Received: 7 September 2023 | Revised: 2 January 2024 | Accepted: 4 January 2024

DOI: 10.1002/ejsc.12078

ORIGINAL PAPER

Official ECSS Journal Open Access WILEY

Maximal and submaximal intended velocity squat sets: Do they selectively impact mechanical performance in paired multijoint upper-body exercise sets?

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Funding information
National Natural Science Foundation of China,

Abstract

This study aimed to investigate how squat protocols performed at maximal and submaximal intended velocities during interset periods of paired upper-body exercises that impact the mechanical performance of these multijoint upper-body exercises. Twenty-one young and healthy adults (seven women) completed three experimental sessions, each comprising four sets of five repetitions at 75% of their 1-repetition maximum, with a 4-min break between sets using the bench press and bench pull exercises. The experimental sessions differed in the protocol utilized during the interset periods: (i) *Passive*—no physical exercise was performed; (ii) SQ_{fast}—5 repetitions of the squat exercise at maximal intended velocity against the load associated with a mean velocity (MV) of 0.75 m s^{-1}; and (iii) SQ_{slow}—5 repetitions of the squat exercise at submaximal velocity (intended MV of 0.50 m s^{-1}) against the load associated with an MV of 0.75 m s^{-1}. Level of significance was $p \leq 0.05$. The main findings revealed negligible differences (effect size [ES] < 0.20) among the exercise protocols (passive vs. SQ_{fast} vs. SQ_{slow}) for all mechanical variables during the bench pull, whereas during the bench press, small differences (ES from 0.23 to 0.31) emerged favoring the passive protocol over SQ_{fast} and SQ_{slow} in terms of mean set velocity and fastest MV of the set. The absence of significant differences between the SQ_{fast} and SQ_{slow} protocols, irrespective of the particular upper-body exercise, implies that the intended lifting velocity does not influence the potential interference effect during paired set training procedures.

KEYWORDS
fatigue, resistance training, superset, velocity-based training

Highlights

- Supersets with the squat exercise appear to exert minimal influence on bench pull mechanical performance but modest interference arises concerning the bench press exercise.

Grant/Award Number: 12250410237;
Universidad de Granada

- The intended lifting velocity utilized in lower-body exercises does not exert an influence on mechanical performance within paired upper-body exercise sets.
- Exercise selection holds greater significance than intended lifting velocity when striving to mitigate interference in superset training.

1 | INTRODUCTION

Resistance training (RT) is an effective method to improve strength, power, hypertrophy, and athletic performance (Kraemer et al., 2004; Mangine et al., 2015) while also decreasing the risk of chronic disease and disability (Khadanga et al., 2019; Westcott, 2012). Neuromuscular adaptations to RT directly depend on the configuration of the RT stimulus (Jukic et al., 2022, 2023; Kraemer et al., 2002). During a typical RT session, individuals engage in several sets of different exercises with interset rest periods ranging from 1 to 7 min (Millender et al., 2021) tailored to the specific training goal. These interset periods usually consist of low intensity active or passive rest activities, such as walking or sitting, designed to promote recovery (e.g., replenishment of the ATP-CP energy system) (Grgic et al., 2017; Wells et al., 2009), and maintain performance (e.g., lifting velocity outputs or work capacity) (González-Hernández et al., 2023; Ratamess et al., 2009). However, to increase training efficiency, coaches can incorporate exercises that target distinct muscle groups or movement patterns during rest intervals known as paired sets (PS) (Robbins et al., 2009; Robbins, Young & Behm, 2010; Robbins, Young, Behm, Payne & Klimstra, 2010; Weakley et al., 2017). It is noteworthy that this alternative method of programming requires careful consideration of exercise choice, intensity, and volume to ensure the main exercise's mechanical performance is not compromised.

Although PS are known to enhance training efficiency (Robbins et al., 2009; Robbins, Young & Behm, 2010; Robbins, Young, Behm, Payne & Klimstra, 2010), there is a concern that they might hinder overall mechanical performance throughout the RT session when compared to traditional RT methods that involve consecutive sets of a single exercise (Weakley et al., 2017). One factor that could potentially alleviate the negative effects of PS on mechanical performance is terminating sets further from failure. Notably, as sets are terminated closer to the point of exhaustion, longer rest intervals are needed to maintain mechanical performance outcomes in subsequent sets (Kraemer et al., 2004; Millender et al., 2021). Scientific evidence suggests that training to failure can lead to greater mechanical strain and metabolic responses during RT, yet it does not optimize athletic performance adaptations (Pareja-Blanco et al., 2017, 2020). Paradoxically, most studies exploring the effects of PS on mechanical performance have employed sets to failure (e.g., loads ranging from 3 to 6 repetition maximum) observing a cumulative effect of general fatigue during PS of bench press and bench pull exercises (i.e., greater percent of decrease in completed bench press repetitions throughout the sets compared to traditional set structures) (Robbins et al., 2009; Robbins, Young & Behm, 2010; Robbins, Young, Behm, Payne & Klimstra, 2010). Recognizing the critical role that proximity to failure plays in shaping the immediate responses to RT, it is essential to devise efficient PS protocols that prevent substantial declines in neuromuscular performance during nonfailure RT sessions.

One approach of implementing PS involves alternating peripheral movements (e.g., combining upper-body [e.g., bench press and bench pull] and lower-body [e.g., back squat; SQ] exercises). García-Orea et al. (2023) reported similar improvements in jumping ability and strength after 6 weeks of traditional or PS configurations using SQ and bench press exercises with frequency, intensity, volume, and proximity to failure matched between groups. Regarding acute responses to RT, Ciccone et al. (2014) demonstrated that the inclusion of two upper-body exercises (bench press and bench pull) during rest intervals in the SQ exercise resulted in compromised lower-body mechanical performance evidenced by a reduction in repetitions to failure and average power output. Similarly, Weakley et al. (2020) showed that performing the SQ exercise during rest intervals of the bench press exercise resulted in lower maintenance of velocity, power, and force compared to traditional RT methods. In addition, Weakley et al. (2017) found greater muscle damage, lactate concentration, and reduced neuromuscular performance after superset and tri-set RT protocols of upper- and lower-body exercises compared to traditional configurations. However, an unexplored question pertains to the impact of the intended lifting velocity during sets of a lower-body exercise on mechanical performance in PS of upper-body exercises. This question gains significance as training at maximal intended velocity has been linked to superior improvements in athletic performance (González-Badillo et al., 2014; Pareja-Blanco et al., 2014), but it promotes greater mechanical and metabolic stress than deliberately lifting at slower velocities (García et al., 2022; Pareja-Blanco et al., 2014). Therefore, more research is warranted to assess the influence of intended lifting velocity (maximal or submaximal) on mechanical performance during PS schemes.

