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Using velocity recordings to predict squat repetitions to failure in high-level wrestlers

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Abstract

The aim of this study was to assess whether lifting velocity (MV) can provide accurate estimations of the maximum number of repetitions that can be performed to failure (RTF) during the parallel back-squat exercise performed in a Smith machine. Thirty male wrestlers from the Turkey Olympic preparation center (age = 22.6 ± 2.2 years) completed four testing sessions: a session to determine the back-squat one-repetition maximum [1RM], two sessions consisting of single sets to failure against three loads (90%-80%-70%1RM), and one session consisting of four sets to failure against the 75%1RM. The goodness-of-fit of the generalized RTF-MV relationship was strong (r^2 = 0.838), but the individualized RTF-MV relationships were stronger (r^2 = 0.957 ± 0.058). Only 3 out of 60 individualized RTF-MV relationships revealed a r^2 lower than the r^2 of the generalized RTF-MV relationship (r^2 = 0.685, 0.779 and 0.810). The reliability of the fastest MV associated with each RTF ranged from acceptable (4 out of 15 RTFs) to high (11 out of 15 RTFs). The raw and absolute errors in the prediction of RTF did not increase under fatigue and were comparable for both generalized (raw errors: –1.0–0.3 repetitions; absolute errors: 1.1–1.7 repetitions) and individualized (raw errors: –0.8 to 0.1 repetitions; absolute errors: 1.2–1.8 repetitions) RTF-MV relationships. These results indicate that RTF can be predicted with acceptable precision from MV recordings in resistance-trained skilled wrestlers during the parallel back-squat exercise performed in a Smith machine.

KEYWORDS

fatigue, linear position transducer, resistance training, strength, velocity-based training

Highlights

- The maximum number of repetitions completed to failure (RTF) can be predicted with acceptable precision from mean velocity (MV) recordings in resistance-trained skilled wrestlers during the parallel back-squat exercise performed in a Smith machine.
- The raw and absolute errors in the prediction of RTF is not influenced by the fatigue levels experienced at the beginning of the set.

- For more accurate RTF-MV relationships, familiarity with lifting at maximal intended velocity and performing sets to failure seems beneficial.

1 | INTRODUCTION

The benefits of resistance training (RT) to enhance both sports performance and health status are beyond doubt (Pesta et al., 2017; Suchomel et al., 2016). It is therefore not surprising that there are numerous position statements that explicitly recommend RT for populations ranging from high-level athletes to patients with diabetes or cancer (Colberg et al., 2016; Cormie et al., 2018; Fragala et al., 2019; Lloyd et al., 2014, 2016). However, the analysis of position statements leaves no doubt that the RT stimulus (e.g., frequency, intensity, or volume) should be population-specific. One of the most important variables when configuring the RT stimulus is the magnitude of the load lifted (i.e., intensity) (Cormie et al., 2010; Holm et al., 2008). The load has been typically assigned to match a specific percentage of the subject's maximum dynamic strength capacity (e.g., 75% of the one-repetition maximum; 1RM) or to allow a specific number of repetitions to be completed before reaching muscular failure (XRM; e.g., 10RM is the load with which subjects can complete a maximum of 10 repetitions) (Thompson et al., 2020). Although both loading prescription methods (%1RM and XRM) are effective to individualize the RT stimulus and induce positive neuromuscular adaptations (Thompson et al., 2020), a drawback of these methods is that the testing procedures required to directly determine the 1RM and other XRMs are time consuming and induce substantial fatigue. Consequently, the 1RM (or XRMs) are frequently determined only once at the beginning of a training cycle and then the loads are prescribed assuming that the 1RM or XRMs remain stable or increase by a fixed amount throughout the training cycle. This assumption is problematic due to the fact that RT-induced neuromuscular adaptations are highly individualistic. Therefore, it is possible that the prescribed loads (% 1RM or XRM) do not match with the actual loads lifted.

