Delineating the Role of Inter-Repetition Interval in the Relationship between Maximum Repetitions to Failure or Repetitions in Reserve and Movement Velocity

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Background: Maximum repetitions to failure (RTF) and repetitions in reserve (RIR) can be estimated through fastest mean velocity ($MV_{fastest}$) and mean velocity (MV), respectively. However, the impact of inter-repetition intervals (IRI) on these relationships in free-weight back squat and bench press exercises is unclear.

Hypothesis: The IRI would affect RTF-$MV_{fastest}$ and RIR-MV relationships, with a higher goodness-of-fit using self-selected IRI (SSIRI) compared with 0 seconds (IRI0) and 3 seconds (IRI3).

Study Design: Crossover study design.

Level of Evidence: Level 3.

Methods: Eighteen male participants completed 1 session per IRI configuration, consisting of 3 single sets of RTF (65%-75%-85% of the 1-repetition maximum) during the free-weight back squat and bench press exercises.

Results: Individualized RTF-$MV_{fastest}$ and RIR-MV relationships were stronger than generalized (median R^2 = 0.98 vs 0.65 and 0.84 vs 0.40, respectively). The goodness-of-fit of the relationships was stronger for SSIRI than for IRI0 during back squat ($P < .01$) and comparable between IRIs during bench press ($P \geq .28$). During back squat, $MV_{fastest}$ values were higher for IRI0 than for IRI3 and SSIRI (eighth-fifteenth repetitions; $P \leq .07$), whereas during the bench press, they were higher for IRI0 than for IRI3 (eleventh-fifteenth repetitions; $P \geq .28$). Overall, MV values associated with each RIR were higher for IRI0 than for SSIRI (10 out of 18 comparisons) during back squat, and for IRI0 than for IRI3 and SSIRI (16 and 14 out of 18 comparisons) during bench press.

Conclusion: These results highlight the importance of standardizing the IRI during set-to-failure to establish RTF-$MV_{fastest}$ and RIR-MV relationships, with SSIRI recommended as a more accurate and effective procedure.

Clinical Relevance: This information may provide practitioners with a valuable tool to objectively quantify the level of effort being exerted during resistance training sets by measuring movement velocity in free-weight exercises.

Keywords: exercise prescription; level of effort; strength training; velocity-based training

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The authors report no potential conflicts of interest in the development and publication of this article.

The authors disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: A.B-R. is currently funded by the Ministry of Science, Innovation and Universities of the government of Spain under a predoctoral grant (grant no.: FPU20/05746). There are no professional relationships with companies or manufacturers who will benefit from the results of the present study for each author.

DOI: 10.1177/19417381251315119

Both neural and structural adaptations that result from resistance training (RT) are influenced by various factors including volume, load, frequency, set structures, exercise type, movement velocity, and rest periods.[12,31] Among these factors, set structures (ie, proximity to failure) used to configure training volume have been identified as a crucial determinant of RT-induced adaptations.[1,12] In this regard, research has demonstrated that RT performed to failure can result in higher levels of neuromuscular fatigue, metabolic responses, and longer time courses of recovery compared with nonfailure.[18,28,30] For instance, Sánchez-Medina and González-Badillo[30] reported that performing ≥8 repetitions per set approaching failure resulted in a significant increase in blood lactate and ammonia response and a decrease in mechanical performance. Even more important, nonfailure RT protocols have been suggested as an optimal stimulus to enhance the strength outcomes in the 1-repetition maximum (1RM) and at high velocities than leading failure RT protocols, which could impair neuromuscular adaptations.[20] Therefore, it is crucial to explore specific methods to determine when a set should end based on the desired proximity to failure.

Velocity-based training has been proposed as an objective method to control proximity to failure during nonfailure RT training sets.[7,19,33] On the one hand, some authors have investigated using the fastest mean velocity (MV) ($\text{MV}_{\text{fastest}}$) of a training set to predict the maximum number of repetitions that can be performed to failure (RTF) (ie, the RTF-$\text{MV}_{\text{fastest}}$ relationship).[3,6,15] Individualized RTF-$\text{MV}_{\text{fastest}}$ relationships (ie, datapoints acquired for each subject are used in the modeling) have demonstrated higher goodness-of-fit (Pearson multivariate coefficients of determination [R^2] = 0.50-1.00 vs 0.45-77) and accuracy in predicting RTF (absolute errors, 1.5-3.0 repetitions vs 2.0-6.2 repetitions) than generalized RTF-$\text{MV}_{\text{fastest}}$ relationships (i.e., datapoints acquired from all subjects are grouped together in the modeling) in several RT exercises.[3,10,15] On the other hand, the use of the MV of each repetition has been recommended to objectively estimate the number of repetitions in reserve (RIR) during RT sets using the RIR-MV relationship.[21,26] Of note, this RIR-MV relationship can be modeled by pooling together the data from various relative loads ($\text{general}_{\text{multiple-loads}}$ and $\text{individual}_{\text{multiple-loads}}$) or specifically for each load ($\text{general}_{\text{load-specific}}$ and $\text{individual}_{\text{load-specific}}$).[26] Interestingly, these RIR-MV equations obtained during an exercise session have demonstrated similar accuracy in subsequent sessions, as shown with the Smith machine prone bench pull exercise (absolute errors ≤ 2 RIR in >40% of occasions).[26] However, further research is needed to confirm the feasibility of this novel velocity-based approach in other RT exercises, as velocity decline is exercise-dependent.[17,29]

Creating both RTF-$\text{MV}_{\text{fastest}}$ and RIR-MV relationships requires participants to perform single sets of repetitions to failure against different relative loads. In this regard, it has been well documented that the repetition velocity can be influenced by the inter-repetition interval (IRI) adopted in each training set.[2,16] For instance, García-Ramos et al[2] reported that longer IRI configurations (5-, 10-, and 15-seconds) resulted in a lower velocity loss during 3 sets of 10 repetitions of Smith machine bench press using 10RM load compared with continuous repetitions (ie, IRI of 0 seconds [IRI0]). It is also plausible that longer IRI configurations could lead to a greater number of repetitions at the same relative load due to the maintenance of blood lactate concentration and greater resynthesis of muscle phosphocreatine stores across the repetitions.[2,32] However, it is worth mentioning that, whereas previous studies have implemented cluster set configurations with subjects having longer IRIs (ie, subjects rested for ≥5 seconds without the weight), it remains unclear whether shorter IRIs (ie, they stay with the weight for ≤5 seconds) could affect RTF-$\text{MV}_{\text{fastest}}$ and RIR-MV modeling or their output predictions. Therefore, investigating the effect of IRI configurations could provide valuable information on how to more accurately create both velocity-based approaches to quantify the level of effort during RT sessions.