To gain insight into the effects of exercise velocity on paired set performance, the present investigation involved subjects performing multiple sets of the bench press and bench pull exercises on different occasions that only differed in the exercise protocol carried out during the interset periods: (i) standard passive rest (*passive protocol*), (ii) SQ at maximal intended lifting velocity (SQ_{fast}), and (iii) SQ at submaximal lifting velocity (SQ_{slow}). Specifically, the objective of this study was to evaluate how both SQ protocols (SQ_{fast} and SQ_{slow}) impact mechanical performance outcomes (mean set velocity [MSV], fastest mean velocity of the set [$MV_{fastest}$], mean velocity of the last repetition of the set [MV_{last}], and mean velocity decrement [$MVD = [MV_{last} - MV_{fastest}]/MV_{fastest} \times 100$]) in comparison to the standard passive rest protocol throughout multiple PS of multijoint upper-body exercises. It was hypothesized that performing SQ_{fast}

protocols during interset periods would result in impaired mechanical performance outcomes in PS of multijoint upper-body exercises compared to the passive and SQ_{slow} protocols. This hypothesis is based on the expectation that the SQ_{fast} protocol places a greater demand on the central nervous system, potentially leading to fatigue and decreased performance in the subsequent upper-body exercise sets.

2 | METHOD

2.1 | Subjects

Twenty-one healthy and physically active individuals agreed to participate in this study (mean ± standard deviation [SD]): 14 men (age: 24.0 ± 4.2 years [range: 19–33 years]; body mass: 80.3 ± 10.8 kg; body height: 1.79 ± 0.08 m; bench press one-repetition maximum [1RM]: 92.0 ± 20.7 kg; bench pull 1RM: 88.7 ± 12.4 kg) and seven women (age: 26.6 ± 9.1 years [range: 19–46 years]; body mass: 60.0 ± 4.2 kg; body height: 1.63 ± 0.04 m; bench press 1RM: 44.4 ± 6.9 kg; bench pull 1RM: 50.9 ± 5.2 kg). None of the subjects had any physical limitation that prevented them from correctly performing the tested exercises. All subjects indicated prior experience with the three exercises, and an experienced researcher verified that all subjects could perform the three exercises with maximum intent during a preliminary session. All subjects were informed about the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study. The study protocol adhered to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board (approval number: blinded for peer review).

2.2 | Study design

A crossover study design was implemented to investigate the impact of various SQ protocols carried out during interset rest periods on the mechanical performance of multiple PS of upper-body exercises. Subjects successfully completed four sessions with 72–96 h of rest between each testing session (Figure 1). The initial session aimed to establish the 1RM for both bench press and bench pull exercises, as well as identify the load corresponding to a mean velocity (MV) of 0.75 m s^{-1} during the SQ exercise. During the three remaining experimental sessions, subjects completed at maximal intended velocity both the bench press and bench pull exercises. For each exercise, subjects completed four sets of five repetitions against the 75%1RM with 4 min of interset rest. The experimental sessions only differed in the exercise protocol implemented during the interset rest periods of the upper-body exercises: (i) *Passive*—no physical exercise was performed; (ii) SQ_{fast}—5 repetitions of the SQ exercise performed at maximal intended velocity against the load associated with a MV of 0.75 m s^{-1}; and (iii) SQ_{slow}—5 repetitions of the SQ exercise performed at submaximal velocity (intended MV of 0.50 m s^{-1}) against the load associated with an MV of 0.75 m s^{-1}.

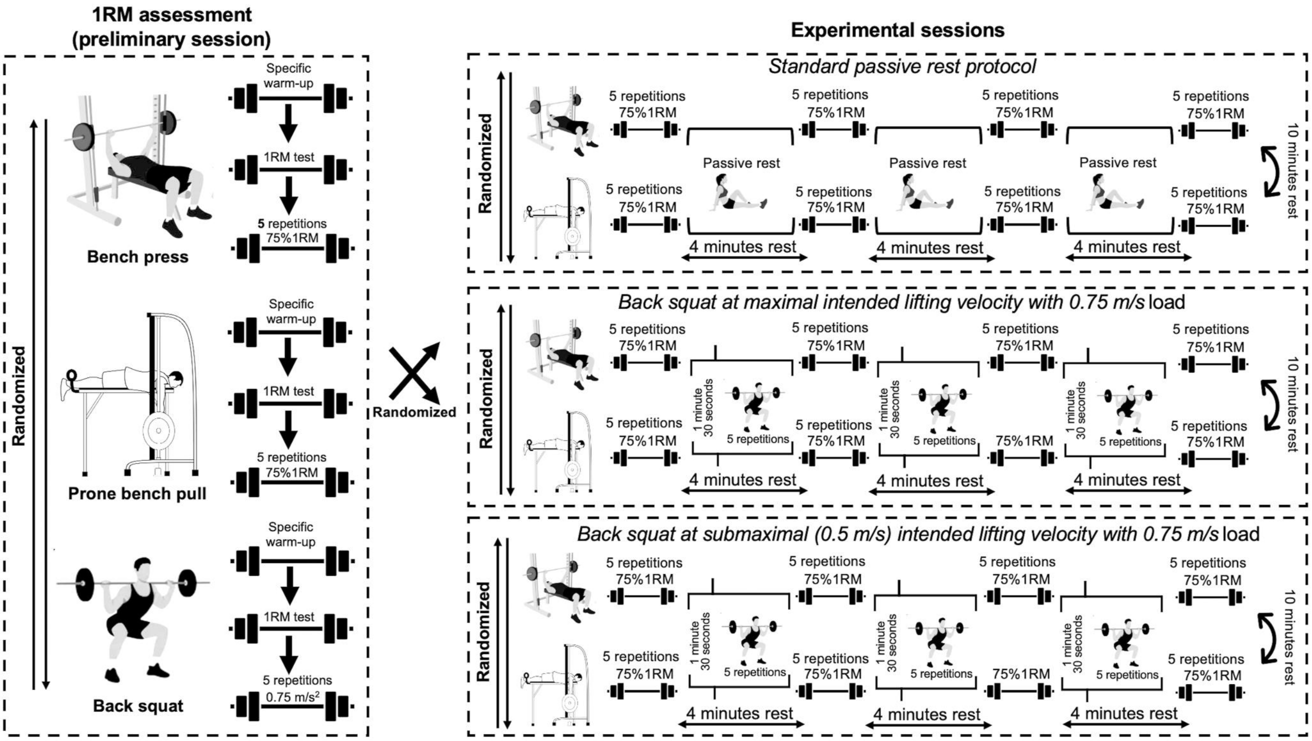

FIGURE 1 Overview of the experimental design.