Recording lifting velocity during RT exercises has been proposed as an objective, quick, and fatigue-free procedure with the potential to prevent mismatch between prescribed and actual loads (González-Badillo & Sánchez-Medina, 2010; Weakley, Mann, et al., 2021). This is because the velocity at which a specific load is lifted takes into account both daily physical readiness and different rates of strength adaptations. Numerous studies have explored the feasibility of using the velocity at which submaximal loads are lifted to predict the 1RM (Banyard et al., 2017; Garcia-Ramos et al., 2019; García-Ramos, Haff, et al., 2018; Jukic et al., 2022). However, the possibility of using lifting velocity as an indicator of the maximum number of repetitions that can be completed to failure (RTF) has only been examined in three studies, including the bench press (García-Ramos, Torrejón, et al., 2018), bench pull (Miras-Moreno et al., 2022), and squat (Jukic et al., 2023) exercises. All of them concluded that the individual assessment of the relationship between lifting velocity and RTF is accurate enough to predict the RTF from the recording of the mean velocity (MV) of the fastest set repetition. Individualized RTF-MV relationships were more accurate than generalized RTF-MV relationships, implying that it would be erroneous to associate a given MV with a specific RTF because the RTF-MV relationship is subject-specific. Of note is that all previous studies recruited physically active individuals with a variety of RT backgrounds. Therefore, it is of interest to elucidate whether the superiority of individualized RTF-MV relationships over generalized RTF-MV relationships is maintained when a more homogeneous group of resistance-trained skilled athletes are recruited.

To date, only the study by Miras-Moreno et al. (2022) has explored the precision of the RTF-MV relationship in predicting RTF under conditions of fatigue. This aspect is crucial given that strength training typically does not occur in isolation, and the activities performed by athletes either before or during the RT session might affect the RTF-MV relationship. Miras-Moreno et al. (2022) discovered that when fatigue develops during a RT session the same fastest MV of the set is associated with a lower RTF. Thus, it is essential to investigate whether fatigue has a greater impact on RTF compared to the fastest MV in a range of other training scenarios.

In the present study a group of high-level wrestlers were tested to elucidate whether lifting velocity can also provide an accurate estimation of RTF during the parallel back-squat exercise performed in a Smith machine. This general objective was addressed by: (i) determining the goodness-of-fit of generalized and individualized RTF-MV relationships, (ii) comparing the within- and between-individual variability of the MV associated with different RTFs, and (iii) computing the raw and absolute errors when estimating the RTF under fatigued and non-fatigued conditions using RTF-MV relationships obtained in previous sessions. Based on previous findings (García-Ramos, Torrejón, et al., 2018; Jukic et al., 2023; Miras-Moreno et al., 2022), we hypothesized (i) a higher goodness-of-fit (i.e., higher r^2) for individualized RTF-MV relationships compared to generalized RTF-MV relationships, (ii) the within-individual variability of the MV associated with different RTF would be considerably lower than the between-individual variability, (iii) the errors at estimating RTF from the RTF-MV relationships obtained in previous sessions would be lower for individualized RTF-MV relationships compared to generalized RTF-MV relationships under both fatigued and non-fatigued conditions, and (iv) the magnitude of the errors would be greater with the increase in the number of sets because under fatigue the RTF is expected to be more compromised than the fastest MV of the set.

2 | METHOD

2.1 | Participants

All male wrestlers from the Turkey Olympic preparation center and their coaches were invited to participate in the study to maximize the statistical power of our study. All athletes staying in this center had at least third place in Turkey. The inclusion criteria were (i) men aged between 18 and 35 years, (ii) being experienced with RT to failure using the parallel back-squat exercise, (iii) accustomed to performing the back-squat exercise at maximal intended velocity in their RT programs, and (iv) being able to perform the parallel back-squat exercise at maximal intended velocity with proper technique against different loads. The first three inclusion criteria were verified through an online questionnaire and the fourth inclusion criterion was checked in the first testing session by an experienced researcher. Subjects were excluded if they presented any physical limitation or injury that could affect back-squat performance. Finally, 30 resistance-trained male wrestlers (mean ± standard deviation [SD]; age = 22.6 ± 2.2 years [range = 19–28 years]; body mass = 79.9 ± 7.9 kg; body height = 1.79 ± 0.05 m; parallel back-squat 1RM = 164.8 ± 25.5 kg; RT experience = 2.8 ± 1.6 years) were recruited for this study. The wrestlers competed in weight categories spanning from 65 to 97 kg. Subjects were not allowed to perform any form of lower-body RT during the course of the study. Prior to the study onset, subjects were informed about the potential risks of the study and they signed a written informed consent form. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board of the University of YYY (IRB approval: YYYY/YYYY/YYYY).

