Artículo original / Original Article

Design of an intervention protocol for time-efficient strength training using alternating sets

Diseño de un protocolo de intervención para el entrenamiento de fuerza eficiente en tiempo utilizando series alternas

Concepção de um protocolo de intervenção para um treino de força eficiente em termos de tempo utilizando séries alternadas

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Abstract

The aim of this research is to design a detailed velocity-based training (VBT) protocol to compare the training effects between traditional sets (TS) and alternating sets (AS). This is a methodological study describing the intervention protocol for application in experimental studies. It is proposed the participation of 40 to 50 strength-trained subjects randomly assigned to two experimental groups (TS and AS) and a control group. Sixteen VBT sessions will be completed over 8 weeks, with two sessions per week (72-96 h apart). Each session will include squat (SQ), bench press (BP) and prone bench press (PBP) exercises performed on a Smith machine in the same sequence. All training variables - including relative loads (%1RM), intra-set velocity loss, number of sets, rest between sets and frequency of sessions - will remain constant. After a familiarisation period, participants will undergo pre- and post-intervention testing, including progressive load testing.

Keywords: set configuration; training protocol; velocity-based training; neuromuscular performance; sport performance.

Resumen

El objetivo de esta investigación es diseñar un protocolo pormenorizado de entrenamiento de la fuerza basado en la velocidad (EBV) que permita comparar los efectos del entrenamiento entre series tradicionales (ST) y series alternas (SA). Se trata de un estudio metodológico en el que se describe el protocolo de intervención para su aplicación en estudios experimentales. Se propone la participación de 40 a 50 sujetos entrenados en fuerza asignados aleatoriamente a dos grupos experimentales (TS y AS) y un grupo control. Se completarán 16 sesiones de EBV durante 8 semanas, con dos sesiones por semana (separadas por 72-96 h.). Cada sesión incluirá ejercicios de sentadilla (SQ), press de banca (BP) y remo tumbado en banco (PBP) realizados en una máquina Smith en la misma secuencia. Todas las variables de entrenamiento -incluidas las cargas relativas (%1RM), la pérdida de velocidad intra-serie, número de series, descanso entre series y frecuencia de las sesiones- permanecerán constantes. Tras un periodo de familiarización, los participantes se someterán a pruebas pre- y post-intervención, incluyendo pruebas de carga progresiva.

Palabras clave: protocolo de entrenamiento; validación; entrenamiento basado en la velocidad; rendimiento neuromuscular; rendimiento deportivo.

Introduction

There are several acute training variables that constitute a resistance training (RT) program (i.e., exercise type and order, load magnitude, number of sets and repetitions, recovery time, and execution velocity) (Kraemer & Ratamess, 2004). Among these variables, the order of exercises and set configuration is particularly relevant, as it can influence physiological responses and subsequent adaptations (Sforzo & Touey, 1996), as well as the time spent during the training session. In this regard, athletes cannot always dedicate lengthy sessions to strength training due to the necessity of addressing other training content (i.e., skill development and other components of physical fitness) (Phibbs et al., 2018). Therefore, whether for health or performance purposes, understanding how training sessions can be designed to optimize available time (i.e., minimizing time expenditure) without significantly compromising results could encourage more individuals to participate in this form of exercise (Iversen et al., 2021) and help prevent dropout from exercise programs. In this context, various RT techniques (i.e., methods of organizing exercises and sets within a session) have been extensively analyzed, all sharing the advantageous feature of substantial intra-session time savings compared to traditional designs (de Souza et al., 2017; Robbins et al., 2010). In this type of time-saving training technique, sets are usually performed alternately between different exercises (usually two), either targeting the same agonist muscle group (e.g., super-set training) or involving antagonistic muscle actions (e.g., agonist–antagonist paired set) (Robbins et al., 2009; Paz et al., 2017). During so-called paired-set training, exercises involving agonist–antagonist muscles are performed alternately with a limited rest period or without a rest period between sets (Robbins et al., 2009). Therefore, time efficiency is achievable because these strategies enable the maintenance of similar relative rest periods between exercises while reducing absolute rest intervals and total training time (Ciccone et al., 2014). From a mechanistic perspective, this configuration preserves the recovery of the prime movers involved in each exercise while allowing antagonist or non-overlapping muscle groups to be trained during the intervening period, thereby maintaining high neuromuscular performance across sets (Robbins et al., 2010; Paz et al., 2017). The alternation also sustains motor unit recruitment and movement velocity through reduced intra-muscle fatigue accumulation, which has been linked to comparable or even superior strength adaptations when training volume and intensity are equated (de Souza et al., 2017; Weakley et al., 2020).