The three exercise protocols were applied in a counterbalanced order. To minimize diurnal variations in strength performance, the experimental sessions were conducted in the university research laboratory with each subject completing their sessions at the same time of day.

2.3 | Procedures

2.3.1 | Preliminary session (session 1)

A general warm-up consisting of 5 min of jogging and dynamic stretching exercises was performed at the beginning of the session. Thereafter, three incremental loading tests (bench press, bench pull, and SQ) were performed in a randomized order. The initial load was set to 20 kg for all exercises. The load was progressively increased in 10 kg increments until the MV was lower than 0.50 m s^{-1} (bench press) or 0.80 m s^{-1} (bench pull and SQ). From that moment, the load was increased in steps of 5 to 1 kg until the 1RM was directly achieved (bench press and bench pull) or until the MV was lower than 0.65 m s^{-1} (SQ). Two repetitions were performed with light-moderate loads (MV $\geq$ 0.50 m s^{-1} for bench press and MV $\geq$ 0.80 m s^{-1} for bench pull and SQ) and one repetition with heavier loads (MV < 0.50 m s^{-1} for bench press and MV < 0.80 m s^{-1} for bench pull and SQ). Recovery time was set to 3 min for light-moderate loads and 5 min for heavier loads. After completing each incremental loading test, subjects took a 5-min rest before engaging in a single set of five repetitions executed at maximal intended velocity. These sets were performed for familiarization purposes, using either 75% of their 1RM for the bench press and bench pull exercises, or the load corresponding to a MV of 0.75 m s^{-1} for the SQ exercise. Note that these loads were used in the three experimental sessions. A MV of 0.75 m s^{-1} approximately represents 65%1RM in the SQ exercise, and it represented 72.1 ± 20.0 kg for men and 37.6 ± 7.7 kg for women (Pérez-Castilla et al., 2020). Successive incremental loading tests were spaced apart by a 10-min interval.

The bench press and bench pull exercises were always performed in a Smith machine (Multipower Fitness Line, Peroga), whereas the SQ was always performed with free-weights (Rock-strong Bar, Ruster Fitness). A validated linear position transducer (GymAware RS, Kinetic Performance Technologies) was vertically attached to the barbell of the Smith machine or to the free-weight barbell and was responsible for providing the MV of each repetition (Weakley, Morrison, et al., 2021). The bench press was performed using the 5-point contact position and touch-and-go technique. During the bench pull, the barbell was stopped precisely for 1–2 s on the Smith machine's telescopic holders when both elbows were fully extended and subjects were instructed to pull the barbell until it contacted with the bottom of the bench (11.0 cm thickness). Finally, during the SQ, subjects were instructed to descend until their thighs were parallel to the floor and immediately after to execute the lifting phase.

2.3.2 | Experimental sessions (sessions 2–4)

The general warm-up was identical as described for session 1. Thereafter, a specific warm-up was performed immediately prior to the effective sets of the bench press and bench pull exercises. This specific warm-up comprised one set of 10 repetitions at ~35% of the 1RM followed by three repetitions at ~55% of the 1RM, and finally, one repetition at ~75% of the 1RM. Regarding the SQ exercise, the specific warm-up routine included one set of 10, five and two repetitions against loads corresponding to 50%, 75%, and 100% of the load associated with a MV of 0.75 m s^{-1}, respectively. After completing the warm-up, subjects rested for 3 min before starting the first set of the upper-body exercise being tested. The order of the bench press and bench pull exercises was randomized, but each individual subject followed the same sequence of exercises in all three experimental sessions. A rest period of 10 min was implemented between the completion of the last set of the first upper-body exercise and the initiation of the first set of the second upper-body exercise.

During the three experimental sessions, subjects performed four sets of five repetitions at 75% of their 1RM with a 4-min break between sets using the bench press and bench pull exercises. The experimental sessions only differed in the exercise protocol (passive, SQ_{fast}, and SQ_{slow}) implemented between two consecutive sets of the same upper-body exercise. The sets of the SQ exercise were initiated 1.5 min after completing the set of the upper-body exercise. Subjects were granted the autonomy to execute the lowering phase of the three exercises at their self-selected velocity (MV was not controlled). However, for the lifting phase, the objective was to perform it with maximum intended velocity with the sole exception being the SQ_{slow} condition. Subjects were provided with real-time feedback on their MV following each repetition. In the SQ_{slow} condition, subjects were prompted to either slow down or speed up their lifting pace in response to the preceding repetition's MV exceeding or falling below 0.50 ms^{-1}, respectively.

2.4 | Statistical analyses

Descriptive values of the mechanical performance outcome are presented as means and SDs. The normal distribution of the data was confirmed by the Shapiro–Wilk test ($p > 0.05$). A two-way repeated-measures analysis of variance (ANOVA) with Bonferroni post hoc corrections (*protocol* [passive vs. SQ_{fast} vs. SQ_{slow}] and *set number* [set 1 vs. set 2 vs. set 3 vs. set 4]) was applied to mean set velocity (MSV), fastest mean velocity of the set ($MV_{fastest}$), mean velocity of the last repetition of the set (MV_{last}), and mean velocity decrement ($MVD = [MV_{last} - MV_{fastest}]/MV_{fastest} \times 100$). The factor sex was not considered because none of the interactions reached statistical significance. A one-way repeated measures ANOVA with Bonferroni post hoc corrections was used to compare between the exercise protocols (passive vs. SQ_{fast} vs. SQ_{slow}) the averaged value from sets

2–4 of MSV, $MV_{fastest}$, MV_{last}, and MVD. The Cohen's *d* effect size (ES) with 95% confidence intervals considering the pooled standard deviation of the compared conditions (passive vs. SQ_{fast} vs. SQ_{slow}) was used to compare the averaged value from sets 2–4 of MSV, $MV_{fastest}$, and MV_{last}. The scale used to interpret the magnitude of the ES was negligible (<0.20), small (0.20–0.49), moderate (0.50–0.79), and large (≥0.80) (Cohen, 1988). All statistical analyses were performed using SPSS software version 22.0 (SPSS Inc.), and statistical significance was set at an alpha level of 0.05.