2.2 | Study design

A repeated-measures design was used to explore whether lifting velocity can provide an accurate estimation of the RTF during the parallel back-squat exercise. Subjects attended to the laboratory on 4 occasions, twice a week, during 2 consecutive weeks, with at least 48 h of rest between consecutive sessions. The first session was used for anthropometric measures and to determine the parallel back-squat 1RM in a Smith machine through an incremental loading test. The same exercise was performed in all testing sessions. The second and third testing sessions were identical and consisted of single sets of repetitions to failure separated by 5 min of rest against 3 loads that were applied in a decremental order (90%1RM, 80%1RM, and 70%1RM). The loads were applied in a decremental order to progressively increase the level of fatigue induced by the different sets (i.e., it is more physically demanding to reach failure with lower loads). The fourth session consisted of 4 sets of repetitions to failure separated by 2 min against the 75% of the 1RM determined in session 1. All sessions were performed at the same time of the day for each subject (±1 h).

Subjects were instructed to perform all repetitions at maximal intended velocity and the MV of the lifting phase was recorded by a linear velocity transducer (GymAware PowerTool, Kinetic Performance Technologies, Canberra, Australia) (Weakley, Morrison, et al., 2021). The generalized RTF-MV relationship was only determined in the second testing session. The individualized RTF-MV relationships were obtained in two separate occasions (second and third testing sessions) to compute the within-individual variability of the MV associated with different RTF. However, for the remaining objectives of our study, only the RTF-MV relationships obtained in the second session were considered. We only utilized data from the first session in which the RTF-MV relationship was established, as repeated consecutive measurements are impractical, and then assessed its accuracy in predicting RTF in a subsequent RT session.

2.3 | Procedures

2.3.1 | Body composition and 1RM assessment (Session 1)

Body mass and height were measured at the beginning of the testing session (Seca model 654, Seca®, Hamburg, Germany). Afterward, a standardized warm-up was completed which involved: 5 min of jogging, lower-body joint mobilization exercises, and 5, 3, and 2 repetitions of the parallel back-squat against 20 kg, 50% of subjects' self-perceived 1RM, and 80% of subjects' self-perceived 1RM, respectively. Finally, subjects performed 2–5 single attempts until reaching the 1RM load. Subjects were allowed to rest 5 min between 1RM attempts and the increment of the loads was decided by consensus between an experienced researcher and the lifter. The purpose of the direct 1RM testing was to ensure that all subjects presented proper squat technique during the execution of maximal lifts. Loads were assigned during sessions 2–4 based on the 1RM determined in session 1.

2.3.2 | Determination of RTF-MV relationships (Sessions 2–3)

The second and third sessions were identical. A standardized warm-up was performed at the beginning of each session consisting of jogging, lower-body joint mobilization exercises, and one set of 10, 3, and 1 repetitions of the parallel back-squat exercise performed against the 30%1RM, 70%1RM, and 90%1RM, respectively. After warming-up, subjects rested for 3 min and then they performed single sets of repetitions to failure against 3 loads that were applied in a decremental order (90%1RM, 80%1RM, and 70%1RM). Each set was separated by 5 min of rest. Subjects received MV feedback immediately after performing each repetition to motivate them to give maximal effort (Weakley et al., 2020). Two trained spotters were present on each side of the barbell to ensure safety and encourage subjects to complete the maximum possible number of repetitions.

