

Individual load-velocity relationship “in situ”: a novel approach for the characterization of muscle function and 1 R.M. estimation.

Luca Ferrari

`luca.ferrari_01@univr.it`

University of Verona, Department of Neurosciences, Biomedicine and Movement Sciences, 37131 Verona, Italy; <https://orcid.org/0000-0002-9855-9659>

Gianluca Bochicchio

aUniversity of Verona, Department of Neurosciences, Biomedicine and Movement Sciences, 37131 Verona, Italy <https://orcid.org/0000-0002-9575-9209>

Silvia Pogliaghi

bUniversity of Foggia, Department of Clinical and Experimental Medicine, 71122, Foggia, Italy
<https://orcid.org/0000-0002-4394-8550>

Research Article

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Abstract

Purpose

The “traditional” load-velocity(L-V) relationship profiling and 1 R.M. estimation require multiple loads, which limits their applicability. We tested the feasibility and validity of an alternative “in situ” L-V profiling method using lifting velocities of simulated training sessions.

Method

We retrospectively analyzed a publicly available dataset on 51 resistance-trained individuals who performed: direct 1 R.M. measures, “traditional” L-V profiling test, and simulated training sessions during which “in situ” individual weight and velocity were recorded. Theoretical maximal load (L_0), movement velocity (V_0), regression slope (LV_{slope}), goodness of fit (R^2), and estimation of 1 R.M. were computed and compared between “traditional” and “in situ” methods. Both 1RM predictions were compared vs the directly measured 1RM.

Results

1 R.M. and V_{1RM} mean values were 128 ± 37.6 kg and 0.35 ± 0.08 m•s⁻¹, respectively. L_0 , V_0 , LV_{slope} , R^2 , and 1 R.M. estimations were not different ($p > 0.05$) between L-V profiling methods. Moreover, both estimates of 1R.M. showed no significant difference ($p > 0.05$), extremely high correlation ($r \geq 0.97$), and not significant bias ($_{\text{trad}}\text{L-V}$, bias = 1.7 kg, precision = 9.7kg, $p > 0.05$; $_{\text{in situ}}\text{L-V}$, bias = 0.7 kg, precision = 7.6kg, $p > 0.05$;) vs the directly measured 1R.M..

Conclusions

In adult recreational lifters, the “in situ” L-V profiling is a feasible and valid method for the characterization of muscle function; it represents a safe and time-efficient alternative to “traditional” L-V profiling and direct 1 R.M. determination in the free weight barbell back squat exercise.

Introduction

Resistance training (RT) is a widely adopted form of exercise aimed at improving muscle power, endurance, and maximal strength for both performance and health purposes [1].

To maximize efficacy and safety, RT programs should be individually tailored based on specific assessments of muscle function [2]. Widely used approaches for this purpose are the determination of the 1 Repetition Maximum (1R.M.) and the force-velocity (F-V) or load-velocity (L-V) profiling [3, 4]. The L-

V relationship is based on the inverse linear relationship between a given load and the maximal velocity at which it can be moved [5, 6]. By taking advantage of this linear stereotyped behavior, it is possible to profile the muscle function through parameters such as maximal Force/Load (L_0), maximal velocity (V_0), and the slope of the load-velocity relationship (LV_{slope}). Moreover, when individual velocity corresponding to 1 R.M. is known or can be estimated based on literature data (i.e., minimal velocity threshold)[3], it is possible to indirectly estimate the 1R.M. from the L-V relationship [6–9].

The above indicators are useful to identify performance limitations (e.g., strength or velocity biased weaknesses) towards the individualization of training goals [10]. Moreover, the individual L-V relationship has been proposed for the fine-tuning of the % of 1 R.M. to be used in training: by providing a combination of external load and target velocity at which it must be moved, i) tailoring accuracy and ii) load adjustment to day-to-day fluctuations in an athlete's performance state [11] can be optimized within a given individual, improving reliability, and safety of the intended stimulus [3, 12, 13].