3 | RESULTS

The MSV of the SQ exercise was greater for the SQ_{fast} protocol (0.72 m s^{-1}) compared to the SQ_{slow} protocol (0.50 m s^{-1}) during the three sets that preceded the sets 2–4 of the bench press and bench pull exercises (Table 1).

The results of the ANOVAs applied to MSV, $MV_{fastest}$, MV_{last}, and MVD during the bench press and bench pull exercises are presented in Table 2. Most main effects and all interactions failed to reach statistical significance ($p > 0.05$). The only two significant main effects were observed during the bench press exercise; a main effect of set for MSV ($p = 0.002$; set 1 [0.439 m s^{-1}] > set 2 [0.428 m s^{-1}] > set 3 [0.420 m s^{-1}] = set 4 [0.419 m s^{-1}]) and a main effect of protocol for $MV_{fastest}$ ($p = 0.029$; passive [0.524 m s^{-1}] > SQ_{slow} [0.501 m s^{-1}] = SQ_{fast} [0.497 m s^{-1}]).

The one-way ANOVA applied to the averaged value from sets 2–4 was significant for $MV_{fastest}$ during the bench press ($F = 3.8$, $p = 0.030$), but no significant differences were detected for other conditions: MSV during the bench press ($F = 2.1$, $p = 0.133$) and bench pull ($F = 0.5$, $p = 0.623$), $MV_{fastest}$ during the bench pull ($F = 0.302$, $p = 0.741$), MV_{last} during the bench press ($F = 1.0$, $p = 0.358$) and bench pull ($F = 0.1$, $p = 0.899$), and MVD during the bench press ($F = 0.7$, $p = 0.494$) and bench pull ($F = 0.0$, $p = 0.964$). Likewise, negligible differences (ES < 0.20) were observed for all dependent variables except for small differences (ES ranged from 0.23 to 0.31) in favor of the passive protocol compared to the SQ_{fast} and SQ_{slow} protocols for the MSV and $MV_{fastest}$ recorded during the bench press exercise (Figure 2).

4 | DISCUSSION

This study was designed to evaluate how two different SQ protocols (SQ_{fast} and SQ_{slow}) influence mechanical performance when compared to a standard passive rest protocol across multiple sets of paired multijoint upper-body exercises. The main findings revealed negligible differences (ES < 0.20) among the exercise protocols (passive vs. SQ_{fast} vs. SQ_{slow}) for all mechanical variables during the bench pull exercise, whereas during the bench press exercise, small differences emerged favoring the passive protocol over SQ_{fast} and SQ_{slow} in terms of MSV and $MV_{fastest}$ (ES ranged from 0.23 to 0.31). Importantly, the absence of notable differences between the SQ_{fast} and SQ_{slow} protocols, regardless of the specific upper-body exercise (bench press or bench pull), underscores that the intended lifting velocity used during lower-body exercises does not exert an influence on mechanical performance in PS of upper-body exercises. Nonetheless, while the integration of SQ sets does not appear to disrupt bench pull mechanical performance, there is a possibility of slight interference for the bench press exercise.

Lifting with maximal intent (i.e., as fast and as explosive as possible) has proven effective in enhancing strength, power, and velocity outputs (García et al., 2022; González-Badillo et al., 2014; Pareja-Blanco et al., 2014) making it a valuable approach for optimizing athletic performance gains (Weakley, Mann, et al., 2021). González-Badillo et al. (2014) demonstrated greater strength gains following a 6-week RT program when individuals executed the bench press exercise at maximal intended velocity. Similarly, Pareja-Blanco et al. (2014) documented superior improvements in lower-body strength, sprint, and jump outcomes after a 6-week RT program when individuals performed the SQ exercise at maximal intended velocity compared to deliberately using a slower lifting velocity. However, this is the first study to investigate the impact of deliberately manipulating lifting velocity on mechanical performance during PS configurations. Recent evidence indicates that squatting at maximal intended velocity could diminish the potential for post-activation performance enhancement in other lower-body activities, such as vertical jumps, likely due to heightened demands on the central nervous system (Baena-Raya et al., 2022, 2023). However, in contrast to our hypothesis, both the SQ_{fast} and SQ_{slow} protocols had a

TABLE 1 Mean set velocity of the squat exercise during the two squat protocols.

		Squat protocol	
Upper-body exercise	**Set number**	**SQ_{fast} (m s^{-1})**	**SQ_{slow} (m s^{-1})**
Bench press	Set 1	0.72 ± 0.06 (0.59, 0.84)	0.50 ± 0.04 (0.42, 0.63)
	Set 2	0.72 ± 0.06 (0.57, 0.83)	0.50 ± 0.02 (0.46, 0.54)
	Set 3	0.72 ± 0.06 (0.62, 0.82)	0.50 ± 0.02 (0.45, 0.55)
Bench pull	Set 1	0.72 ± 0.06 (0.60, 0.84)	0.50 ± 0.03 (0.44, 0.54)
	Set 2	0.72 ± 0.06 (0.60, 0.86)	0.50 ± 0.02 (0.45, 0.56)
	Set 3	0.72 ± 0.07 (0.61, 0.83)	0.50 ± 0.03 (0.43, 0.58)

Note: Data presented as means ± standard deviation (range). SQ_{fast}, 5 repetitions of the squat exercise performed at maximal intended velocity; SQ_{slow}, 5 repetitions of the squat exercise performed at an intentional submaximal velocity.

TABLE 2 Two-way repeated-measures analysis of variance (ANOVA) comparing MSV, $MV_{fastest}$, and MV_{last} of four sets of the bench press exercise that differed in the exercise protocol performed during the interset rest periods.