The aims of this study were to (1) compare the goodness-of-fit of the RTF-$\text{MV}_{\text{fastest}}$ and RIR-MV relationships under different IRI configurations (IRI0, 3 seconds interval between continuous repetitions [IRI3], and self-selected interval between continuous repetitions <5 seconds [SSIRI]), and (2) examine the influence of IRI on the $\text{MV}_{\text{fastest}}$ and MV values associated with different RTFs (from 1 to 15) and RIRs (from 5 to 0), respectively.

METHODS

Subjects

Eighteen male sports science students (age, 22.9 ± 1.6 years [range, 21-26 years]; body height, 1.73 ± 0.06 m; body mass, 79.8 ± 14.4 kg) participated in this study (data presented as means and standard deviations). All subjects were physically active through their standard academic curriculum (approximately 8 physical activity classes per week) and were accustomed to performing the back squat and bench press exercises as a part of their regular training (1RM = 101.7 ± 33.2 kg and 74.1 ± 24.1 kg [1.3 ± 0.2 and 0.9 ± 0.3 normalized per kilogram of body mass], respectively). No musculoskeletal limitations that could affect testing were reported. All subjects were informed of the procedures and signed a written informed consent form before initiating the study. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board.

Design

A repeated-measures design was used to compare RTF-$\text{MV}_{\text{fastest}}$ and RIR-MV relationships between different IRI configurations. Subjects attended the faculty research laboratory on 5 separate occasions. The first 2 sessions were used to familiarize the subjects with the testing protocols (1 session per exercise). Sessions 3 to 5 consisted of performing single sets of repetitions to momentary muscular failure (ie, when a lift cannot be completed with a full range of motion without deviation from the prescribed exercise form) during the back squat and bench press exercises against 3 relative loads (65%, 75%, and 85% of the 1RM). A specific IRI configuration was used in each session (IRI0, IRI3, and SSIRI). All sessions were separated by 48 to 72 hours of rest and were performed at the same time of the day for each subject and under similar environmental conditions (approximately 22 °C and 60% humidity).

Methodology

Body height using a stadiometer (Avanutri 201) and body mass using a digital balance (Ventus B-300 A) were measured at the beginning of the first familiarization session. The warm-up consisted of 5 minutes of running at a self-selected pace, dynamic stretching exercises, and 1 set of 6, 4, and 2 repetitions at 40%, 60%, and 80% of the subjects' self-perceived 1RM for free-weight back squat and bench press exercises, respectively. The rest between loads was set to 3 minutes. The fastest repetition of each load was used to create the individualized load-velocity relationships and, consequently, 1RM was estimated as the load associated with an MV of 0.33 m s^{-1} and 0.17 m s^{-1} for the back squat and bench press exercises, respectively.[22,24] A linear position transducer (Chronojump Boscosystem) was used to collect the MV of all repetitions throughout the study.[27] Validity (systematic bias and random errors ≤0.03 m s^{-1} with respect to an optical motion sensing system) and reliability (coefficient of variation ≤ 6.24%; intraclass correlation coefficient ≥ 0.72) of the Chronojump device for the recording of MV have been reported elsewhere.[27] The cable was attached vertically to the left side of the barbell and the movement velocity feedback was reported to the subjects for each repetition.

After warming up, subjects performed single sets of repetitions to muscular momentary failure during free-weight back squat and bench press exercises, using loads of 65% 1RM, 75% 1RM, and 85% 1RM, in a randomized order. All sessions maintained the same load sequence for each subject.[15] Rest periods of 10 minutes were implemented between successive sets. In a randomized order, a specific IRI configuration was applied in each session: IRI0, IRI3, and SSIRI. The IRI began once the subjects returned to the initial position of the evaluated exercise. A detailed description of the free-weight back squat and bench press exercises has been provided elsewhere.[22,23]

Statistical Analyses

Descriptive data are presented as means and standard deviations, while R^2 and the standard error of the estimate (SEE) are presented through their median values and ranges. The normal distribution of the data was confirmed using the Shapiro-Wilk test ($P > .05$). A 2-way repeated-measures analysis of variance (ANOVA) (IRI [IRI0 vs IRI3 vs SSIRI] × load [65% 1RM, 75%1RM, and 85%1RM]) was conducted on the RTF, $MV_{fastest}$ and last (MV_{last}) repetition of each set. Simple linear regression models were used to determine the generalized and individualized RTF-$MV_{fastest}$ and RIR-MV relationships separately for each IRI configuration. The generalized RTF-$MV_{fastest}$ relationships were obtained by pooling together data from all subjects, whereas individualized RTF-$MV_{fastest}$ relationships were determined specifically for each subject. Three general RIR-MV relationships were obtained, 2 specifics for each load ($general_{load\text{-}specific}$) and 1 grouping the data from the 2 relative loads ($general_{multiple\text{-}loads}$). Note that for the 75% 1RM, 2 subjects were excluded from the analyses because they completed <6 RTFs. For this reason, the RIR-MV modeling for the 85% 1RM load was not performed either. The same RIR-MV relationships were constructed specifically for each subject (ie, $individual_{load\text{-}specific}$ and $individual_{multiple\text{-}load}$). The goodness-of-fit of the generalized and individualized RTF-$MV_{fastest}$ and RIR-MV relationships was assessed by the R^2 and SEE. To compare the goodness-of-fit of the RTF-$MV_{fastest}$ and RIR-MV relationships between IRI configurations, a 1-way repeated-measures ANOVA was applied to the Fisher *z*-transformed Pearson correlation coefficients.

Finally, 1-way repeated-measures ANOVAs were used to compare the estimated $MV_{fastest}$ and MV values for each RTF and RIR between the 3 IRI configurations. Greenhouse-Geisser correction was used when the Mauchly's sphericity test was violated, and pairwise differences were identified using Bonferroni's post hoc corrections. The magnitude of the differences was quantified through the standardized mean differences (Hedge's *g* effect size [ES]) with the corresponding 95% confidence intervals (CI) and was interpreted as follows: trivial (<0.20), small (0.20-0.59), moderate (0.60-1.19), large (1.20-2.00), and very large (>2.00).[8] Statistical analyses were performed using the software package SPSS (IBM SPSS Version 25.0). Statistical significance was set at $P \leq .05$.

RESULTS

There was a significant main effect of IRI for RTF during back squat and bench press exercises ($F_{(2,34)} \geq 8.2$; $P < .01$; ie, lower RTF for IRI0 than for IRI3 and SSIRI [$P < .01$; ES ≥ –0.55; 95% CI, –1.22 to 0.11]) as well for MV_{last} during the bench press exercise ($F_{(2,34)} = 4.7$; $P = .03$; ie, lower MV_{last} for IRI3 than for IRI0 [$P = .06$; ES = 0.73; 95% CI, 0.05 to 1.40]). The main effect of the load was also significant for RTF and $MV_{fastest}$ during back squat and bench press exercises ($F_{(2,34)} \geq 101.6$; $P < .01$; ie, lower RTF and $MV_{fastest}$ with increasing load [$P < .01$; ES ≥ 2.01; 95% CI, 1.21 to 2.81]). Only the IRI × load interaction achieved the statistical significance for RTF during the bench press exercise ($F_{(4,68)} = 3.1$; $P = .02$; ie, differences between IRI conditions were higher for 65% 1RM, followed by 75% 1RM and, finally, by 85% 1RM [$P < .01$; ES ≥ 1.36; 95% CI, 0.63 to 2.08)]) (Table 1).