2.3.3 | Effect of fatigue on RTF prediction accuracy (Session 4)

The warm-up was identical to that described for sessions 2 and 3. After warming-up, subjects rested for 3 min and then they performed 3 sets of repetitions to failure with 75% of the 1RM determined in session 1. Subjects were allowed to rest for only 2 min between successive sets because we were interested in inducing significant amounts of fatigue. The progressive increase in fatigue with the increment in the number of sets was expected to manifest by decreasing both the fastest MV of the set and RTF. This session was only completed by 29 subjects, as one subject got injured during the third session (pain in the groin area).

2.3.4 | Measurement equipment and exercise technique

The parallel back-squat exercise was always performed in a Smith machine (Technogym, Gambettola, Italy). The feet were shoulder-width apart and the barbell remained in contact with the upper back ("high bar position"). From the initial position, subjects were required to descend in a continuous motion until their thighs were parallel to the floor and immediately after to perform the lifting phase at maximal intended velocity without jumping off the ground. The GymAware linear position transducer, which was vertically attached to the barbell of the Smith machine, was used for recording the MV (average velocity from the first positive velocity until the velocity is 0 $m\cdot s^{-1}$) of every repetition.

2.4 | Statistical analysis

Data are presented as means and SD. The normal distribution of the data was confirmed by the Shapiro-Wilk test ($p > 0.05$). Two-way repeated-measures ANOVAs (session [1 vs. 2] × load [70%1RM vs. 80%1RM vs. 90%1RM]) with Bonferroni post hoc tests were applied to compare the RTF, fastest MV and last MV. The Greenhouse-Geisser correction was applied when the Mauchly's sphericity test was violated ($p < 0.05$). Simple linear regression models were used to establish the generalized and individualized relationships between the fastest MV of the set and RTF. A generalized RTF-MV relationship was constructed considering all data points from the third session (30 subjects × 3 sets = 90 data points). 60 individualized (30 subjects × 2 sessions) RTF-MV relationships were determined considering the 3 sets of each session. The goodness-of-fit of the generalized and individualized RTF-velocity relationships was assessed by the Pearson's multivariate coefficient of determination (r^2). The between-sessions reliability of the MV associated with each RTF (from 1 to 15) was assessed by the within-subjects coefficient of variation (CV [%] = standard error of measurement/subjects' mean score × 100) and the intraclass correlation coefficient (ICC; model 3,1) with their respective 95% confidence intervals. A high and acceptable reliability was deemed when the CV was lower than 5% and 10%, respectively (Miras-Moreno et al., 2022). The between-subjects CV (between-subjects SD/subjects' mean score × 100) was also computed to report the between-subjects variability in the fastest MV associated with the same RTFs. One-way repeated-measures ANOVAs with Bonferroni post hoc tests were applied to compare the RTF, fastest MV and last MV between the 4 sets completed in the fourth session. Finally, two-way repeated-measures ANOVAs (regression model [individualized RTF-MV relationship vs. generalized RTF-MV relationship] × set number [set 1 vs. set 2 vs. set 3 vs. set 4]) with Bonferroni post hoc tests were applied to the raw and absolute errors obtained when comparing the actual and predicted RTFs. Reliability analyses were performed by means of a customized 2019 Microsoft Excel® spreadsheet (version 16.32, Microsoft Corporations, Redmond, Washington, USA) (Hopkins, 2000), while the software package SPSS (IBM SPSS version 25.0, Chicago, IL, USA) was used for the remaining analyses. Alpha was set at 0.05. The final database of the study can be downloaded through the following link: https://osf.io/zh3k7/?view_only=002f6df6a6f645e9851d9caff9c8594a.

3 | RESULTS

Table 1 depicts the effect of the load lifted on RTF, MV, and last MV. The RTF and fastest MV were significantly reduced with the decrement in the load (90%1RM < 80%1RM < 70%1RM). The last MV was significantly lower for the 90%1RM (0.26 ± 0.06 $m\cdot s^{-1}$) compared to the 80%1RM (0.29 ± 0.05 $m\cdot s^{-1}$) and 70%1RM (0.31 ± 0.06 $m\cdot s^{-1}$). The fastest MV and last MV were generally greater in the first session compared to the second session, but the differences only reached statistical significance at 90%1RM for the fastest MV (session 1: 0.40 ± 0.03 $m\cdot s^{-1}$ vs. session 2: 0.38 ± 0.03 $m\cdot s^{-1}$).