			Set number				
Exercise	**Variable**	**Protocol**	**Set 1**	**Set 2**	**Set 3**	**Set 4**	**ANOVA**
Bench press	MSV (m s^{-1})	Passive	0.45 ± 0.09	0.44 ± 0.10	0.43 ± 0.11	0.43 ± 0.10	Protocol: $F = 2.6$, $p = 0.086$, $\eta p^2 = 0.116$
		SQ_{fast}	0.43 ± 0.08	0.42 ± 0.09	0.41 ± 0.08	0.41 ± 0.09	**Set: F = 5.7, $p = 0.002$, $\eta p^2 = 0.222$**
		SQ_{slow}	0.43 ± 0.08	0.42 ± 0.07	0.42 ± 0.07	0.41 ± 0.07	Protocol × Set: $F = 0.3$, $p = 0.939$, $\eta p^2 = 0.014$
	$MV_{fastest}$ (m s^{-1})	Passive	0.53 ± 0.09	0.52 ± 0.10	0.52 ± 0.10	0.52 ± 0.10	**Protocol: F = 3.9, $p = 0.029$, $\eta p^2 = 0.163$**
		SQ_{fast}	0.50 ± 0.08	0.50 ± 0.09	0.49 ± 0.08	0.49 ± 0.09	Set: $F = 2.4$, $p = 0.074$, $\eta p^2 = 0.109$
		SQ_{slow}	0.52 ± 0.08	0.50 ± 0.08	0.50 ± 0.07	0.49 ± 0.08	Protocol × Set: $F = 0.5$, $p = 0.740$, $\eta p^2 = 0.024$
	MV_{last} (m s^{-1})	Passive	0.37 ± 0.09	0.37 ± 0.11	0.35 ± 0.12	0.34 ± 0.11	Protocol: $F = 1.6$, $p = 0.223$, $\eta p^2 = 0.072$
		SQ_{fast}	0.35 ± 0.08	0.33 ± 0.09	0.34 ± 0.10	0.33 ± 0.09	Set: $F = 2.1$, $p = 0.111$, $\eta p^2 = 0.095$
		SQ_{slow}	0.35 ± 0.09	0.34 ± 0.08	0.34 ± 0.08	0.33 ± 0.08	Protocol × Set: $F = 0.7$, $p = 0.682$, $\eta p^2 = 0.032$
	MVD (%)	Passive	30.7 ± 12.7	30.2 ± 13.0	35.0 ± 13.0	36.1 ± 15.2	Protocol: $F = 0.3$, $p = 0.747$, $\eta p^2 = 0.014$
		SQ_{fast}	31.4 ± 9.3	34.6 ± 10.8	31.8 ± 13.7	34.3 ± 10.9	Set: $F = 1.4$, $p = 0.262$, $\eta p^2 = 0.064$
		SQ_{slow}	32.7 ± 10.2	31.3 ± 10.9	31.0 ± 11.8	33.1 ± 11.0	Protocol × Set: $F = 1.2$, $p = 0.293$, $\eta p^2 = 0.058$
Bench pull	MSV (m s^{-1})	Passive	0.72 ± 0.07	0.73 ± 0.07	0.72 ± 0.07	0.71 ± 0.07	Protocol: $F = 0.8$, $p = 0.452$, $\eta p^2 = 0.039$
		SQ_{fast}	0.72 ± 0.06	0.72 ± 0.05	0.72 ± 0.07	0.71 ± 0.06	Set: $F = 1.4$, $p = 0.250$, $\eta p^2 = 0.066$
		SQ_{slow}	0.71 ± 0.06	0.72 ± 0.07	0.71 ± 0.06	0.71 ± 0.06	Protocol × Set: $F = 0.8$, $p = 0.550$, $\eta p^2 = 0.040$
	$MV_{fastest}$ (m s^{-1})	Passive	0.78 ± 0.06	0.78 ± 0.06	0.78 ± 0.06	0.77 ± 0.06	Protocol: $F = 0.6$, $p = 0.562$, $\eta p^2 = 0.028$
		SQ_{fast}	0.77 ± 0.06	0.77 ± 0.06	0.78 ± 0.07	0.76 ± 0.05	Set: $F = 2.1$, $p = 0.106$, $\eta p^2 = 0.096$
		SQ_{slow}	0.76 ± 0.06	0.78 ± 0.06	0.77 ± 0.06	0.77 ± 0.05	Protocol × Set: $F = 0.7$, $p = 0.685$, $\eta p^2 = 0.032$
	MV_{last} (m s^{-1})	Passive	0.67 ± 0.07	0.68 ± 0.09	0.67 ± 0.08	0.66 ± 0.09	Protocol: $F = 0.6$, $p = 0.531$, $\eta p^2 = 0.031$
		SQ_{fast}	0.68 ± 0.06	0.66 ± 0.06	0.68 ± 0.08	0.67 ± 0.06	Set: $F = 0.3$, $p = 0.802$, $\eta p^2 = 0.016$
		SQ_{slow}	0.65 ± 0.08	0.67 ± 0.08	0.67 ± 0.07	0.66 ± 0.07	Protocol × Set: $F = 1.0$, $p = 0.412$, $\eta p^2 = 0.049$
	MVD (%)	Passive	13.2 ± 5.3	13.6 ± 7.3	13.8 ± 5.6	14.0 ± 7.4	Protocol: $F = 0.4$, $p = 0.705$, $\eta p^2 = 0.017$
		SQ_{fast}	11.6 ± 4.0	14.3 ± 4.8	13.7 ± 5.7	12.9 ± 4.3	Set: $F = 0.6$, $p = 0.589$, $\eta p^2 = 0.031$
		SQ_{slow}	14.3 ± 6.9	14.4 ± 6.0	13.1 ± 5.5	13.3 ± 5.9	Protocol × Set: $F = 0.9$, $p = 0.500$, $\eta p^2 = 0.043$

Note: MSV, mean set velocity; MV, mean velocity; SQ_{fast}, 5 repetitions of the squat exercise performed at maximal intended velocity; SQ_{slow}, 5 repetitions of the squat exercise performed at an intentionally moderate (submaximal) velocity. Bold values indicate significant differences ($p < 0.05$).