While several studies have analyzed alternating set exercise configurations, such as paired sets or super-set models (i.e., agonist-antagonist and agonist-agonist pairings) (de Souza et al., 2017; Robbins et al., 2009; Robbins et al., 2010a; Robbins et al., 2010b; Paz et al., 2016, 2017), there is currently a lack of evidence in the literature regarding paired exercises that alternate upper- and lower-body muscle groups performed successively (i.e., paired alternating-limb sets, also referred to as "agonist-peripheral") (Weakley et al., 2017; Weakley et al., 2020; Peña et al., 2023). Furthermore, most studies addressing this issue have typically focused on the acute effects of no more than two different exercises (de Souza et al., 2017; Robbins et al., 2009; Robbins et al., 2010a; Robbins et al., 2010b; Paz et al., 2016, 2017; Weakley et al., 2017). Although these investigations provide insights into the differences between various set configurations, knowledge about chronic effects is limited (Robbins et al., 2009; Merrigan et al., 2019; Weakley et al., 2020; Peña et al., 2023), despite the common practice of combining sets between exercises that involve different or the same muscle groups in various training contexts (i.e., fitness centers, sports clubs, and rehabilitation clinics). Accordingly, further studies comparing the effects of performing paired/alternating sets within a training program on muscle strength and physical performance are needed, especially when three exercises are combined in the set.

On the other hand, most of these studies have employed procedures to determine and dose the training load based on the maximum number of repetitions that can be performed with a given submaximal weight (e.g., 10RM, 12RM), often performing each set at or near muscle failure (Robbins et al., 2009; Robbins et al., 2010a; Robbins et al., 2010b). This approach fails to account for the high variability among participants (coefficient of variation of approximately 15-20%) when performing the maximum number of repetitions possible per set at a given relative load (%1RM) (González-Badillo et al., 2017; Rodríguez-Rosell et al., 2020). Similarly, other studies have used a percentage of 1RM to determine relative load

and training dosage (Weakley et al., 2017; Merrigan et al., 2019); however, this procedure also has significant limitations, such as the high variability or fluctuation in the current RM value over time due to various factors (e.g., performance improvements following several training sessions, stress levels, sleep quality, etc.) (González-Badillo et al., 2010; Morenas-Aguilar et al., 2025). Notably, none of these studies have utilized a velocity-based training (VBT) approach for training prescription, load monitoring, and assessing the training effect on physical performance during RT programs. In summary, this new approach is characterized by an accurate and real-time determination of relative load by measuring the fastest repetition of a set executed at maximal intended velocity (González-Badillo et al., 2010; González-Badillo et al., 2017).