The goodness-of-fit of the generalized RTF-MV relationship was strong ($r^2 = 0.838$) (Figure 1). However, the goodness-of-fit of the individualized RTF-MV relationships were generally stronger ($r^2 = 0.957 \pm 0.058$ [range: 0.685, 1.000]). Only 3 out of 60 individualized RTF-MV relationships revealed a r^2 lower than the r^2 of the generalized RTF-MV relationship ($r^2 = 0.685$, 0.779 and 0.810).

The reliability of the fastest MV associated with each RTF ranged from acceptable (5 out of 15 RTFs) to high (10 out of 15 RTFs) (Table 2). The within-subject CV was always greater than the between-subjects CV.

The RTF and the fastest MV were progressively reduced with the increment in the number of sets (set 1 > set 2 > set 3 > set 4), whereas the last MV was significantly greater for set 1 compared to sets 2, 3 and 4 (Table 3). The raw and absolute errors in the prediction of RTF did not differ between the individualized and generalized RTF-MV relationships.

TABLE 1 Comparison between the three relative loads of the number of repetitions completed before reaching muscular failure (RTF) and the mean velocity (MV) of the fastest and last repetitions of the sets.

		Load			ANOVA		
Variable	Session	70%1RM	80%1RM	90%1RM	Session	Load	Interaction
RTF	1	15.0 ± 1.5	8.0 ± 0.9[a]	4.2 ± 0.9[a,b]	$F = 0.2$ $p = 0.687$	**$F = 769.7$ $p < 0.001$**	$F = 0.3$ $p = 0.736$
	2	15.8 ± 1.5	8.5 ± 0.7[a]	4.0 ± 0.6[a,b]			
Fastest MV (m·s^{-1})	1	0.61 ± 0.02	0.50 ± 0.02[a]	0.40 ± 0.03[a,b]	**$F = 4.6$ $p = 0.040$**	**$F = 657.0$ $p < 0.001$**	$F = 0.6$ $p = 0.532$
	2	0.60 ± 0.03	0.49 ± 0.04[a]	0.38 ± 0.03[a,b,c]			
Last MV (m·s^{-1})	1	0.32 ± 0.07	0.30 ± 0.05	0.27 ± 0.06[a,b]	**$F = 4.6$ $p = 0.041$**	**$F = 13.1$ $p < 0.001$**	$F < 0.1$ $p = 0.988$
	2	0.30 ± 0.06	0.28 ± 0.05	0.25 ± 0.05[a,b]			

Note: Values are presented as mean ± standard deviations. Bold values indicate significant differences (p 〈 0.005).
Abbreviations: 1RM, 1-repetition maximum; ANOVA, analysis of variance.
[a]significantly different than 70%1RM.
[b]significantly different than 80%1RM.
[c]significantly different than the session 1.

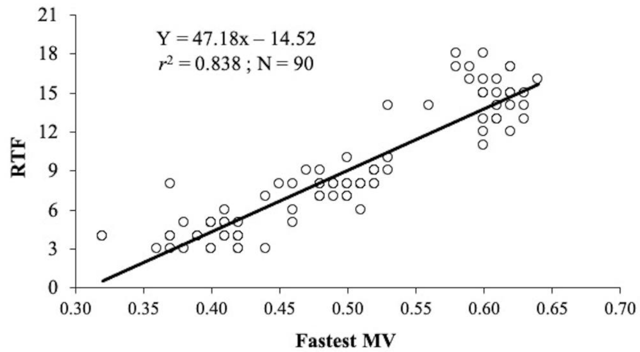

FIGURE 1 Relationship between the maximum number of repetitions performed before reaching muscular failure (RTF) and the fastest mean velocity (MV) of the set during the parallel back-squat exercise performed in a Smith machine. r^2, Pearson's multivariate coefficient of determination; N, numbers of trials included in the regression analysis.