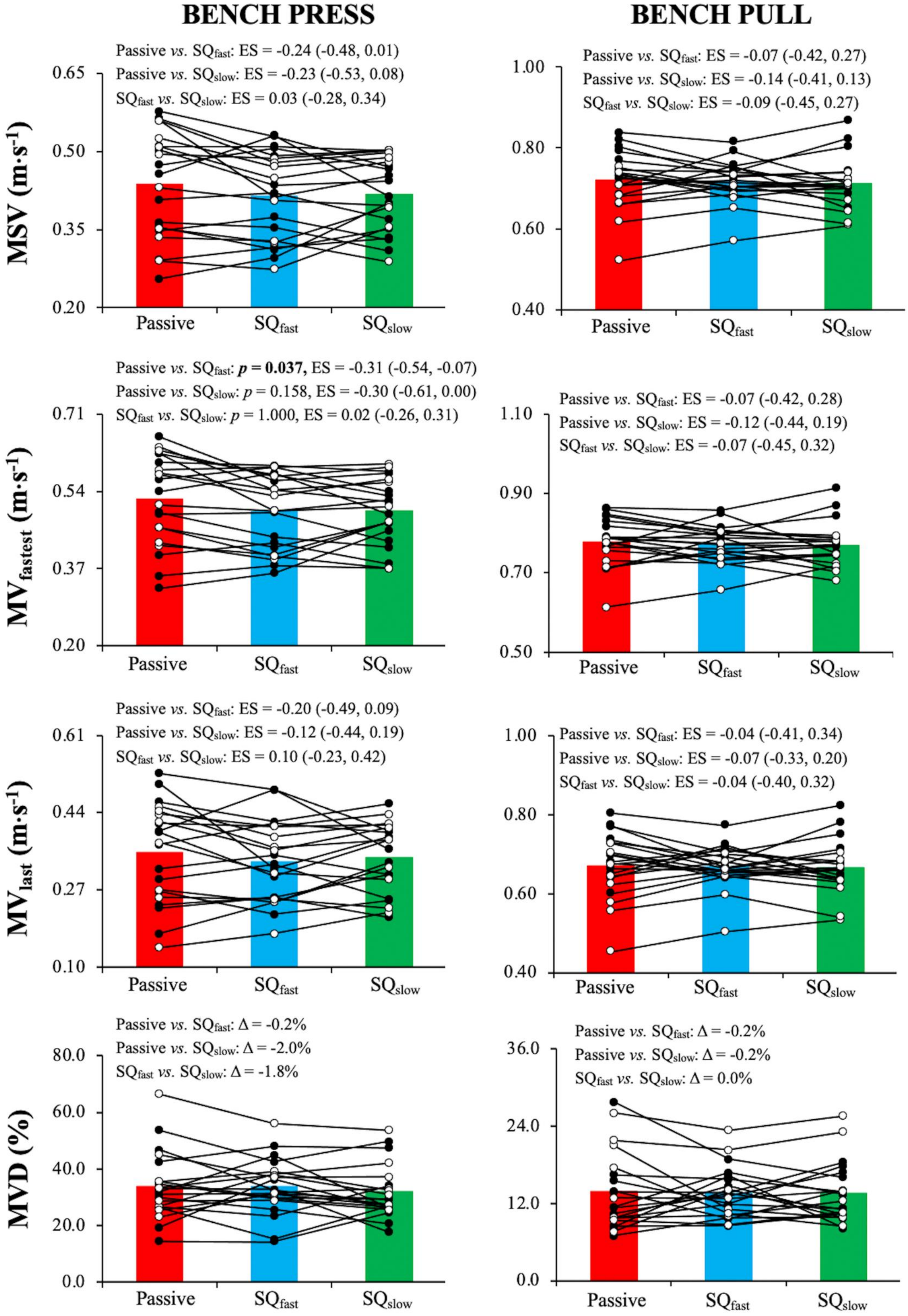

FIGURE 2 Individual values and comparisons for the average values of sets 2–4 between the exercise protocols for mean set velocity (MSV; upper panels), mean velocity of the fastest repetition ($\text{MV}_{\text{fastest}}$; middle-upper panels), mean velocity of the last repetition (MV_{last}; middle-lower panels), and mean velocity decrement (MVD; lower panels) using the bench press (left panels) and bench pull (right panels) as the upper-body exercises. SQ_{fast}, 5 repetitions of the squat exercise performed at maximal intended velocity; SQ_{slow}, 5 repetitions of the squat exercise performed at an intentionally moderate (submaximal) velocity; ES, Cohen's *d* effect size. *p*-values, adjusted through Bonferroni post hoc corrections, are provided solely for $\text{MV}_{\text{fastest}}$ in the bench press condition, as it was the only instance where analysis of variance showed a significant main effect.

comparable impact on mechanical performance outcomes in PS of multijoint upper-body exercises. Thus, it could be advisable to prioritize the SQ_{fast} protocol over the SQ_{slow} protocol when implementing PS through alternating peripheral movements for effectively enhancing both lower- and upper-body strength adaptations concurrently.

Despite the underpinning RT variables being identical for both upper-body exercises (four sets of five repetitions at 75%1RM with a 4-min rest between sets), the bench press led to a greater degree of fatigue compared to the bench pull irrespectively of the exercise protocol (passive, SQ_{fast}, and SQ_{slow}). This heightened fatigue was evidenced by the progressive reduction in MSV with increasing number of sets for the bench press (p = 0.002), whereas MSV remained consistent across the sets for the bench pull (p = 0.257). Factors contributing to the heightened bench press fatigue encompass variations in muscle activation patterns, biomechanical demands, and the specific muscle groups involved in the movements (Robbins et al., 2009; Robbins, Young & Behm, 2010; Robbins, Young, Behm, Payne & Klimstra, 2010; Srinivasan et al., 2007). The muscles predominantly involved in the bench pull have a higher percentage of type I (fatigue-resistant) muscle fibers compared to the muscles primarily used in the bench press exercise (Srinivasan et al., 2007). Thus, it has been suggested that the musculature involved in pulling movements may be more resistant to fatigue than those involved in pushing movements (Robbins et al., 2009; Robbins, Young & Behm, 2010; Robbins, Young, Behm, Payne & Klimstra, 2010). Notably, while the differences in mechanical performance across the exercise protocols (passive, SQ_{fast}, and SQ_{slow}) were negligible for the bench pull exercise, they became more pronounced during the bench press exercise with the passive protocol demonstrating a tendency toward superior mechanical performance over SQ_{fast} and SQ_{slow} protocols. These findings highlight the importance of not only factoring in exercise intensity and volume but also the exercise selection when incorporating PS in order to mitigate declines in mechanical performance during training. When the goal is to sustain mechanical performance throughout the entirety of the RT session, it is prudent to avoid pairing two exercises that elicit substantial fatigue.

While this study offers valuable insights into the influence of intended lifting velocity (maximal or submaximal) on mechanical performance during PS, there are certain limitations that must be acknowledged. First, the sample size consisted of individuals with moderate strength levels being recommended to explore whether the findings of this study can be extrapolated to more experienced athletes or untrained populations. Second, given the sex related differences in muscle fatigability, strength gains and acute response to RT (Hunter, 2014; Rissanen et al., 2022), additional research is warranted to assess the sex-specific influence of intended lifting velocity on mechanical performance during PS schemes. It should be noted that in our study, the factor "sex" was not considered, despite having recruited 7 women, because it failed to reach any significant interaction in the different ANOVAs applied in this study. Third, although PS training has demonstrated higher metabolic accumulation and muscle damage compared to traditional RT (Weakley et al., 2020), this study has focused exclusively on mechanical performance outcomes. Given the known detrimental effects of increased blood lactate, ammonia, or creatine kinase on neuromuscular performance (Pareja-Blanco et al., 2017, 2020), future research should include these physiological variables to provide a more robust foundation for understanding our current findings.