The goodness-of-fit for generalized relationships obtained from different IRI configurations was moderate between RTF and $MV_{fastest}$ (Figure 1) and somewhat weaker between RIR and MV ($general_{load\text{-}specific}$ [Figures 2 and 3] and $general_{multiple\text{-}loads}$ [Figure 4]). However, the individualized relationships showed stronger goodness-of-fit. Specifically, the individualized RTF-$MV_{fastest}$ relationship ($R^2 = 0.98$ [0.66-1.00]; SEE, 1.2 repetitions [0.0-7.3 repetitions]) and the individualized RIR-MV

Table 1. Descriptive characteristics of back squat and bench press sets performed to momentary muscular failure against 65%, 75%, and 85% 1RM using different IRIs

Exercise	Variable	%1RM	IRI0	IRI3	SSIRI	ANOVA
Back squat	RTF	65	17.2 ± 7.2	21.9 ± 8.4	20.9 ± 5.1	IRI, $F_{(2,34)} = 11.7$; $P < .01$ Load, $F_{(2,34)} = 101.6$; $P < .01$ Interaction, $F_{(4,68)} = 1.6$; $P = .19$
		75	10.7 ± 4.3	13.2 ± 4.9	13.9 ± 2.6	
		85	5.6 ± 2.5	7.4 ± 3.3	7.1 ± 1.9	
	$MV_{fastest}$ ($m \cdot s^{-1}$)	65	0.65 ± 0.07	0.65 ± 0.06	0.63 ± 0.04	IRI, $F_{(2,34)} = 0.5$; $P = .90$ Load, $F_{(2,34)} = 305.4$; $P < .01$ Interaction, $F_{(4,68)} = 1.2$; $P = .33$
		75	0.53 ± 0.07	0.53 ± 0.05	0.54 ± 0.04	
		85	0.44 ± 0.08	0.44 ± 0.04	0.44 ± 0.04	
	MV_{last} ($m \cdot s^{-1}$)	65	0.32 ± 0.08	0.31 ± 0.04	0.29 ± 0.02	IRI, $F_{(2,34)} = 0.4$; $P = .61$ Load, $F_{(2,34)} = 3.3$; $P = .05$ Interaction, $F_{(4,68)} = 2.6$; $P = 0.08$
		75	0.30 ± 0.07	0.30 ± 0.05	0.29 ± 0.02	
		85	0.29 ± 0.05	0.27 ± 0.04	0.30 ± 0.02	
Bench press	RTF	65	17.1 ± 3.9	19.7 ± 4.5	20.4 ± 4.1	IRI, $F_{(2,34)} = 8.2$; $P = .01$ Load, $F_{(2,34)} = 256.3$; $P < .01$ Interaction, $F_{(4,68)} = 3.1$; $P = .02$
		75	11.7 ± 2.9	12.6 ± 3.8	13.8 ± 2.7	
		85	6.1 ± 2.6	7.3 ± 2.6	7.2 ± 2.0	
	$MV_{fastest}$ ($m\ s^{-1}$)	65	0.62 ± 0.12	0.58 ± 0.09	0.58 ± 0.08	IRI, $F_{(2,34)} = 1.3$; $P = .27$ Load, $F_{(2,34)} = 289.9$; $P < .01$ Interaction, $F_{(4,68)} = 1.3$; $P = .23$
		75	0.48 ± 0.09	0.46 ± 0.08	0.48 ± 0.08	
		85	0.35 ± 0.09	0.33 ± 0.07	0.35 ± 0.07	
	MV_{last} ($m \cdot s^{-1}$)	65	0.21 ± 0.07	0.17 ± 0.03	0.17 ± 0.03	IRI, $F_{(2,34)} = 4.7$; $P = .03$ Load, $F_{(2,34)} = 3.2$; $P = .07$ Interaction, $F_{(4,68)} = 1.6$; $P = .20$
		75	0.19 ± 0.06	0.17 ± 0.02	0.17 ± 0.01	
		85	0.17 ± 0.03	0.16 ± 0.03	0.17 ± 0.02	

1RM, 1-repetition maximum; ANOVA, analysis of variance; IRI, inter-repetition interval; IRI0, IRI of 0 seconds; IRI3, IRI of 3 seconds; MV, mean velocity; $MV_{fastest}$, MV of the fastest repetition completed in the set; MV_{last}, MV of the last repetition completed in the set; RTF, maximum number of repetitions completed before reaching muscular failure; SSIRI, self-selected IRI of <5 seconds.
Data are presented as mean ± SD.