Accordingly, given the scarcity of specific studies in the scientific literature, along with the aforementioned limitations, experimental research is needed to determine the effect on physical performance of performing paired alternating-limb sets while avoiding muscle failure. Additionally, this research should be based on a procedure that utilizes execution velocity to control training load and evaluate its effects (i.e., VBT). To achieve this, intervention protocols that detail the processes prior to and during the training intervention are essential for conducting studies aimed at optimizing the available time during sessions and improving physical performance. Therefore, this study aims to describe the intervention protocol designed to compare the effects of traditional sets (TS) and alternating sets (AS) on physical performance using a VBT approach. The inclusion of three exercises -one lower-body (full squat [SQ]) and two antagonistic upper-body exercises (bench press [BP] and prone bench pull [PBP])- was chosen to replicate full-body strength training sessions commonly prescribed in athletic and recreational programs, where lower-body and upper-body pushing and pulling movements are combined within the same workout to promote balanced muscular development and training efficiency. Using three exercises, rather than two, also maximizes potential time savings and provides adequate recovery for each muscle group within the alternating set configuration. This design reflects common multi-exercise set structures reported in the literature (Robbins et al., 2010; de Souza et al., 2017; Peña et al., 2023) and may increase the practical applicability of the findings. We hypothesize that AS, performed with moderate fatigue (i.e., less than half the maximum possible repetitions per set), will yield comparable improvements in mean propulsive velocity with submaximal loads and countermovement jump height as TS, with equivalence defined as between-group differences <0.20 Hedges' g, while substantially reducing total training time.

Materials and Methods

Study design

This study is a descriptive and explanatory analysis of the development and implementation of a research protocol within the field of strength training. The protocol centers on evaluating the feasibility of strategies for organizing exercise sets within training sessions, as well as the reliability of their application. For data collection and to document the application processes, we will utilize the Intervention Description and Replication (TIDieR) checklist (Hoffmann et al., 2014) and the Transparent Reporting (TREND) guidelines (Vallvé et al., 2005), both of which provide evidence-based recommendations for detailing the content of clinical trial protocols and randomized controlled studies. The methodological aspects for applying this intervention protocol in a quasi-experimental longitudinal study are outlined and justified below. These include the procedures for sample recruitment, details on study materials (including variables of interest) and methods, descriptions of the training sessions, and the data analysis approach that will be used to either support or refute the research hypothesis.

This study will include two randomized experimental groups: a traditional set group (TS) and an alternating set group (AS). This methodological design will facilitate the analysis and comparison of changes in vertical jump performance and strength in the SQ, BP, and PBP exercises performed on a Smith machine. Both experimental groups will follow the same VBT program but with different set configurations. The TS group will first complete all sets of the SQ exercise, followed by all sets of the BP, and finally all sets of the PBP. In contrast, the AS group will perform the SQ, BP, and PBP exercises successively in an alternating manner (Figure 1).

For the purpose of this study, and after a familiarization period, both experimental groups will train twice a week for a period of 8 weeks, utilizing the same: 1) relative load magnitude (60-80% 1RM) for each exercise and progression of it throughout the training period; 2) predetermined intra-set velocity loss (%VL) of 15% for the SQ and 20% for the BP and PBP; 3) specified training exercises and order (SQ followed by BP, and BP followed by PBP); 4) number of sets per exercise (3); and 5) inter-set recovery time (4 min), along with rest periods of 72-96 h between sessions. All participants will undergo the same testing procedure (described below) before (Pre-) and after (Post-) the training intervention, using a battery of tests. Participants will be required to refrain from any other form of strenuous physical activity, exercise training, or sports competition throughout the duration of the investigation. Every testing and training session will be conducted in a research laboratory under the direct supervision of experienced investigators/assistants, at the same time of day (±1.5 h) for each participant, and under similar environmental conditions concerning temperature and humidity.
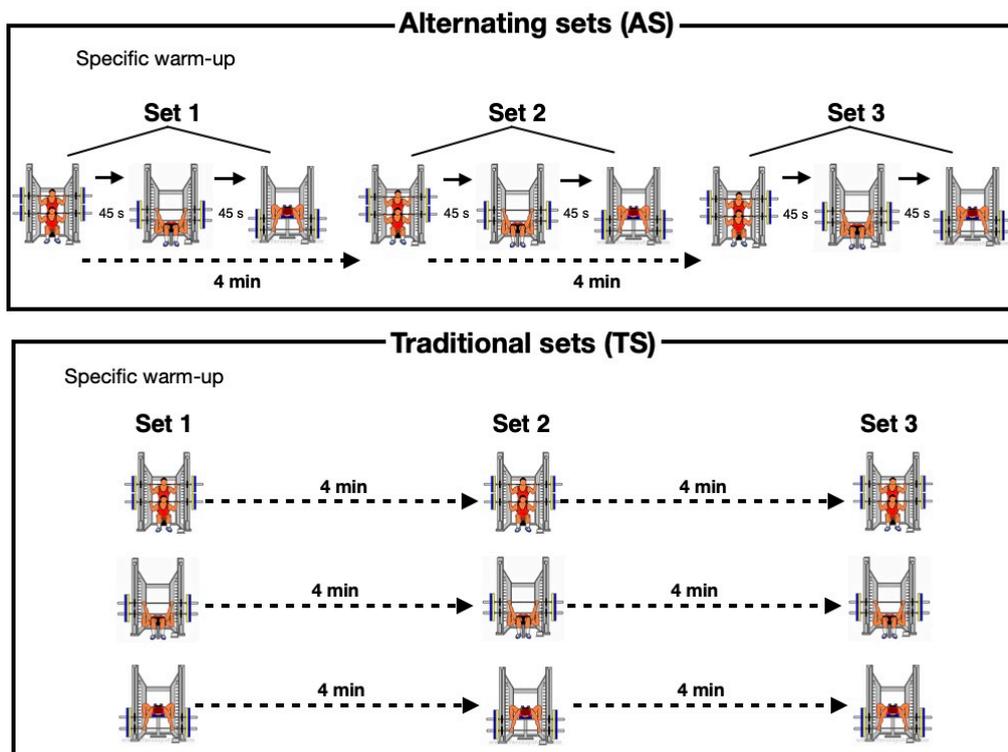