5 | CONCLUSIONS

The key findings of this study demonstrate minimal distinctions across the exercise protocols (passive, SQ_{fast}, and SQ_{slow}) concerning all mechanical variables in the context of the bench pull exercise. However, during the bench press exercise, some notable differences were observed favoring the passive protocol over SQ_{fast} and SQ_{slow} in terms of mean set velocity (MSV) and fastest set velocity ($MV_{fastest}$). Importantly, the lack of substantial differences between the SQ_{fast} and SQ_{slow} protocols, irrespective of the specific upper-body exercise (bench press or bench pull), highlights that the intended lifting velocity utilized in lower-body exercises does not wield an impact on mechanical performance within paired upper-body exercise sets. Nonetheless, while the inclusion of SQ sets appears to exert minimal influence on bench pull mechanical performance, a potential for modest interference arises concerning the bench press exercise. These findings imply that exercise selection holds greater significance than intended lifting velocity when striving to mitigate interference in PS training.

ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China under grant 12250410237. The authors would like to thank all subjects for their commitment to the study. Funding for open access charge: Universidad de Granada/CBUA.

CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest to declare.

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REFERENCES

Baena-Raya, Andrés, David M. Díez-Fernández, Amador García-Ramos, Borja Martinez-Tellez, Daniel Boullosa, Alberto Soriano-Maldonado, and Manuel A. Rodríguez-Pérez. 2023. "Acute Mechanical and Skin Temperature Responses to Different Interrepetition Rest Intervals during Full-Squat Exercise." *International Journal of Sports Physiology and Performance* 18(6): 674–81. https://doi.org/10.1123/ijspp.2022-0482.

Baena-Raya, Andrés, Amador García-Ramos, Sergio Sánchez-López, Pedro Jiménez-Reyes, and Manuel A. Rodríguez-Pérez. 2022. "Acute Effects of Low Volume versus High Volume Squat Protocols on Vertical Jump Performance." *Medicina dello Sport* 75(4): 518–28. https://doi.org/10.23736/s0025-7826.22.04172-2.

Ciccone, Anthony B., Lee E. Brown, Jared W. Coburn, and Andrew J. Galpin. 2014. "Effects of Traditional vs. Alternating Whole-Body Strength Training on Squat Performance." *The Journal of Strength & Conditioning Research* 28(9): 2569–77. https://doi.org/10.1519/jsc.0000000000000586.

Cohen, Jacob. 1988. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. New York: Lawrence erlabum associates.

García, Juan Manuel Yáñez, Ricardo Mora-Custodio, Juan Ribas-Serna, Juan José González-Badillo, and David Rodríguez-Rosell. 2022. "Movement Velocity as a Determinant of Actual Intensity in Resistance Exercise." *International Journal of Sports Medicine* 43(12): 1033–42. https://doi.org/10.1055/a-1834-6693.

García-Orea, Guillermo Peña, David Rodríguez-Rosell, Ángel Ballester-Sánchez, Marzo Edir Da Silva-Grigoletto, and Noelia Belando-Pedreño. 2023. Upper-lower Body Super-sets vs. Traditional Sets for Inducing Chronic Athletic Performance Improvements. *PeerJ* 11: e14636. https://doi.org/10.7717/peerj.14636.

González-Badillo, Juan José, David Rodríguez-Rosell, Luis Sánchez-Medina, Esteban M. Gorostiaga, and Fernando Pareja-Blanco. 2014. "Maximal Intended Velocity Training Induces Greater Gains in Bench Press Performance Than Deliberately Slower Half-Velocity Training." *European Journal of Sport Science* 14(8): 772–81. https://doi.org/10.1080/17461391.2014.905987.

González-Hernández, Jorge M., Pedro Jimenez-Reyes, Danica Janicijevic, James J. Tufano, Gonzalo Marquez, and Amador Garcia-Ramos. 2023. "Effect of Different Interset Rest Intervals on Mean Velocity during the Squat and Bench Press Exercises." *Sports Biomechanics* 22(7): 834–47. https://doi.org/10.1080/14763141.2020.1766102.

Grgic, Jozo, Bruno Lazinica, Pavle Mikulic, James W. Krieger, and Brad Jon Schoenfeld. 2017. "The Effects of Short versus Long Inter-set Rest Intervals in Resistance Training on Measures of Muscle Hypertrophy: A Systematic Review." *European Journal of Sport Science* 17(8): 983–93. https://doi.org/10.1080/17461391.2017.1340524.

Hunter, Sandra K. 2014. "Sex Differences in Human Fatigability: Mechanisms and Insight to Physiological Responses." *Acta Physiologica* 210(4): 768–89. https://doi.org/10.1111/apha.12234.

Jukic, Ivan, Alejandro Pérez Castilla, Amador García Ramos, Bas Van Hooren, Michael R. McGuigan, and Eric R. Helms. 2023. "The Acute and Chronic Effects of Implementing Velocity Loss Thresholds during Resistance Training: A Systematic Review, Meta-Analysis, and Critical Evaluation of the Literature." *Sports Medicine* 53(1): 177–214. https://doi.org/10.1007/s40279-022-01754-4.

Jukic, Ivan, Eric R. Helms, Michael R. McGuigan, and Amador García-Ramos. 2022. "Using Cluster and Rest Redistribution Set Structures as Alternatives to Resistance Training Prescription Method Based on Velocity Loss Thresholds." *PeerJ* 10: e13195. https://doi.org/10.7717/peerj.13195.

Khadanga, Sherrie, Patrick D. Savage, and Philip A. Ades. 2019. "Resistance Training for Older Adults in Cardiac Rehabilitation." *Clinics in Geriatric Medicine* 35(4): 459–68. https://doi.org/10.1016/j.cger.2019.07.005.

Kraemer, William J., and Nicholas A. Ratamess. 2004. "Fundamentals of Resistance Training: Progression and Exercise Prescription." *Medicine & Science in Sports & Exercise* 36(4): 674–88. https://doi.org/10.1249/01.mss.0000121945.36635.61.

Kraemer, William J., Nicholas A. Ratamess, and Duncan N. French. 2002. "Resistance Training for Health and Performance." *Current Sports Medicine Reports* 1(3): 165–71. https://doi.org/10.1249/00149619-200206000-00007.