For the above reasons, as well as for the widespread availability of affordable technological devices capable of easily measuring barbell velocity [14], the individual assessment of L-V relationships has now become a common practice for the prescription, administration, and monitoring of safe and effective resistance training programs ^{5,8–11}.

The first studies approaching this methodology for the estimation of 1 R.M. focused on “generalized group equations” [5], while recently the “individual” L-V relationship took over, as it showed to produce better prediction of the 1-repetition maximum (1RM) [3].

Despite the usefulness of the individual L-V relationship, its assessment has been accompanied by some concerns, such as the exposure to nearly maximal intensities, the need for high motivation, and for a specific testing session (i.e., preparation, and organization), and, finally, the relatively time-consuming nature of the protocol (i.e., the need to use between 5 and 9 increasing loads)[6, 15]. Even if these characteristics do not represent a drawback in some contexts, they could limit the application of the individual L-V relationship in large groups (i.e., team sports) and/or in frail, unfit individuals. Moreover, the movement/exercise-dependent [3] nature of the L-V relationship could represent a limitation to the use of the method when a large number of exercises must be assessed.

In search for a time-and cost-effective solution for F-V profiling, some attempts have been made, such as the reduction of the datapoints for profiling (e.g., a 2-point method) ^{15–17} or the use of so-called “passive data” (i.e., not expressly recorded for testing purposes). Morin et al. [16] recently presented a methodological approach to assess the “in situ” GPS acceleration-speed profile of soccer players (i.e., force-velocity profile assessed based on passive data recorded during matches/training without the need to organize a dedicated assessment session). Since then, similar “in situ” approaches have been successfully adopted in several studies [17–20]. [21].

To the best of our knowledge, no study has yet applied this innovative “in situ”/“passive data-based” approach to assess the L-V relationship in resistance training. Given the methodological and practical

relevance of individualized L-V profiling in RT, this study is the first to explore whether the “in situ” method (based on velocity data collected during regular training sessions) can serve as a feasible and valid alternative to the “traditional” L-V assessment.

Therefore, our aims were twofold: i) to investigate the feasibility and validity of profiling the individual L-V relationship (L_0 , V_0 , LV_{slope} , R^2 , and estimated 1 R.M.) using a “in situ” approach, by using velocity data collected over different simulated training sessions in comparison with the “traditional” L-V relationship; ii) to investigate the validity of the “in situ” L-V relationship in estimating the 1 R.M. by comparing it with the actual value of 1 R.M. and with the “traditional” L-V profiling method.

We hypothesized that the “in situ” method would prove both feasible (i.e., $R^2 > 0.9$) for profiling the L-V relationship and valid and accurate for estimating 1RM (Standard Error of Estimate < 10 kg), offering a promising alternative to the “traditional” L-V method.

Methods

Procedure, participants, and equipment

For the purpose of this study, we used a freely available database belonging to a published study that had a different objective from our current work (Jukic et al. 2023 [12]). The protocol of the above study was approved by the Auckland University of Technology Ethics Committee (approval number: 20/55) and the Code of Ethics of the World Medical Association. All experiments were performed in accordance with relevant guidelines and regulations. Since we retrospectively analyzed the available dataset and all methods were carried out in accordance with the University Ethical Board regulations, our University Ethical Board waived the requirement for ethics approval and informed consent to participate.

The dataset from Jukic et al[12] contained data from fifty-one resistance-trained participants (15 females and 36 males; back squat 1RM/body mass = 1.24 ± 0.32 and 1.79 ± 0.35 for females and males, respectively). The inclusion criteria were: athletes of both sexes between 18 and 40 years of age, with at least six months of resistance training experience in the back squat exercise, including at least two sessions per week, and one performing the back squat. Exclusion criteria were: longer than two weeks without training in the period of the evaluation; taking medication known to alter metabolic or cardiovascular function; presence of musculoskeletal injury; current use or history of using anabolic steroids.

Data collection

For a more comprehensive description of the study protocol, please refer to Jukic et al[12]. Briefly, each participant visited the laboratory five times, with each visit separated by 48–72 h. Table 1 summarizes the key information about the protocol, equipment used, and variables measured.