4 | DISCUSSION

This study evidenced that during the parallel back-squat exercise performed in a Smith machine it is possible to predict the RTF with acceptable precision from MV recordings in resistance-trained skilled athletes. This conclusion is based on the following findings: (i) a high goodness-of-fit of both generalized and individualized RTF-MV relationships, (ii) an acceptable (RTFs from 1 to 4) or high (RTFs from 5 to 15) reliability for the MV associated with different RTFs, (iii) the raw and absolute errors at estimating RTF were low (<2 repetitions) and comparable for generalized and individualized RTF-MV relationships obtained in a preliminary session, and (iv) the magnitude of the errors when estimating RTF from MV recordings were not affected by fatigue. These results collectively suggest that RTF–MV relationships can be used to prescribe the loads to match a specific XRM during the parallel back-squat exercise performed in a Smith machine.

The accuracy in the prediction of RTF from MV recordings was superior to the previously reported outcomes for the bench press (García-Ramos, Torrejón, et al., 2018), bench pull (Miras-Moreno et al., 2022), and free-weight squat (Jukic et al., 2023). These results apparently contradict the lower accuracy in the prediction of the 1RM from the load-velocity relationship obtained during lower-body exercises (e.g., squat or deadlift) compared to upper-body exercises (e.g., bench press and bench pull) (Banyard et al., 2017; Garcia-Ramos et al., 2019; Janicijevic et al., 2021; Ruf et al., 2018). However, an important point to note is that while previous studies tested recreationally-trained individuals (García-Ramos, Torrejón, et al., 2018; Jukic et al., 2023; Miras-Moreno et al., 2022), a group of high-level wrestlers with extensive RT experience were recruited for this study. Since accuracy is unlikely to be superior for the squat exercise due to its greater technical complexity, these results suggest that to optimize the accuracy of RTF-MV relationships it is important to be very familiar with both lifting at maximal intended velocity and performing sets to failure. However, this hypothesis should be tested in future studies, since RT experience previously failed to influence the reliability of velocity outputs during the bench press exercise (Janicijevic et al., 2020), and Jukic et al. (2023) revealed that sex, training status and history, and personality traits did not affect the goodness of fit of general and individual RTF-velocity relationships or their prediction accuracy.

The goodness-of-fit was greater for individualized compared to generalized RTF-MV relationships. However, the differences in r^2 between both types of RTF-MV relationships tended to be lower in this study ($\Delta = 0.12$ [$r^2 = 0.96$ for individualized and 0.84 for generalized]) compared to the differences reported for the bench press ($\Delta = 0.21$ [$r^2 = 0.98$ for individualized and 0.77 for generalized]), bench pull ($\Delta = 0.26$ [$r^2 = 0.96$ for individualized and 0.70 for generalized]), and squat ($\Delta = 0.51$ [$r^2 = 0.98$ for individualized and 0.45–0.49 for generalized]) (García-Ramos, Torrejón, et al., 2018; Jukic et al., 2023; Miras-Moreno et al., 2022). The lower differences are explained by the greater goodness-of-fit of the generalized RTF-

TABLE 2 Reliability of the fastest mean velocity (MV) of the set associated with different maximum number of repetitions completed before reaching muscular failure (RTF).

