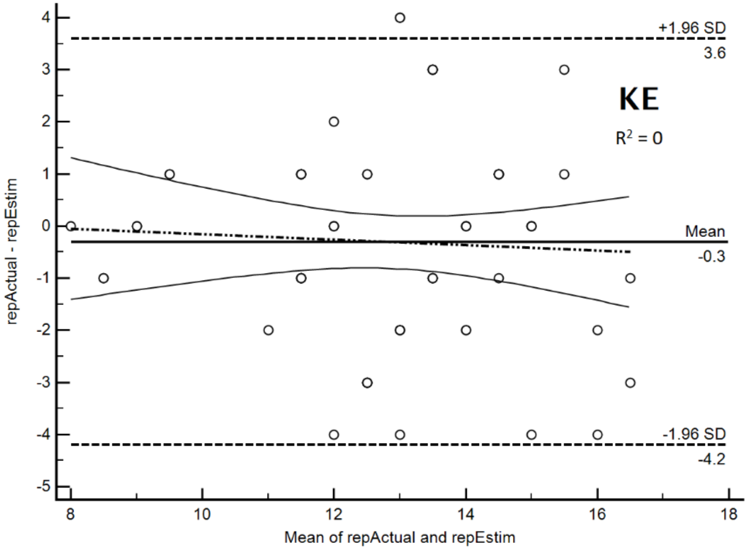
Table 4. The magnitude and relative frequency of estimation errors between actual repetitions and estimates

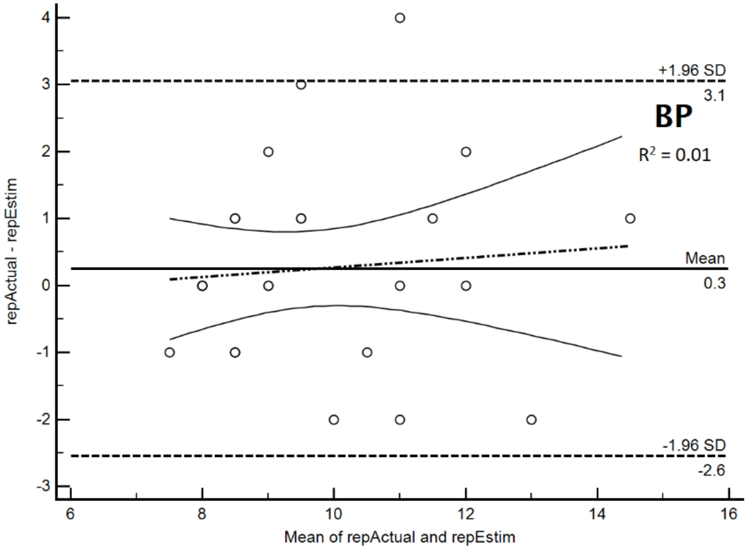
	Lat pulldown n = 88			Knee extension n = 62			Bench press n = 28			Overall n = 178		
Difference	f	f%	∑%	f	f%	∑%	f	%	∑%	f	f%	∑%
0	23	26,1		12	19,4		9	32,1		44	24.7	
1	32	36,4	62,5	25	40,3	59,7	12	42,9	75,0	69	38.8	63.5
2	26	29,5	92,0	9	14,5	74,2	5	17,9	92,9	40	22.5	86.0
3	5	5,7	97,7	10	16,1	90,3	1	3,6	96,4	16	9.0	94.9
4	2	2,3	100	6	9,7	100	1	3,6	100	9	5.1	100

n= number of repetitions; f = frequency; f% = relative frequency; ∑% =relative frequency sum.


ALL
R² = 0.04
+1.96 SD
3.3
Mean
-0.0
-1.96 SD
-3.4
repActual - repEstim
4
3
2
1
0
-1
-2
-3
-4
-5
6
8
10
12
14
16
18
20
Mean of repActual and repEstim


LP
R² = 0.09
+1.96 SD
3.1
Mean
0.1
-1.96 SD
-3.0
repActual - repEstim
4
3
2
1
0
-1
-2
-3
-4
6
8
10
12
14
16
18
20
Mean of repActual and repEstim


KE
R² = 0
+1.96 SD
3.6
Mean
-0.3
-1.96 SD
-4.2
repActual - repEstim
4
3
2
1
0
-1
-2
-3
-4
-5
8
10
12
14
16
18
Mean of repActual and repEstim


BP
R² = 0.01
+1.96 SD
3.1
Mean
0.3
-1.96 SD
-2.6
repActual - repEstim
4
3
2
1
0
-1
-2
-3
6
8
10
12
14
16
Mean of repActual and repEstim