Table 1

A Description of the 5 visits to the laboratory is summarized along with the equipment used, and measured variables.

Visit #	Session type	Protocol	Equipment used	Measured variables
1	Familiarization session	Participants' body mass and height were taken. Participants completed 3 repetitions at 20, 40, and 60% of their estimated 1RM, and 10 repetitions at 60% of their estimated 1RM. Participants practiced lifting the barbell up as fast as they could.	Three pairs (left and right side) of the following different instruments were used contextually to measure barbell velocity: GymAware (GymAware Power	Load (kg) Mean Concentric Velocity (MV, m/s) Peak Concentric Velocity (PV, m/s)
2	Testing session	The 1RM protocol consisted of 3 repetitions at 20%, 3 repetitions at 40%, 3 repetitions at 60%, 1 repetition at 80%, and 1 repetition at 90% of an estimated 1RM, followed by 1RM attempts. After each successful attempt, the load was increased in consultation with the participant, using increments of 1 to 12.5 kg until no further weight could be lifted or until the movement technique was compromised. Participants were instructed to perform the concentric (upward) portion of each repetition as fast as possible	Tool; Kinetic Performance Technologies, Canberra, Australia) PUSH2 (PUSH Inc., Toronto, ON, Canada) Vmaxpro (alias EnodePro; Blaumann & Meyer –Sports Technology UG, Magdeburg, Germany)	
3	Testing session	Same as day two		
4	Repetitions to failure sessions	Participants performed a total of three sets to muscular failure with 90, 80, and 70% 1RM, respectively.		
5	Repetitions to failure sessions	Same as day four		

The participants had to abstain from any additional lower-body training in addition to the laboratory sessions during their participation in the study.

Data extraction and analysis

In our study, we extracted from the Gymaware (GymAware Power Tool; Kinetic Performance Technologies, Canberra, Australia) database the following data only:

- 1 R.M. (i.e. the maximum load lifted successfully) and the respective mean concentric velocity (i.e. the velocity value corresponding to this load (V_{1RM})) for each participant from the “Testing” session 2 were taken as is;
- The individual weight and the highest mean concentric lifting velocity for each load from the “Testing” session 3 were extracted and used to compute the individual L-V profile, excluding the data relative to the maximal load lifted (1 R.M.). Then, a linear regression was run on these data points to obtain the individual L-V relationships [22].

From the newly individual L-V relationship, we extrapolated the following main variables: L_0 , which is the theoretical maximal load (y intercept of the linear regression equation); V_0 is the theoretical maximum movement velocity (x intercept of the linear regression equation); LV_{slope} is the angular coefficient of the Load-velocity profile (i.e., the regression equation slope). In addition, we calculated the coefficient of determination (R^2) of the L-V relationship as an index of feasibility. Finally, the estimated 1 R.M. was computed by resolving the individual “traditional” L-V relationship for $x=V_{1RM}$ from session 2;

- For assessing the “in situ” individual L-V relationship, we extracted, pooled, and placed in ascending order the mean concentric lifting velocity for each load from “Repetitions to failure” sessions 4 and 5 for each individual. For each participant, we selected the highest two of the pooled velocities (i.e. the two fastest repetitions) for each load lifted. Then, a linear regression was run on these data points to obtain the individual “in situ” L-V relationship[16].

The main variables obtained were the same as the “Traditional” L-V relationship: L_0 , V_0 , LV_{slope} , and R^2 . Finally, as for the “traditional” approach, the estimated 1 R.M. was computed by resolving the individual “in situ” L-V relationship for $x=V_{1RM}$ from session 2.

In Fig. 1, a typical example of “traditional” and “in situ” L-V relationship is graphically represented.

Statistics

All data are presented as mean $\pm$ standard deviation.

To investigate the feasibility of the “in situ” approach in correctly profiling the L-V relationship compared to the “traditional” method, a paired t-test was run on L_0 , V_0 , LV_{slope} , R^2 and estimated 1 R.M. values.