Image prepared by the author.

Figure 1. Schematic representation of the training protocol for alternating-set (top panel) and traditional-set configurations (bottom panel). In the traditional sets (TS) group, all sets of the SQ exercise are completed before progressing to the BP and PBP exercises. In contrast, the alternating sets (AS) group completes the first set of each exercise in a sequential, alternating manner. For both groups, an inter-set rest interval of 4 min is used for each exercise. However, for the AS group, an additional 45-second interval is allocated between transitions from SQ to BP and BP to PBP within each alternating sequence. Note: The estimated time required to complete the AS sequence among the three exercises is approximately 11–12 min, while the TS protocol requires approximately 26-28 min.

Table 1. Schedule of research protocol activities.

#Week	Type of session	Purpose	Session features
W1	Familiarization: 2 sessions	Improve execution technique (SQ, BP, PBP, CMJ).	Practice with varied relative loads, 2 sessions separated by ≥48 h.
W2	Pre-testing: 1 session	Assess CMJ, load–velocity relationship, and estimated 1RM in SQ, BP, and PBP.	Battery of tests: CMJ → SQ → BP → PBP.
W3	Training: 2 sessions (60% 1RM)	Initial submaximal load work.	Relative load: 60%.
W4	Training: 2 sessions (60% 1RM)	Same as W3.	Relative load: 60%.
W5	Training: 2 sessions (65% 1RM)	Progressive load increase.	Relative load: 65%.
W6	Training: 1 session (65% 1RM) and 1 session (70% 1RM)	Transition to higher loads.	Session 1: 65%; Session 2: 70%.
W7	Training: 2 sessions (70% 1RM)	Adaptation to moderate-high load.	Relative load: 70%.
W8	Training: 2 sessions (75% 1RM)	Progressive increase.	Relative load: 75%.
W9	Training: 1 session (75% 1RM) and 1 session (80% 1RM)	Final high-load phase.	Session 1: 75%; Session 2: 80%.
W10	Training: 2 sessions (80% 1RM)	Final heavy-load work.	Relative load: 80%.
W11	Post-testing: 1 session	Final performance assessment.	Same protocol and absolute loads (kg) as Pre-test.

Note 1: SQ: Squat exercise; BP: Bench press exercise; PBP: Prone bench pull exercise; MPV: Mean propulsive velocity (m/s^{-1}) of the first (or fastest) repetition of the first set.