RTF	Session 1 (m·s^{-1})	Session 2 (m·s^{-1})	Within-subjects CV (%) (95% CI)	ICC (95% CI)	Between-subjects CV (%)
1	0.34 ± 0.03	0.33 ± 0.04	8.0 (6.4, 10.8)	0.40 (0.06, 0.66)	10.3
2	0.36 ± 0.03	0.35 ± 0.04	7.0 (5.5, 9.4)	0.42 (0.08, 0.68)	9.1
3	0.38 ± 0.03	0.37 ± 0.03	6.1 (4.9, 8.2)	0.45 (0.11, 0.69)	8.1
4	0.40 ± 0.03	0.39 ± 0.03	5.4 (4.3, 7.2)	0.47 (0.14, 0.71)	7.3
5	0.42 ± 0.03	0.41 ± 0.03	4.8 (3.8, 6.5)	0.49 (0.16, 0.72)	6.7
6	0.44 ± 0.03	0.43 ± 0.03	4.4 (3.5, 5.9)	0.51 (0.19, 0.73)	6.2
7	0.46 ± 0.03	0.45 ± 0.03	4.2 (3.3, 5.6)	0.52 (0.20, 0.74)	5.9
8	0.48 ± 0.03	0.47 ± 0.03	4.0 (3.2, 5.4)	0.53 (0.21, 0.74)	5.8
9	0.50 ± 0.03	0.49 ± 0.03	4.0 (3.2, 5.4)	0.52 (0.20, 0.74)	5.7
10	0.52 ± 0.03	0.51 ± 0.03	4.1 (3.2, 5.5)	0.51 (0.19, 0.73)	5.7
11	0.54 ± 0.03	0.53 ± 0.03	4.2 (3.3, 5.6)	0.50 (0.17, 0.72)	5.8
12	0.56 ± 0.03	0.55 ± 0.03	4.4 (3.5, 5.9)	0.48 (0.15, 0.71)	6.0
13	0.58 ± 0.04	0.57 ± 0.03	4.6 (3.6, 6.2)	0.47 (0.13, 0.70)	6.2
14	0.60 ± 0.04	0.59 ± 0.04	4.8 (3.8, 6.5)	0.45 (0.11, 0.69)	6.4
15	0.62 ± 0.04	0.61 ± 0.04	5.0 (4.0, 6.8)	0.44 (0.10, 0.69)	6.7

Note: Values are presented as means ± standard deviations.

Abbreviations: 95% CI, 95% confidence interval; CV, coefficient of variation; ICC, intraclass correlation coefficient.

TABLE 3 Comparison between the 4 sets performed to failure of the maximum number of repetitions completed before reaching muscular failure (RTF), the mean velocity (MV) of the fastest and last repetition of the set, and the raw and absolute errors obtained when predicting RTF using the individualized and generalized RTF-MV relationships.

	Set number				ANOVA		
	Set 1	Set 2	Set 3	Set 4	Set	Model	Interaction
RTF	12.6 ± 1.2	9.7 ± 1.4[a]	7.2 ± 1.2[a,b]	5.6 ± 1.5[a,b,c]	**F = 225.1; p < 0001**	------	------
Fastest MV (m·s^{-1})	0.55 ± 0.02	0.51 ± 0.03[a]	0.47 ± 0.05[a,b]	0.42 ± 0.04[a,b,c]	**F = 114.2; p < 0.001**	------	------
Last MV (m·s^{-1})	0.30 ± 0.05	0.27 ± 0.04[a]	0.25 ± 0.05[a]	0.26 ± 0.05[a]	**F = 10.3; p < 0.001**	------	------
Raw error (repetitions)							
Individualized RTF-MV	−0.79 ± 1.39	0.03 ± 1.67[a]	0.07 ± 2.43	−0.52 ± 2.44	**F = 3.4; p = 0.037**	F = 0.1 p = 0.806	**F = 6.3 p = 0.013**
Generalized RTF-MV	−1.01 ± 1.44	−0.03 ± 1.36[a]	0.26 ± 1.97[a]	−0.16 ± 1.86			
Absolute error (repetitions)							
Individualized RTF-MV	1.21 ± 1.03	1.27 ± 1.05	1.75 ± 1.67	1.81 ± 1.69	F = 2.1; p = 0.103	F = 0.9 p = 0.341	F = 1.8 p = 0.149
Generalized RTF-MV	1.44 ± 1.00	1.11 ± 0.76	1.65 ± 1.05	1.29 ± 1.33			

Note: Values are presented as means ± standard deviations. Bold values indicate significant differences (p 〈 0.005).

Abbreviations: ANOVA, analysis of variance; MV, mean velocity.

[a]significantly different than set 1.

[b]significantly different than set 2.

[c]significantly different than set 3.