Mangine, Gerald T., Jay R. Hoffman, Adam M. Gonzalez, Jeremy R. Townsend, Adam J. Wells, Adam R. Jajtner, Kyle S. Beyer, et al. 2015. "The Effect of Training Volume and Intensity on Improvements in Muscular Strength and Size in Resistance-Trained Men." *Physiology Report* 3(8): 1–17. https://doi.org/10.14814/phy2.12472.

Millender, Desmond J., Zachary A. Mang, Jason R. Beam, Rogelio A. Realzola, and Len Kravitz. 2021. "The Effect of Rest Interval Length on Upper and Lower Body Exercises in Resistance-Trained Females." *International Journal of Exercise Science* 14: 1178–91.

Pareja-Blanco, Fernando, David Rodríguez-Rosell, Per Aagaard, Luis Sánchez-Medina, Juan Ribas-Serna, Ricardo Mora-Custodio, Carlos Otero-Esquina, Juan Manuel Yáñez-García, and Juan José González-Badillo. 2020. "Time Course of Recovery from Resistance Exercise with Different Set Configurations." *The Journal of Strength & Conditioning Research* 34(10): 2867–76. https://doi.org/10.1519/jsc.0000000000002756.

Pareja-Blanco, Fernando, David Rodriguez-Rosell, Luis Sanchez-Medina, Esteban Gorostiaga, and Juan Jose González-Badillo. 2014. "Effect of Movement Velocity during Resistance Training on Neuromuscular Performance." *International Journal of Sports Medicine* 35(11): 916–24. https://doi.org/10.1055/s-0033-1363985.

Pareja-Blanco, Fernando, David Rodríguez-Rosell, Luis Sánchez-Medina, Joaquín Sanchis-Moysi, Cecilia Dorado, Ricardo Mora-Custodio, Juan Manuel Yáñez-García, et al. 2017. "Effects of Velocity Loss during Resistance Training on Athletic Performance, Strength Gains and Muscle Adaptations." *Scandinavian journal of medicine & science in sports* 27(7): 724–35. https://doi.org/10.1111/sms.12678.

Pérez-Castilla, Alejandro, Amador García-Ramos, Paulino Padial, Antonio J. Morales-Artacho, and Belén Feriche. 2020. "Load-velocity Relationship in Variations of the Half-Squat Exercise: Influence of Execution Technique." *The Journal of Strength & Conditioning Research* 34(4): 1024–31. https://doi.org/10.1519/jsc.0000000000002072.

Ratamess, Nicholas A., Brent A. Alvar, Tammy K. Evetoch, Terry J. Housch, W. Ben Kibler, William J. Kraemer, and N. Travis Triplett. 2009. "American College of Sports Medicine Position Stand. Progression Models in Resistance Training for Healthy Adults." *Medicine & Science in Sports & Exercise* 41: 687–708.

Rissanen, Joonas, Simon Walker, Fernando Pareja-Blanco, and Keijo Häkkinen. 2022. "Velocity-based Resistance Training: Do Women Need Greater Velocity Loss to Maximize Adaptations?" *European Journal of Applied Physiology* 122(5): 1269–80. https://doi.org/10.1007/s00421-022-04925-3.

Robbins, Daniel W., Warren B. Young, and David G. Behm. 2010. "The Effect of an Upper-Body Agonist-Antagonist Resistance Training Protocol on Volume Load and Efficiency." *The Journal of Strength & Conditioning Research* 24(10): 2632–40. https://doi.org/10.1519/jsc.0b013e3181e3826e.

Robbins, Daniel W., Warren B. Young, David G. Behm, and Warren R. Payne. 2009. "Effects of Agonist-Antagonist Complex Resistance Training on Upper Body Strength and Power Development." *Journal of Sports Sciences* 27(14): 1617–25. https://doi.org/10.1080/02640410903365677.

Robbins, Daniel W., Warren B. Young, David G. Behm, Warren R. Payne, and Marc D. Klimstra. 2010b. "Physical Performance and Electromyographic Responses to an Acute Bout of Paired Set Strength Training versus Traditional Strength Training." *The Journal of Strength & Conditioning Research* 24(5): 1237–45. https://doi.org/10.1519/jsc.0b013e3181cc60ec.

Srinivasan, Ramesh C., Matthew P. Lungren, Joseph E. Langenderfer, and Richard E. Hughes. 2007. "Fiber Type Composition and Maximum Shortening Velocity of Muscles Crossing the Human Shoulder." *Clinical Anatomy* 20(2): 144–9. https://doi.org/10.1002/ca.20349.

Weakley, Jonathon, Bryan Mann, Harry Banyard, Shaun McLaren, Tannath Scott, and Amador Garcia-Ramos. 2021. "Velocity-based Training: From Theory to Application." *Strength and Conditioning Journal* 43(2): 31–49. https://doi.org/10.1519/ssc.0000000000000560.

Weakley, Jonathon, Matthew Morrison, Amador García-Ramos, Rich Johnston, Lachlan James, and Michael H. Cole. 2021. "The Validity and Reliability of Commercially Available Resistance Training

Monitoring Devices: A Systematic Review." *Sport Medicine* 51(3): 443–502. https://doi.org/10.1007/s40279-020-01382-w.

Weakley, Jonathon J. S., Kevin Till, Dale B. Read, Padraic J. Phibbs, Gregory Roe, Joshua Darrall-Jones, and Ben L. Jones. 2020. "The Effects of Superset Configuration on Kinetic, Kinematic, and Perceived Exertion in the Barbell Bench Press." *The Journal of Strength & Conditioning Research* 34(1): 65–72. https://doi.org/10.1519/jsc.0000000000002179.

Weakley, Jonathon J. S., Kevin Till, Dale B. Read, Gregory A. B. Roe, Joshua Darrall-Jones, Padraic J. Phibbs, and Ben Jones. 2017. The Effects of Traditional, Superset, and Tri-set Resistance Training Structures on Perceived Intensity and Physiological Responses. *European Journal of Applied Physiology* 117(9): 1877–89. https://doi.org/10.1007/s00421-017-3680-3.

Wells, Greg D., Hiran Selvadurai, and Ingrid Tein. 2009. "Bioenergetic Provision of Energy for Muscular Activity." *Paediatric Respiratory Reviews* 10(3): 83–90. https://doi.org/10.1016/j.prrv.2009.04.005.

Westcott, Wayne L. 2012. "Resistance Training Is Medicine: Effects of Strength Training on Health." *Current Sports Medicine Reports* 11(4): 209–16. https://doi.org/10.1249/jsr.0b013e31825dabb8.