Note 2: In all training sessions, 3 sets are performed per exercise (SQ, BP, and PBP), with relative load adjusted to the target MPV, intra-set velocity loss thresholds of 15% (SQ) and 20% (BP and PBP), fixed order (SQ → BP → PBP), 4-min inter-set rest, and 72–96 h between sessions.

Participants

For a longitudinal study type with pre-intervention and post-intervention research design, the sample would be composed of approximately 44 strength-trained young men aged between 18 and 25 years. The sample size will be calculated using the G*Power statistical software, as outlined in the statistical analyses section. The expected effect size (f = 0.33) and estimated required sample were determined based on similar prior studies using comparable participant characteristics (e.g., age, sex, training level).

Eligibility criteria

To participate in this research, participants must meet the following inclusion criteria: 1) have consistently engaged in structured, supervised RT programs for at least the previous 24 consecutive months, with a minimum frequency of ≥2 sessions/week (each session including multi-joint free-weight and/or machine exercises for both upper- and lower-body muscle groups); 2) be familiar with performing BP, SQ, and PBP exercises (alternatively, other types of back exercises); 3) refrain from any form of intense physical activity or training during the study period. This 24-month minimum was selected because most neuromuscular and morphological adaptations plateau after ~18–24 months of structured resistance training, ensuring participants are experienced lifters and beyond the early learning phase (Suchomel et al., 2018).

The exclusion criteria are as follows: 1) having any known disease or health condition that could pose a risk during intense physical exertion (e.g., renal dysfunction, cardiac abnormalities, respiratory or metabolic diseases, osteoarticular

pathologies, etc.); 2) consumption of any substances that could alter physical performance or hormonal balance for several months before or during the study.

Participant recruitment and group allocation

The sampling technique employed, as recommended by the TIDieR and TREND checklists, will be non-probabilistic, based on accessibility (Azorín & Sánchez-Crespo, 1994). After participant selection, participants will be stratified by baseline full-squat 1RM relative to body mass (threshold: ≤1.5 vs. >1.5 × body mass) before random allocation. Within each stratum, participants were assigned to TS or AS groups using a computer-generated random sequence to ensure balanced distribution of initial strength levels. Each group will be randomly formed to contain an equal number of participants, with the groups categorized as TS and AS.

An informational meeting will be conducted to explain the purpose of the study and the experimental procedures. Participants will then be asked to provide written consent by signing an informed consent form prior to their involvement in the study. This research will receive prior approval from the Ethics Committee of the institution (university and/or research center) where the study is conducted.

Variables

Independent, dependent, and controlled variables

A detailed description of the independent, dependent, and controlled intervening variables is provided in Table 2.

Table 2. Summary of independent, dependent, and controlled intervening variables.

Independent variables	Dependent variables	
	Physical performance variables	**Variables derived from the analysis of training performed**
Set configuration: TS vs. AS	Countermovement Jump (CMJ) height (cm). Estimated 1RM (kg) in the SQ, BP, and PBP exercises. Effect on the load-velocity relationship for the SQ, BP, and PBP exercises, measured through the MPV (m/s^{-1}) at all common absolute loads used in Pre- and Post-tests	Mean propulsive velocity (MPV, m/s^{-1}) of the first (or fastest) repetition of the first set in each session of the training program. Average velocity (m/s^{-1}) of the entire training program, quantifying only the repetitions performed with the training load (i.e., excluding warm-up repetitions). Average number of repetitions performed across all sets in each session. Time spent per training session (min).
Controlled intervening variables		

Weekly training frequency (2)
Training exercises and sequence/order of performance (SQ→ BP→ PBP)
Relative load (60–80% 1RM)
Velocity loss thresholds (15% vs. 20%)
Number of sets (3)
Rest intervals (4 min inter-set, 72–96 h inter-session)
Testing procedures (Pre- and Post-)
Validity of the velocity measuring device (T-Force Dynamic Measurement System, Ergotech Consulting S.L., Murcia, Spain), and its correct installation and calibration according to the manufacturer's guidelines.
Technical execution of the exercises (participant's level of experience) and familiarization with and adherence to the applied evaluation protocol.
Environmental conditions and schedule of the evaluation sessions.
Physical condition of the participants: adequate night rest, absence of previous intense physical activity, nutrition, etc.
Sex of the participants: all male or female participants.