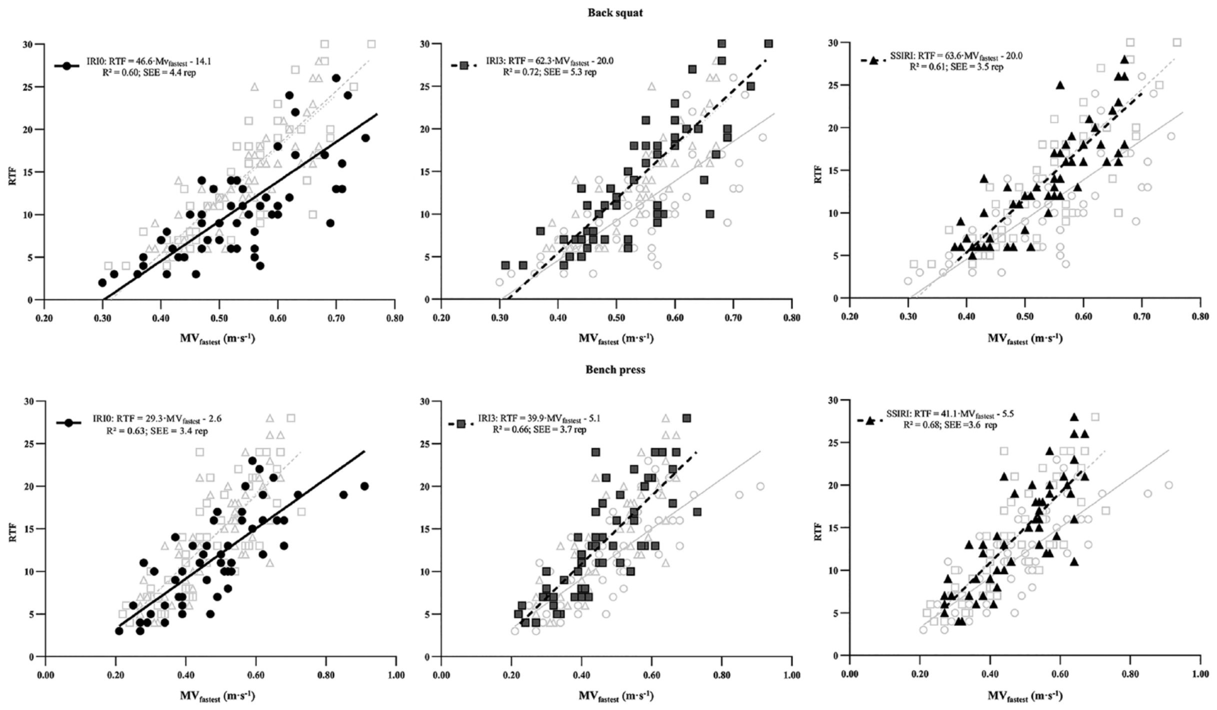

Figure 1. Relationship between RTF and MV$_{fastest}$ during back squat (upper panel) and bench press (lower panel) exercises using different IRIs. Each panel highlights a specific IRI configuration in the same exercise (left to right, IRI0, black circles and continuous line; IRI3, gray squares and dashed line; SSIRI, black triangles and dashed line) with R^2 and SEE. Open light gray points represent other IRI conditions highlighted in other graphics to facilitate comparisons across different IRI conditions. IRI, inter-repetition interval; IRI0, IRI of 0 seconds; IRI3, IRI of 3 seconds; MV, mean velocity, MV$_{fastest}$, fastest MV; R^2, coefficient of determination; RTF, maximum number of repetitions completed before reaching muscular failure; SEE, standard error of the estimate; SSIRI, self-selected IRI of <5 seconds.

relationship for individual$_{load\text{-}specific}$ (R^2 = 0.89 [0.24-1.00]; SEE, 0.7 RIR [0.0-1.8 RIR]), and for individual$_{multiple\text{-}loads}$ (R^2 = 0.69 [0.16-0.96]; SEE, 1.0 RIR [0.4-1.7 RIR]).

When comparing different IRI configurations for the back squat exercise, the individualized RTF-MV$_{fastest}$ and RIR-MV relationship had a higher goodness-of-fit ($F_{(2,34 \text{ or } 2,30)} \geq 4.4$; $P <$ .01) for SSIRI compared with IRI0 ($P \leq .07$; ES ≥ 0.67; 95% CI, 0.60 to 2.04). For the bench press exercise, the goodness-of-fit for the different IRI configurations was comparable ($F_{(2,34)} \leq 1.3$; $P \geq .23$).

There was a significant main effect for the MV$_{fastest}$ associated with RTFs from eighth to fifteenth during the back squat exercise ($F_{(2,34)} \geq 6.2$; $P < .01$; ie, higher MV$_{fastest}$ for IRI0 than for SSIRI [$P \leq .03$; ES ≥ 0.89; 95% CI, 0.12 to 1.57)] and IRI3 [$P \leq .04$; ES ≥ 0.78; 95% CI, 0.08 to 1.44)]) and from eleventh to fifteenth during the bench press exercise ($F_{(2,34)} \geq 4.3$; $P \leq .04$; ie, higher MV$_{fastest}$ for IRI0 than for IRI3 [$P < .01$; ES ≥ 0.64; 95% CI, –0.03 to 1.31)]) (Table 2). The main effect was also significant for the MV associated with RIRs from 5 to 0 using individual$_{load\text{-}specific}$ equations at 65% 1RM and from 5 to 2 using individual$_{multiple\text{-}load}$ equations during the back squat exercise ($F_{(2,34 \text{ or } 2,30)} \geq 4.3$; $P \leq .024$; ie, lower MV for SSIRI than for IRI0 [$P \leq .043$; ES ≥ 0.53; 95% CI, –0.14 to 1.19)] and IRI3 [$P \leq .05$; ES ≥ 0.46; 95% CI, –0.21 to 1.12); only for RIR 4 and 3 using individual$_{load\text{-}specific}$ equations at 65% 1RM). For the bench press exercise, significant main effects were observed for the MV associated with RIRs from 5 to 0 using the individual$_{load\text{-}specific}$ equations at 65% 1RM, from 5 to 1 using individual$_{load\text{-}specific}$ equations at 75% 1RM, and, finally, from 5 to 0 using the individual$_{multiple\text{-}load}$ equations ($F_{(2,34)} \geq 5.4$; $P \leq .02$; i.e., higher MV for IRI0 than for IRI3 [$P \leq .05$; ES ≥ 0.67; 95% CI, 0.00 to 1.34); except for RIR 1 using individual$_{load\text{-}specific}$ equations at 75% 1RM] and SSIRI [$P \leq .05$; ES ≥ 0.95; 95% CI, 0.26 to 1.64); except for RIR 0 using individual$_{load\text{-}specific}$ equations at 65% 1RM and individual$_{multiple\text{-}load}$ equations]) (Table 3).

DISCUSSION

This study was designed to (1) compare goodness-of-fit of the RTF-MV$_{fastest}$ and RIR-MV relationships under different IRI configurations, and (2) examine the influence of IRI on the MV$_{fastest}$ and MV values associated with different RTFs (from 1 to