MV relationship in the present study, while the goodness-of-fit of individualized RTF-MV relationships remained consistent across studies. The higher goodness-of-fit of the generalized RTF-MV relationship reported in this study is likely due to the greater homogeneity in the training background of the wrestlers recruited in this study, since they were all involved in the same RT program during the months prior to data collection. Although it should be established in future studies, the greater inter-individual consistency in the MV associated with different RTFs observed in this study is more likely caused by the high homogeneity of the individuals included in the generalized RTF-MV relationship than by the exercise itself.

Contrary to the findings of Miras-Moreno et al. (2022) who reported lower errors when estimating RTFs from individualized compared to generalized RTF-MV relationships, we observed that the raw and absolute errors in the prediction of RTF did not differ between both types of RTF-MV relationships. These discrepancies are likely caused by the higher homogeneity in the RT background of the subjects recruited for this study. It is also important to highlight that the magnitude of the errors was not affected by the number of sets. Miras-Moreno et al. (2022) reported during the bench pull a larger overestimation of RTF under fatigue because the increment in the number of sets compromised RTF more than the fastest MV of the set. As expected, in the present study we also observed that the increase in the number of sets was associated with a decrease of both RTF and the fastest MV of the set. However, in the present study the decrement of both variables under fatigue was comparable and this explains why the raw errors in the prediction of RTF remained stable across the RT session. Considering that our research protocol varied in two aspects with respect to the study conducted by Miras-Moreno et al. (2022)—the exercise (squat vs. bench pull) and the population (high-level wrestlers vs. recreationally trained physical education students)—future studies should aim to clarify whether variations in the RTF-MV relationships under fatigue are predominantly influenced by the type of exercise, the level of RT experience, or a combination of both factors.

Finally, some limitations and directions for future research should be addressed. This is the first study to explore the RTF-MV relationship in a sample of highly experienced RT athletes since the sample of previous studies was always composed by individuals with a variety of RT backgrounds (García-Ramos, Torrejón, et al., 2018; Jukic et al., 2023; Miras-Moreno et al., 2022). It remains uncertain whether the higher precision of the RTF-MV relationship observed in our study, as opposed to that in Jukic et al. (2023), is attributable to the different equipment used (Smith machine vs. free-weights), the resistance training background of the participants, or a combination of these factor. Future studies should directly compare the RTF-MV relationships between different equipment and populations to provide clearer insights into this topic. To fully explore the applicability of the RTF-MV relationship, future research should incorporate female athletes. This inclusion will allow for a comprehensive analysis to determine if the accuracy observed in males holds true for female athletes as well. Another limitation is that the fatigue protocol, which consisted of four sets of repetitions to failure separated by 2 minutes of rest, was more exhausting than the typical RT sessions performed by athletes. It is yet to be determined how the accuracy of the RTF-MV relationship might be influenced by other training activities, such as specific wrestling practice, that athletes typically engage in prior to a RT session. Finally, although the present study did not include the 100%1RM load in constructing RTF-MV relationships to avoid executing a single maximal lift, athletes who frequently lift loads allowing fewer than four repetitions to failure may experience improved accuracy in the RTF-MV relationship if this load is also considered in the model.

5 | CONCLUSIONS

RTF during the parallel back-squat exercise performed in a Smith machine can be predicted with acceptable precision from MV recordings in resistance-trained experienced wrestlers. In this homogenous group, both generalized and individualized RTF-MV relationships were equally effective in predicting the RTF. However, while the generalized RTF-MV relationship presented in this study is valuable as a reference point, we recommend that practitioners use individualized RTF-MV relationships whenever possible to ensure high accuracy with their athletes. Finally, the fatigue induced by consecutive sets performed to failure induced a comparable decrease in both RTF and the fastest MV of the set, suggesting that the same RTF-MV relationship can be used under fatigued and non-fatigued conditions. Therefore, our findings indicate that once the individualized RTF-MV relationship is established, coaches can prescribe training loads to match a specific XRM based on MV recordings with a satisfactory level of precision.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests.

DATA AVAILABILITY STATEMENT

The final database of the study can be downloaded through the following link: https://osf.io/zh3k7/?view_only=cdb0cc3b20ad4cdcb8b66cd1f596b58a.

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