Instruments

Lineal velocity transducer: Two units of a linear velocity transducer (T-Force Dynamic Measurement System; Ergotech Consulting Ltd, Murcia, Spain) and its associated software (version 3.70) will be used for measuring velocity of every repetition during all training and testing sessions. A complete description and analysis of this device's reliability is reported elsewhere (Sánchez-Medina et al., 2017).

Smith machine: The three RT exercises will be performed on two Smith machines during the training sessions (Multipower, Technogym, USA) without any counterweight mechanism. The extendable cable of each linear velocity transducer will be fixed to the right end of the bar. The use of a Smith machine is recommended in this study to restrict the displacement of the bar to the vertical direction, ensuring more consistent and safe measurements (Pallarés et al., 2014).

Infrared optical jumping device: Jump height will be estimated by an infrared timing device that measures flight time (Optojump Next; Microgate, Bolzano, Italy). The accuracy of this system for calculating flight time and jump height estimation has been analyzed, demonstrating high reproducibility (Glaththorn et al., 2011) and excellent relative and absolute reliability (Attia et al., 2017).

Procedure and measurement of physical performance variables

Execution technique of the SQ, BP and PBP exercises

A detailed description of the execution technique for the SQ (Sánchez-Medina et al., 2014), BP (Pallarés et al., 2014), and PBP (Sánchez-Medina et al., 2017) exercises has been previously provided. Participants in both experimental groups (TS and AS) will perform the same execution technique for the three exercises during the testing sessions as they do in the training sessions. This includes a full range of motion, a controlled eccentric phase (with a momentary pause between the eccentric and concentric phases only in the BP and PBP exercises), and a concentric phase performed at maximal intended velocity.

Familiarization and testing sessions

The previous week before the initial evaluation (i.e., Pre-test) and two weeks prior to the intervention, participants will undergo a familiarization period aimed at improving the execution technique for the SQ, BP, and PBP exercises (e.g., initial and final positions, and lifting the load at maximal intended velocity), as well as for the countermovement jump (CMJ). During this period, all participants will complete at least two familiarization sessions, spaced more than 48 h apart. Participants will be considered to have achieved adequate technique proficiency when they can perform each exercise through the full range of motion, maintain correct body alignment, and execute the concentric phase at the target maximal intended velocity (± 0.05 m·s^{-1}) without technical errors for at least two consecutive repetitions, as verified by the supervising researchers.

After the familiarization period and one week before the start of the intervention, participants' physical performance will be evaluated in a single session using a battery of tests conducted in the following sequence: (1) CMJ test; (2) progressive loading test for the SQ exercise; (3) progressive loading test for the BP exercise; and (4) progressive loading test for the PBP exercise. A detailed description of the CMJ and RT testing protocols has been previously documented (Sánchez-Medina et al., 2010; Sánchez-Medina et al., 2014; Sánchez-Medina et al., 2017). All three progressive loading tests will be conducted on the Smith machines equipped with the linear velocity transducers to measure the velocity of each repetition. For each absolute load (kg) in the progressive loading tests, only the best repetition—defined as the one with the fastest MPV and executed with correct form—will be considered for subsequent analysis (Peña et al., 2023). The reliability of the CMJ test will be assessed through test-retest variation coefficients and intraclass correlation coefficients.