To investigate the ability of the “in situ” and “traditional” L-V methods to estimate the actual 1 R.M., estimated and directly measured values of 1 R.M. were compared by 1-way repeated measures ANOVA. Moreover, a Pearson’s correlation coefficient, and Bland–Altman analysis [23] followed by a one-sided z-test on the bias were performed separately between the gold standard method and both the indirect estimates.

The Pearson’s correlation coefficient (r) was interpreted as follows: trivial (< 0.1); small (0.10–0.29); moderate (0.30–0.49); large (0.50–0.69); very large (0.70–0.89); extremely large (0.90–1.00)[24]. The

significance level was set at $p < 0.05$.

Results

The 1 R.M. and V_{1RM} mean values measured during “testing” session 2 were 128 ± 37.6 kg and 0.35 ± 0.08 m•s⁻¹, respectively.

Mean values of L_0 , V_0 , LV_{Slope} , R^2 of both L-V profiling methods are presented in Table 2.

Table 2

The main variables of the individual load-velocity profile are derived from the “Traditional” and the “in situ” approach.

	Trad_L-V relationship	In-situ_L-V relationship	Mean difference	SE difference	p	Effect Size
L_0	169.42 ± 46.81	169.82 ± 47.645	-0.40	1.41	0.77	-0.04
V_0	1.45 ± 0.14	1.47 ± 0.15	-0.02	0.01	0.08	-0.25
LV_{Slope}	-116.50 ± 31.08	-115.50 ± 31.60	-0.97	1.72	0.57	-0.08
R^2	0.98 ± 0.02	0.98 ± 0.02	0.00	0.00	0.19	0.19
e1R.M.	128.80 ± 39.87	129.82 ± 40.77	-1.03	0.86	0.24	-0.17
L_0 : maximal theoretical load; V_0 : maximal theoretical velocity; LV_{Slope} : slope of the Load-Velocity linear relationship, e1R.M.: estimated 1 repetition maximum. e1R.M.: estimated 1 R.M.; SE difference: Standard Error difference; * $p < 0.05$						

The comparison between actual and predicted 1 R.M. mean values for each L-V method is presented in Fig. 2 along with the Pearson’s correlation coefficient and Bland-Altman analysis.

Figure 2 along with the Pearson’s correlation coefficient and Bland-Altman analysis.

Discussion

This study investigated the feasibility and validity of profiling the individual L-V relationship (L_0 , V_0 , LV_{Slope} , R^2 , and estimated 1 R.M.) using an innovative “in situ” approach, by comparison with the “traditional” L-V profiling. Moreover, the study tested the validity of both the “traditional” and “in situ” L-V relationships in estimating the 1 R.M. by comparing these estimates with the gold standard method (i.e., direct measure of 1 R.M.). Our results showed that an “in situ” profiling of the individual L-V relationship based on “passive” training data is feasible and valid, as shown by the non-different values of L_0 , V_0 , LV_{Slope} , R^2 , and estimated 1 R.M., compared to the “traditional” method. In addition, our study confirmed that “traditional” L-V profiling allows an accurate estimate of 1 R.M.. Finally, our study was the first to demonstrate that the “in situ” approach is equally valid then the “traditional” approach in estimating the

directly measured 1 R.M.. These results support the use of the “in situ” approach for L-V profiling and 1 R.M. prediction as a safe, valid, precise, time-efficient alternative to “traditional” L-V profiling and the direct 1RM determination, in the free weight barbell back squat exercise.

Our 1 R.M. and V_{1RM} values were consistent with those found in literature for back squat in recreational age-matched lifters of both sexes (1 R.M. = 128 ± 37.6 vs $\sim 153.1 \pm 6.32$ kg; $V_{1RM} = 0.35$ vs 0.31 m/s).