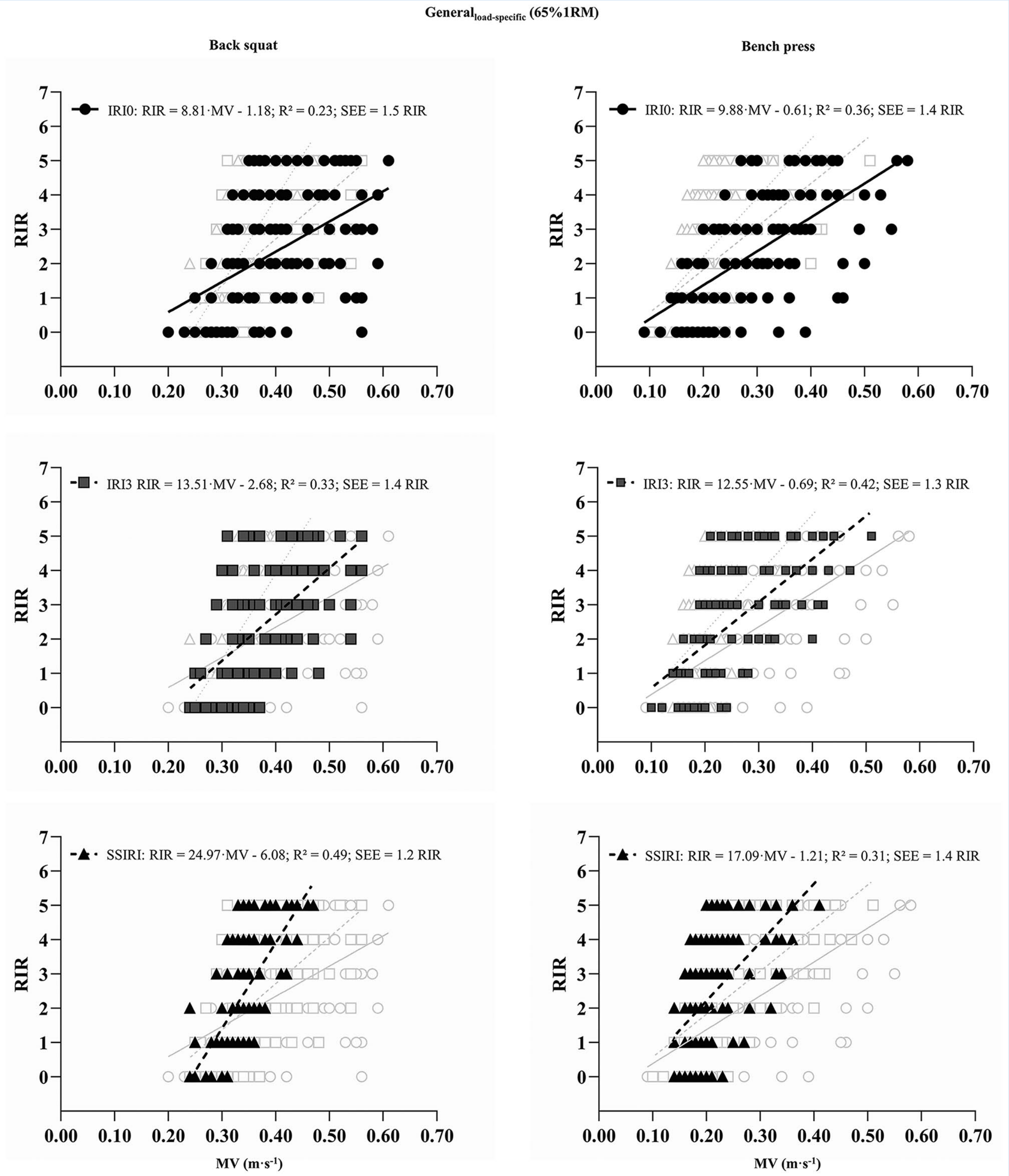

Figure 2. Relationship between RIR and repetition MV constructed for 65% of 1RM during back squat (left panels) and bench press (right panels) exercises using different IRIs. Each panel highlights a specific configuration in the same exercise (top to bottom, IRI0, black circles and continuous line; IRI3, gray squares and dashed line; SSIRI, black triangles and dashed line) with R^2 and SEE. Open light gray points represent other IRI conditions highlighted in other graphics to facilitate comparisons across different IRI conditions. IRI, inter-repetition interval; IRI0, IRI of 0 seconds; IRI3, IRI of 3 seconds; MV, mean velocity, R^2, coefficient of determination; RIR, number of repetitions left in reserve; SEE, standard error of the estimate; SSIRI, self-selected IRI of <5 seconds.

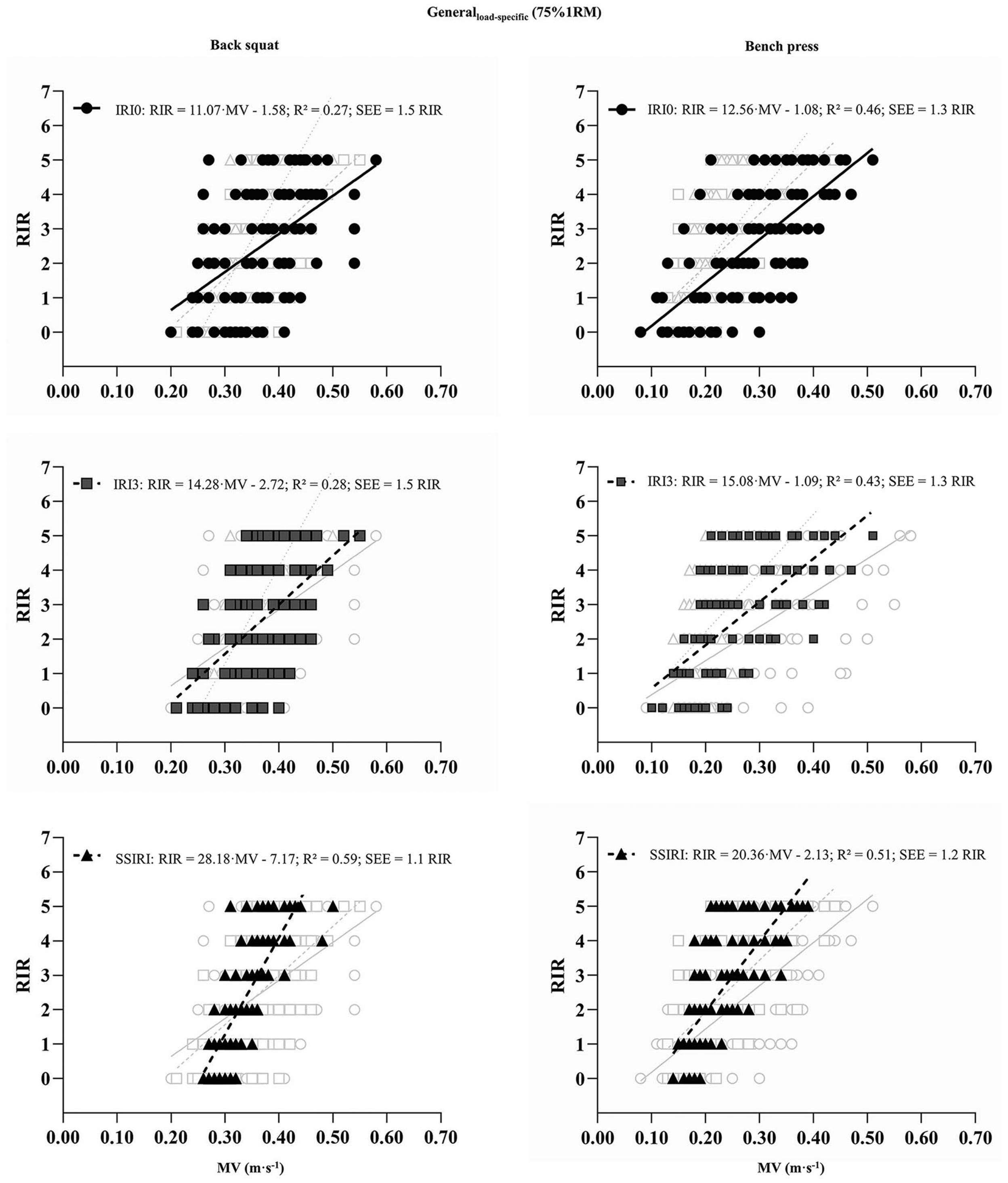

Figure 3. Relationship between RIR and repetition MV constructed for 75% of 1RM during back squat (left panels) and bench press (right panels) exercises using different IRIs. Each panel highlights a specific configuration in the same exercise (top to bottom, IRI0, black circles and continuous line; IRI3, gray squares and dashed line; SSIRI, black triangles and dashed line) with R^2 and SEE. Open light gray points represent other IRI conditions highlighted in other graphics to facilitate comparisons across different IRI conditions. IRI, inter-repetition interval; IRI0, IRI of 0 seconds; IRI3, IRI of 3 seconds; MV, mean velocity, R^2, coefficient of determination; RIR, number of repetitions left in reserve; SEE, standard error of the estimate; SSIRI, self-selected IRI of <5 seconds.