The following neuromuscular performance variables derived from the progressive loading tests will be used for analysis and comparison between groups (TS vs AS): (a) individual estimation of the 1RM from the MPV attained against the heaviest load (kg) lifted in each test according to the following equations: $100 \times kg/(-5.961 \times MPV2) - (50.71 \times MPV) +$

117, for the SQ (Sánchez-Medina et al., 2017), $100 \times kg/(8.4326 \times MPV2) - (73.501 \times MPV) + 112.33$, for the BP (González-Badillo et al., 2010), and $100 \times kg/(13.2596 \times MPV2) - (93.867 \times MPV) + 144.38$ for the PBP (Sánchez-Medina et al., 2014); (b) average MPV attained against all absolute loads common to Pre- and Post-tests; (c) average MPV at all absolute loads common to both tests at velocities equal to or greater than 1.00 m·s^{-1} (AV ≥ 1.0), 0.80 m·s^{-1} (AV ≥ 0.8), and 1.05 m·s^{-1} (AV ≥ 1.05) for the SQ, BP, and PBP exercises, respectively; and (d) average MPV at all common absolute loads lifted at velocities less than 1.00 m·s^{-1} (AV < 1.0), 0.80 m·s^{-1} (AV < 0.8), and 1.05 m·s^{-1} (AV < 1.05) for the SQ, BP, and PBP exercises, respectively. The last three variables have demonstrated high reliability and allow for a more comprehensive analysis of training-induced adaptations across the load-velocity spectrum compared to focusing solely on the 1RM value (Pallarés et al., 2014; Pareja-Blanco et al., 2014).

Before performing the first test, participants will complete a general standardized warm-up protocol lasting 5 min. This warm-up will consist of jogging, joint mobilization exercises, and dynamic stretching, followed by a specific warm-up protocol that includes progressive loads for each RT exercise (explained later). Participants will also perform five countermovement jumps (CMJs) at progressively increasing effort (30 s rest) and three CMJs at maximal effort (45 s). All participants will be assessed with the same testing procedure and battery of tests before (Pre-test) and after (Post-test) the 8-week training intervention. The time elapsed between the Pre-test and the start of the intervention will be 72–96 h, and the same duration will be maintained between the end of the training period and the post-test.

Note: Comprehensive safety procedures, stopping rules, and adverse events reporting are detailed in the Annex 1.

Training sessions

Before each training session, participants in both experimental groups will complete a general standardized warm-up (as described above) and a specific warm-up, consisting of three sets of eight, five, and two repetitions (with a 2-min rest between sets) at loads of 20 kg, 25 kg, and the proposed absolute load that best corresponds to the scheduled target MPV. These loads will be performed at moderate, high, and maximal intended velocity, respectively. Detailed characteristics of the scheduled VBT program for both groups are provided in Table 3 (SQ exercise), Table 4 (BP exercise), and Table 5 (PBP exercise).

Between three and five days following the initial evaluation, all participants will complete a total of 16 VBT sessions over 8 weeks, with two sessions per week and 72–96 h between sessions. Each session will involve performing the SQ, BP, and PBP exercises in the same sequence on a Smith machine. Apart from the set structuring (i.e., TS vs. AS), all training variables—including relative loads (%1RM), intra-set %VL for each exercise, number of sets per exercise, rest between sets, and frequency of sessions with each relative load—will remain consistent across the two experimental conditions throughout the intervention.

In line with the VBT procedure, the training relative load (%1RM) for each session will be individualized based on the MPV of the fastest repetition, derived from the established load-velocity relationship for SQ (Sánchez-Medina et al., 2017), BP (González-Badillo et al., 2010), and PBP (Sánchez-Medina et al., 2014). The target MPV for the first (typically fastest) repetition of the initial set of each session will serve as an indicator of %1RM (e.g., 1.00 m · s^{-1} ≈ 60% 1RM in SQ). After adjusting the load (kg) to achieve the target MPV (±0.03 m · s^{-1}) associated with the %1RM, this load will be maintained for all sets in that session.