The feasibility of the “in situ” approach in terms of building a proper L-V relationship was first verified based on the goodness of fit of the individual linear relationship between load and velocity, as measured through the R^2 values[25]. Briefly, R^2 represents how well the regression line minimizes the sum of the squared differences (residuals) between the actual data points and itself (i.e., the predicted values from the line)[25]. Previous studies have shown very high values of R^2 (0.98–0.99) [9, 26] for the “traditional” method of L-V relationship for different exercises. Our R^2 values of both “traditional” and “in situ” approaches were very high and similar to what was found in literature ($R^2 = 0.98 \pm 0.02$ for both methods). This confirms the feasibility and validity of the “traditional” profiling and supports the “in situ” profiling as an equally valid alternative. This result is interesting because the traditional L-V relationship included a wider range of velocity data (from $\sim 20\%$ to $\sim 90\%$ of the 1R.M.) compared to the “in situ” L-V relationship, which was biased towards medium-to-high intensities (from 70% to 90% of the 1R.M. only). The difference in data range could have potentially led the “traditional” L-V relationship to be better “driven” along the extremities of the relation, especially close to V_0 . Importantly, when an equal number of data points, though from a narrower range of loads, is used, “in situ” L-V profiling offers a valid option for identifying possible deficits in strength or velocity and consequently for tailoring individual training goals [2, 4]. Moreover, it is worth considering that under ecological conditions, all the loads and respective velocities, including those of the warm-up, could be used to build the “in situ” L-V relationship, potentially improving its overall validity.

Regarding the estimation of 1 R.M., our results confirmed that the “Traditional” method yielded a valid, precise, and accurate estimation of the actual 1 R.M.. Indeed, our estimates of 1R.M. compared to the measured values were characterized by smaller bias and higher precision (1 R.M. Bias: 0.7 kg, Precision: 7.6 kg) compared to what has been reported in the literature for similar lower body exercises (Standard error of estimates: 10.6kg for the back squat)[3, 9]. Finally, the same validity and precise estimation of the 1 R.M. compared to the gold standard method were found for the “in situ” approach (1 R.M. Bias: 1.7 kg, Precision: 9.7 kg), confirming it as a valid alternative to the “traditional” relationship for the indirect estimation of 1 R.M.. Interestingly, when compared with the other alternative simplified method for L-V profiling (i.e., 2-point method), our novel “in situ” approach appears to be more accurate and precise for both the L-V profiling and the 1 R.M. estimate [27]. While the very controlled conditions under which the experimental data were originally collected (e.g., homogeneous participants' proficiency in the squat technique and/or the strictly controlled laboratory conditions) could have contributed to the above results, these findings appear very promising.

It is important to underline that, when compared to the “traditional” L-V profiling and direct 1 R.M. measurement, the proposed “in situ” method has several practical advantages. For example, it allows the assessment of an individual load-velocity relationship and the estimate of 1 R.M. without the need for dedicated assessment sessions (i.e., as reported in Morin et al.[16], “testing the players without testing them”). This represents a great advantage, especially when a large number of individuals should be evaluated (i.e., team sports) or when several exercises need to be assessed. In fact, the “in situ” approach allows the assessment of several exercises within the same training session, with the only requirement of a device able to measure lifting velocities. Moreover, the submaximal nature of this approach improves the overall safety in comparison with the direct 1 R.M. measurement. Another important feature of the “in situ” approach is its independence from individual motivation or fluctuations in individual performance. In fact, the method considers only the individual's best performance (i.e., the greatest velocities) over a period of time, neglecting possible aberrant lifting velocities due to different reasons (e.g., lack of motivation, fatigue, etc.). Finally, the “in situ” approach is auto-adaptive to the improvement or decrement of an individual's performance over time, without the need for recurrent dedicated monitoring sessions.