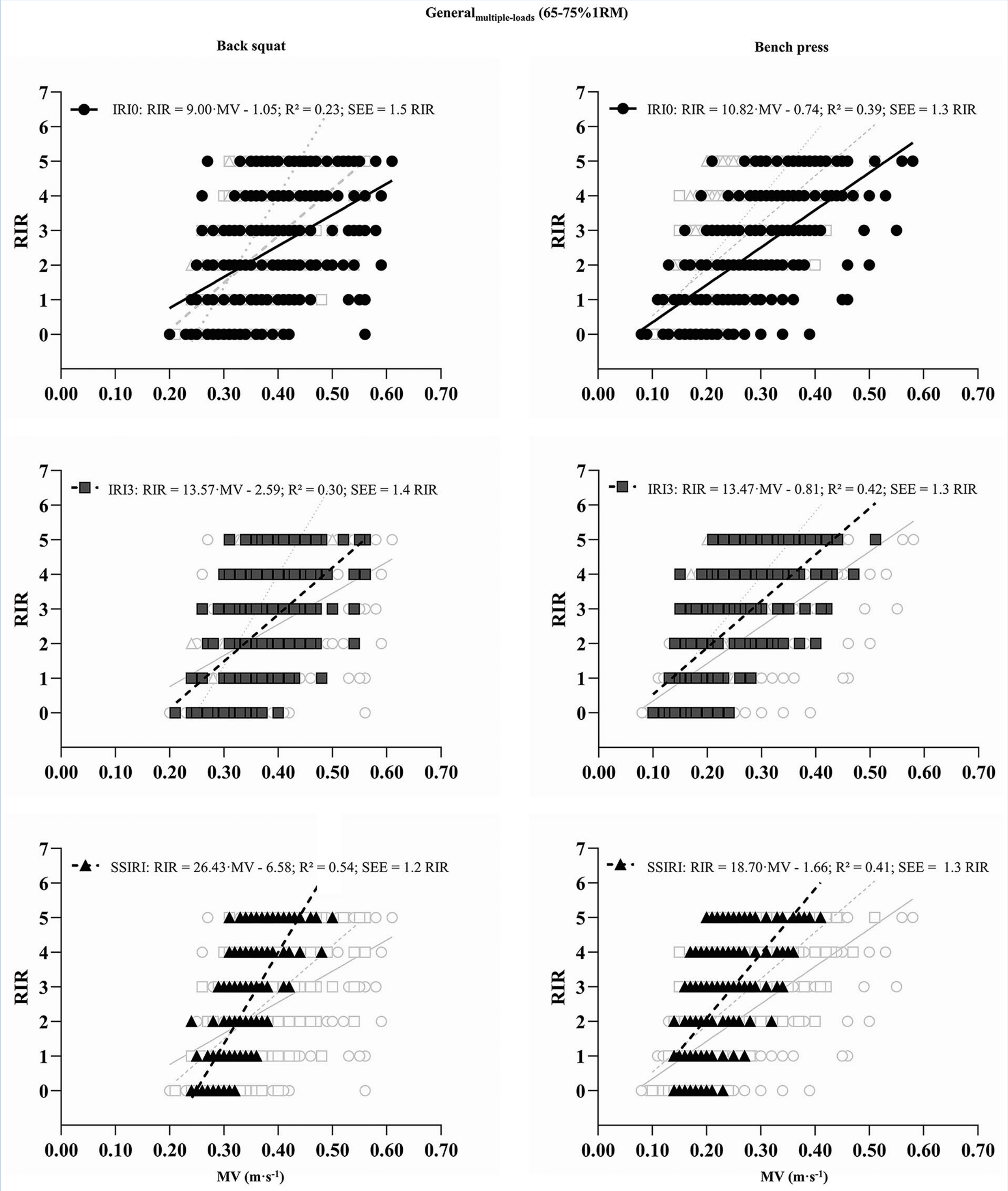

Figure 4. Relationship between RIR and repetition MV constructed by pooling the data from 65% and 75% of 1RM (general$_{\text{multiple-loads}}$) during back squat (left panels) and bench press (right panels) exercises using different IRIs. Each panel highlights a specific configuration in the same exercise (top to bottom, IRI0, black circles and continuous line; IRI3, gray squares and dashed line; SSIRI, black triangles and dashed line) with R^2 and SEE. Open light gray points represent other IRI conditions highlighted in other graphics to facilitate comparisons across different IRI conditions for each exercise. IRI, inter-repetition interval; IRI0, IRI of 0 seconds; IRI3, IRI of 3 seconds; MV, mean velocity, R^2, coefficient of determination; RIR, number of repetitions left in reserve; SEE, standard error of the estimate; SSIRI, self-selected IRI of <5 seconds.

Table 2. Comparison of $MV_{fastest}$ of the set associated with each RTF during back squat and bench press exercises using different IRIs

Exercise	RTF	$MV_{fastest}$ (m s^{-1})			ANOVA	
		IRI0	IRI3	SSIRI	$F_{(2,34)}$	*P* value
Back squat	1	0.36 ± 0.07	0.34 ± 0.09	0.34 ± 0.07	0.4	.67
	2	0.38 ± 0.07	0.35 ± 0.08	0.36 ± 0.07	0.8	.47
	3	0.40 ± 0.07	0.37 ± 0.07	0.38 ± 0.06	1.1	.36
	4	0.42 ± 0.06	0.39 ± 0.06	0.39 ± 0.06	1.6	.21
	5	0.44 ± 0.06	0.41 ± 0.06	0.41 ± 0.05	2.4	.11
	6	0.46 ± 0.06	0.42± 0.05	0.42 ± 0.05	3.0	.06
	7	0.48 ± 0.06	0.44 ± 0.05	0.44 ± 0.05	4.6	.02
	8	0.50 ± 0.06*†	0.46 ± 0.05	0.45 ±0.04	6.2	<.01
	9	0.52 ± 0.07*†	0.47 ± 0.05	0.47 ± 0.04	7.2	<.01
	10	0.54 ± 0.07*†	0.49 ± 0.06	0.48 ± 0.04	7.7	<.01
	11	0.56 ± 0.07*†	0.51 ± 0.07	0.50 ± 0.04	8.6	<.01
	12	0.58 ± 0.08*†	0.53 ± 0.08	0.52 ± 0.04	9.7	<.01
	13	0.61 ± 0.09*†	0.54 ± 0.08	0.53 ± 0.04	9.4	<.01
	14	0.63 ± 0.09*†	0.56 ± 0.09	0.55 ± 0.04	9.9	<.01
	15	0.65 ± 0.10*†	0.58 ± 0.10	0.56 ± 0.05	9.9	<.01
Bench press	1	0.21 ± 0.07	0.22 ± 0.06	0.24 ± 0.11	0.4	.68
	2	0.24 ± 0.07	0.24 ± 0.05	0.26 ± 0.10	0.3	.74
	3	0.27 ± 0.07	0.26 ± 0.05	0.28 ± 0.09	0.2	.75
	4	0.29 ± 0.07	0.28 ± 0.05	0.29 ± 0.08	0.2	.75
	5	0.32 ± 0.07	0.30 ± 0.05	0.31 ± 0.07	0.4	.60
	6	0.34 ± 0.07	0.32 ± 0.05	0.33 ± 0.07	0.8	.44
	7	0.37 ± 0.07	0.34 ± 0.05	0.35 ± 0.06	1.1	.33
	8	0.39 ± 0.07	0.36 ± 0.05	0.37 ± 0.06	1.7	.20
	9	0.42 ± 0.08	0.38 ± 0.06	0.39 ± 0.06	2.8	.09
	10	0.45 ± 0.08	0.40 ± 0.06	0.41 ± 0.06	3.3	.07
	11	0.47 ±0.08*	0.42 ± 0.06	0.43 ± 0.06	4.3	.04
	12	0.50 ± 0.09*	0.44 ± 0.07	0.45 ± 0.07	5.1	.03
	13	0.52 ± 0.09*	0.46 ± 0.07	0.47 ±0.07	5.4	.02
	14	0.55 ± 0.10*	0.48 ± 0.08	0.49 ± 0.08	5.7	.02
	15	0.57 ± 0.10*	0.50 ± 0.08	0.51 ± 0.09	6.0	.01

ANOVA, analysis of variance; MV mean velocity; $MV_{fastest}$, fastest MV; IRI, inter-repetition interval; IRI0, IRI of 0 seconds; IRI3, IRI of 3 seconds; RTF, maximum number of repetitions completed before reaching muscular failure; SSIRI, self-selected IRI of <5 seconds.

Data are presented as mean ± SD.

*Significantly higher than IRI3.

†Significantly higher than SSIRI ($P \leq .05$; ANOVA with Bonferroni's correction).

Table 3. Comparison of the repetition mean velocity associated with each number of RIR during back squat and bench press exercises using different IRIs

Exercise	Equation	RIR	Mean velocity (m s^{-1})			ANOVA	
			IRI0	IRI3	SSIRI	*F*	*P* value
Back squat	Load-specific (65% 1RM)	5	0.48 ± 0.09†	0.44 ± 0.07	0.39 ± 0.05	7.6	<.01
		4	0.45 ± 0.08†	0.42 ± 0.06†	0.37 ± 0.04	7.7	<.01
		3	0.43 ± 0.08†	0.40 ± 0.06†	0.35 ± 0.03	7.5	<.01
		2	0.40 ± 0.07†	0.37 ± 0.05	0.33 ± 0.03	6.6	<.01
		1	0.38 ± 0.07†	0.35 ± 0.05	0.31 ± 0.02	6.2	<.01
		0	0.35 ± 0.08†	0.32 ± 0.04	0.29 ± 0.02	4.9	.02
	Load-specific (75% 1RM)	5	0.43 ± 0.08	0.41 ± 0.06	0.40 ± 0.04	1.3	.28
		4	0.41 ± 0.07	0.39 ± 0.06	0.37 ± 0.04	1.3	.29
		3	0.38 ± 0.07	0.38 ± 0.05	0.35 ± 0.03	1.5	.25
		2	0.36 ± 0.06	0.36 ± 0.05	0.33 ± 0.02	1.4	.27
		1	0.33 ± 0.06	0.34 ± 0.05	0.31 ± 0.02	1.2	.33
		0	0.31 ± 0.06	0.32 ± 0.05	0.29 ± 0.02	1.6	.33
	Multiple-load (65%-75% 1RM)	5	0.45 ± 0.07†	0.43 ± 0.05	0.39 ± 0.04	4.4	.02
		4	0.43 ± 0.07†	0.40 ± 0.05	0.37 ± 0.04	4.4	.02
		3	0.40 ± 0.07†	0.38 ± 0.05	0.35 ± 0.03	4.4	.02
		2	0.38 ± 0.06†	0.36 ± 0.04	0.33 ± 0.02	4.2	.02
		1	0.35 ± 0.06	0.34 ± 0.04	0.31 ± 0.02	3.6	.04
		0	0.33 ± 0.06	0.32 ± 0.04	0.29 ± 0.01	2.9	.07

(continued)

Table 3. (continued)

Exercise	Equation	RIR	Mean velocity ($m\ s^{-1}$)			ANOVA	
			IRI0	IRI3	SSIRI	*F*	*P* value
Bench press	Load-specific (65% 1RM)	5	0.41 ± 0.08*†	0.34 ± 0.09	0.26 ± 0.07	17.5	<.01
		4	0.37 ± 0.08*†	0.30 ± 0.08	0.24 ± 0.06	17.5	<.01
		3	0.33 ± 0.08*†	0.27 ± 0.06	0.23 ± 0.05	15.8	<.01
		2	0.30 ± 0.08*†	0.24 ± 0.05	0.21 ± 0.04	12.8	<.01
		1	0.26 ± 0.08*†	0.20 ± 0.05	0.19 ± 0.03	8.7	<.01
		0	0.22 ± 0.09*	0.17 ± 0.05	0.17 ± 0.03	5.4	<.01
	Load-specific (75% 1RM)	5	0.38 ± 0.07*†	0.31 ± 0.08	0.29 ± 0.07	8.4	<.01
		4	0.34 ± 0.07*†	0.28 ± 0.06	0.27 ± 0.05	8.1	<.01
		3	0.30 ± 0.07*†	0.25 ± 0.05	0.24 ± 0.04	8.2	<.01
		2	0.27 ± 0.06*†	0.22 ± 0.04	0.21 ± 0.03	7.1	<0.01
		1	0.23 ± 0.06†	0.20 ± 0.04	0.19 ± 0.02	5.4	.02
		0	0.19 ± 0.07	0.17 ± 0.03	0.16 ± 0.01	3.2	.08
	Multiple-load (65%-75% 1RM)	5	0.39 ± 0.07*†	0.32 ± 0.07	0.28 ± 0.05	18.3	<.01
		4	0.35 ± 0.07*†	0.29 ± 0.06	0.25 ± 0.04	17.8	<.01
		3	0.32 ± 0.07*†	0.26 ± 0.05	0.23 ± 0.04	17.0	<.01
		2	0.28 ± 0.07*†	0.23 ± 0.04	0.21 ± 0.03	14.8	<.01
		1	0.24 ± 0.07*†	0.20 ± 0.04	0.19 ± 0.02	10.2	<.01
		0	0.21 ± 0.07*	0.17 ± 0.03	0.17 ± 0.02	6.1	.01

1RM, 1-repetition maximum; ANOVA, analysis of variance; IRI0, IRI of zero seconds; IRI3, IRI of 3 seconds; RIR, repetitions in reserve; SSIRI, self-selected IRI of <5 seconds.