This approach has some limitations. The present study used velocity data collected using a high-quality linear position transducer[12]. However, the intrinsic quality of the commercially available devices for the measurement of the lifting velocity could affect the accuracy and repeatability of both the L-V profiling and 1 R.M. predictions [3]. Therefore, the practitioners/coaches should be mindful of the technical characteristics of the different devices [3, 16], while the impact, if any, of the measurement quality on the profiling variables and 1 R.M. estimate remains to be quantified. Moreover, the very controlled conditions under which the experimental data were originally collected (e.g., homogeneous participants' proficiency in the squat technique and/or the strictly controlled laboratory-simulated field condition) could have contributed to the high accuracy and precision of the “in situ” method. Therefore, the robustness of the “in-situ” approach under real-world coaching conditions (i.e., actual training session in the gym) will require a specific verification.

Conclusions

In adult recreational lifters, the L-V profiling based on “in situ” data is a feasible and valid method for the characterization of muscle function; it represents a safe and time-efficient alternative to “traditional” L-V profiling and direct 1 R.M. determination in the free weight barbell back squat exercise. This novel approach could be used by practitioners and coaches for assessing muscle function, estimating maximal strength, and improving training intensity prescriptions, monitoring, and fine-tuning in resistance training programs.

Practical Implications

- The “in situ” individual Load-Velocity profile could characterize muscle function, without needing dedicated assessment days.
- This new time and effort-saving approach could be used when the maximal strength needs to be estimated/monitored in a large group of individuals and/or in a large number of exercises/movements.
- We recommend that an ample range of loads and velocities (i.e., from warm-up load to sub-maximal intensities) should be included in the computation of the “in situ” Load-Velocity relationship to allow a valid estimation of the 1 R.M..

Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

All authors contributed to the study conception and design. Material preparation and analysis were performed by Luca Ferrari and Gianluca Bochicchio. The first draft of the manuscript was written by Luca Ferrari and Silvia Pogliaghi, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript

Confirmation of ethical compliance

This study retrospectively analyzed a freely available dataset, therefore, the University Ethical Board waived the requirement for ethics approval and informed consent to participate, and all methods were carried out in accordance with the University Ethical Board regulations

Ethics approval

Since we retrospectively analyzed an available dataset, the University Ethical Board waived the requirement for ethics approval and informed consent to participate, and all methods were carried out in accordance with the University Ethical Board regulations

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Figures

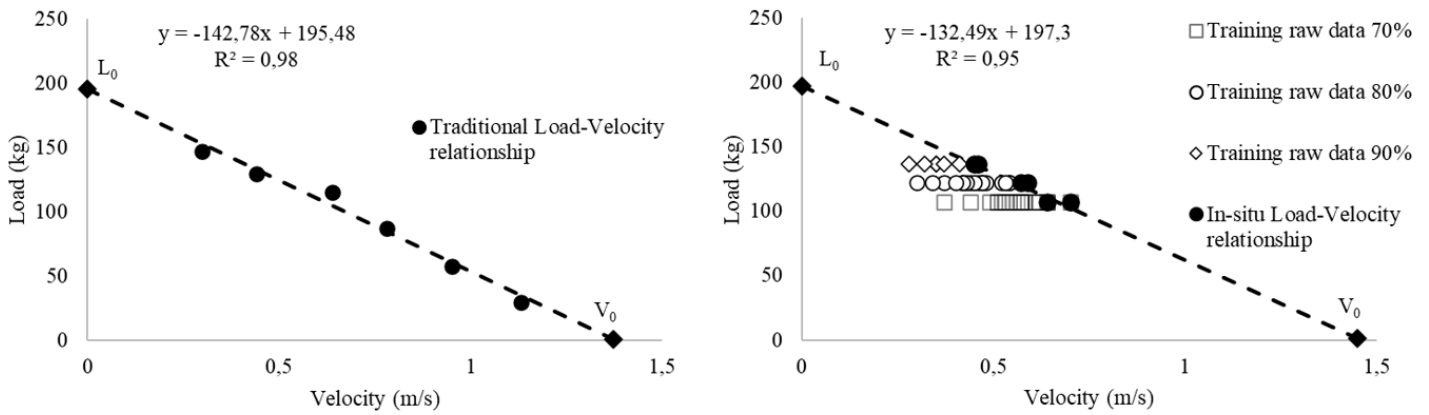


Figure 1

On the left side of the figure, the “Traditional” L-V relationship obtained from a testing session on a representative subject is presented; on the right side of the figure, the “in situ” L-V relationship obtained from training data of a representative subject is presented. The white dots indicate the 51 raw data points derived from the six trials of the “Repetitions to failure” sessions (2 trials for each intensity); the 6 black dots indicate the two fastest velocities for each load lifted that were used to compute the “in situ” individual L-V relationship. On both figures, the dashed regression lines are reported, along with the linear equations and R^2 .

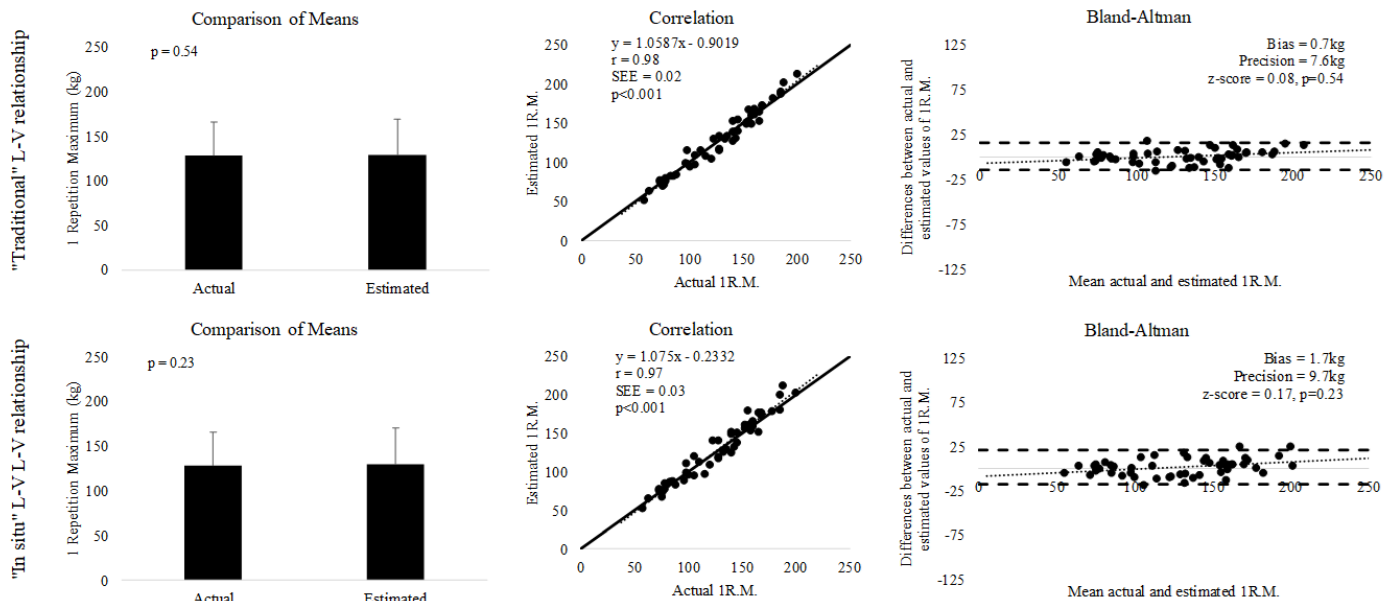


Figure 2

The left graphics of the figure refer to the comparison between the average values of the measured 1 R.M. and the estimates from either the “Traditional” L-V relationship (top graphic) or the “in situ” L-V relationship (bottom graphic). The middle graphics report correlation plots between Actual and Estimated values are shown along with the Pearson correlation coefficient (r), p-value, Standard Error of Estimates (SEE), regression (dashed line), and identity (solid line) lines. In the right graphics, the Bland Altman analysis between Actual and Estimated values is reported (top graphic “traditional” method and bottom graphic “in situ” method): individual differences are plotted as a function of the mean of the two measures. Bias, Precision, and Z-score are shown along with limits of agreement (dashed lines) and bias (solid lines).