Data are presented as mean ± SD.

*Significantly higher than IRI3.

†Significantly higher than SSIRI ($P \leq .05$; ANOVA with Bonferroni's correction).

15) and RIRs (from 5 to 0), respectively. The main findings of the current investigation revealed that (1) the goodness-of-fit of the individualized RTF-$MV_{fastest}$ and RIR-MV relationships was stronger for SSIRI than for IRI0 during the back squat exercise or comparable between the different IRI configurations during the bench press exercise, (2) the $MV_{fastest}$ values obtained from the eighth to fifteenth RTFs were higher for the IRI0 than for IRI3 and SSIRI during the back squat exercise and from eleventh to fifteenth RTFs were higher for IRI0 than for IRI3 during the bench press exercise, while the MV values associated with each RIR were generally higher for IRI0 than for SSIRI (10 out of 18 comparisons) during the back squat exercise and for IRI0 than for IRI3 and SSIRI (16 and 14 out of 18 comparisons, respectively) during the bench press exercise. Collectively, these results highlight the importance of standardizing the IRI during the sets to failure used to create the RTF-$MV_{fastest}$ and RIR-MV relationships.

The individualized RTF-$MV_{fastest}$ and RIR-MV relationships obtained for each IRI configuration were markedly stronger than the generalized RTF- $MV_{fastest}$ and RIR-MV relationships. Importantly, these results concur with previous research that reported stronger goodness-of-fit with individualized rather than generalized RTF-$MV_{fastest}$ relationships for different RT exercises (R^2 = 0.77 vs 0.87-1.00 for the Smith machine bench press[3]; 0.70 vs 0.83-1.00 for the Smith machine prone bench pull[15]; and 0.45-0.49 vs 0.50-1.00 for the free-weight back squat and RIR-MV relationships (R^2 = 0.29-49 vs 0.58-0.98 [load-specific][10]; and 0.42 vs 0.38-0.83 [multiple-loads] for the Smith machine prone bench pull.[26] Of note, our hypothesis was partially confirmed since stronger RTF-$MV_{fastest}$ and RIR-MV relationships were obtained from SSIRI than from IRI0 during the back squat exercise, while the goodness-of-fit of both relationships was comparable across IRI configurations during the bench press exercise. It is possible to hypothesize that performing sets to failure using the SSIRI method, which involves higher RTFs and velocity maintenance, can enhance the linearity of regression models obtained from technically complex exercises like the free-weight back squat. Therefore, practitioners should consider instructing subjects to perform a brief SSIRI during the sets to failure used to establish the RTF-$MV_{fastest}$ and RIR-MV relationships. Incorporating this methodological aspect can enhance the accuracy of both velocity-based approaches for quantifying the level of effort (ie, how many repetitions to perform concerning the maximum number of repetitions that can be completed with a given load [XRM]) being exerted in each training set).

For the first time, we compared not only the goodness-of-fit of the RTF-$MV_{fastest}$ and RIR-MV relationships but also the $MV_{fastest}$ and MV values associated with each RTF and RIR, respectively. Overall, our findings indicate that the $MV_{fastest}$ (from roughly the eighth to the fifteenth RTFs) and MV (from roughly 5 to 0 RIRs) were generally higher for the IRI0 than for IRI3 and/or SSIRI during the free-weight back squat and bench press exercises. In that sense, longer IRI configurations (up to 5 seconds) may enhance concentration, technical execution, and alleviate discomfort during sets to failure.[14,25,26] In fact, it can be hypothesized that longer inter-repetition rests may allow for greater maintenance of phosphocreatine stores, adenosine triphosphate resynthesis, and metabolite clearance.[4,5,11] Consequently, our results show SSIRI configuration leads a steeper RTF-$MV_{fastest}$ and RIR-MV relationships due to (1) higher RTFs completed against each relative load (ie, higher RTFs for the same $MV_{fastest}$) and (2) greater velocity maintenance in each set to failure (ie, lowest MV values for the same RIR). Thus, to make effective training decisions based on individualized RTF-$MV_{fastest}$ and RIR-MV relationships, it is necessary to standardize the IRI used during the sets to failure. From a practical standpoint, we recommend practitioners use an SSIRI as a more ecologically valid procedure that not only enhances the accuracy of the individualized RTF-$MV_{fastest}$ and RIR-MV relationships but also increases RTF and velocity maintenance.

Although the present study provides novel information to objectively know the level of effort exerted during the training sets from velocity records, readers should be mindful of some limitations. First, the generalizability of current results may be limited to male sports science students. Second, the relative loads were estimated from the individualized load-MV relationship in each testing session, which might lead to a slight overestimation.[9] However, it should be noted that no significant differences were observed for the $MV_{fastest}$ of each set, suggesting that a similar relative load should be expected. Furthermore, it is plausible that 1RM estimates slightly differ when minimum velocity thresholds determined in machine-based exercises are applied to free-weight exercises.[13] Finally, since it is not practical to complete different sets to failure in every single training session to develop each person's RTF-$MV_{fastest}$ and RIR-MV profile, future studies should examine whether the individualized RTF-$MV_{fastest}$ and RIR-MV equations obtained during an initial testing session accurately predicts the RTF and RIR in subsequent training sessions for different RT exercises.[10,15]

CONCLUSION

The individualized RTF-$MV_{fastest}$ and RIR-MV relationships have recently been proposed to objectively quantify the level of effort being exerted in training sets through movement. The RTF-$MV_{fastest}$ relationships are used for the prescription of the loads associated with a specific XRM to decide how many repetitions to perform in each training set, while the RIR-MV relationships allow you to control proximity to failure by knowing the specific RIR in each training set. To model these 2 relationships, it is necessary to perform previous sets to momentary muscular failure against different relative loads. In this regard, our findings have emphasized the need to standardize the IRI during sets to failure, as it influences the precision of the RTF-$MV_{fastest}$ and RIR-MV relationships, as well as the velocity ($MV_{fastest}$ or MV) associated with a given RTF or RIR. From a practical perspective, an SSIRI could be recommended as a more ecologically valid (ie, subjects adopt a brief IRI based on their needs), accurate (ie, higher goodness-of-fit of RTF-MV$_{fastest}$ and RIR-MV relationships), and effective procedure (ie, steeper RTF-MV$_{fastest}$ and RIR-MV relationships due to higher RTF and velocity maintenance in the set, respectively).

ACKNOWLEDGMENT

The authors would like to thank all the subjects who selflessly participated in the study. The results of this study do not constitute an endorsement of the product by the authors.

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