Volume (i.e, number of repetitions per set) will be regulated by the intra-set %VL, with each set terminating once the specified %VL threshold is reached, irrespective of the number of repetitions completed by each participant (Rodríguez-Rosell et al., 2020). All repetitions in each session will be monitored and recorded using a linear position transducer. During training, participants will receive immediate velocity feedback and will be encouraged to perform each repetition at maximal intended velocity. Fixed moderate intra-set %VL values will be set for each exercise using the transducer software to

ensure a comparable level of fatigue across participants by the end of each set (Gonzalez-Badillo et al., 2017). Different %VL thresholds will be applied across exercises (15% for SQ and 20% for BP and PBP) to keep repetitions per set below half the maximum possible for the given load and to standardize effort between exercises (Rodríguez-Rosell et al., 2020). This strategy is supported by evidence showing that specific %VL thresholds correspond to distinct levels of metabolic stress, neuromuscular fatigue, and hormonal response, which differ by muscle mass involved. Slightly lower thresholds are therefore recommended for lower-body exercises to prevent excessive fatigue, while slightly higher thresholds are needed for upper-body pressing and pulling exercises to match the relative effort (Sánchez-Medina & González-Badillo, 2011; Pareja-Blanco et al., 2017).

Two researchers will assist each session to ensure correct exercise technique and to adjust absolute loads as needed to align with the scheduled intensity (i.e., MPV) for each session. For the AS group, each training session will require two Smith machines and two linear velocity transducers, with the SQ and BP exercises performed on one Smith machine and the PBP on the other. This 45-second period is determined from pilot testing with eight trained participants (20.4 ± 1.9 y; 2.5 ± 0.8 y training experience) completing AS sequences under supervision. This duration consistently allowed assistants to adjust loads and participants to reposition correctly without extending total session time beyond the intended time-efficiency goal. Similar transition durations have been reported as adequate in RT research involving multiple exercises (Paz et al., 2017; Weakley et al., 2020) and reflect realistic time requirements in practical strength training environments. This adjustment process will be repeated for each set.

Table 3. Descriptive characteristics of the scheduled velocity-based squat training program for both experimental groups.

# Session	1	2	3	4	5	6	7	8
Target MPV (m·s-1)	1.00	1.00	1.00	1.00	0.92	0.92	0.92	0.84
1RM (%)	~60%	~60%	~60%	~60%	~65%	~65%	~65%	~70%
Sets x VL (%)	3 x 15%	3 x 15%	3 x 15%	3 x 15%	3 x 15%	3 x 15%	3 x 15%	3 x 15%
# Session	9	10	11	12	13	14	15	16
Target MPV (m·s-1)	0.84	0.84	0.76	0.76	0.76	0.68	0.68	0.68
1RM (%)	~70%	~70%	~75%	~75%	~75%	~80%	~80%	~80%
Sets x VL (%)	3 x 15%	3 x 15%	3 x 15%	3 x 15%	3 x 15%	3 x 15%	3 x 15%	3 x 15%

Note: MPV: mean propulsive velocity attained against the intended load (%1RM); VL: Velocity loss.

Table 4. Descriptive characteristics of the scheduled velocity-based bench press training program for both experimental groups.

# Session	1	2	3	4	5	6	7	8
Target MPV (m·s^{-1})	0.78	0.78	0.78	0.78	0.70	0.70	0.70	0.62
1RM (%)	~60%	~60%	~60%	~60%	~65%	~65%	~65%	~70%
Sets x VL (%)	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%
# Session	9	10	11	12	13	14	15	16
Target MPV (m·s^{-1})	0.62	0.62	0.55	0.55	0.55	0.47	0.47	0.47
1RM (%)	~70%	~70%	~75%	~75%	~75%	~80%	~80%	~80%
Sets x VL (%)	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%

Note: MPV: mean propulsive velocity attained against the intended load (%1RM); VL: Velocity loss.

Table 5. Descriptive characteristics of the scheduled velocity-based prone bench pull training program for both experimental groups.

# Session	1	2	3	4	5	6	7	8
Target MPV (m·s^{-1})	1.06	1.06	1.06	1.06	0.98	0.98	0.98	0.91
1RM (%)	~60%	~60%	~60%	~60%	~65%	~65%	~65%	~70%
Sets x VL (%)	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%
# Session	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Target MPV (m·s^{-1})	0.91	0.91	0.84	0.84	0.84	0.77	0.77	0.77
1RM (%)	~70%	~70%	~75%	~75%	~75%	~80%	~80%	~80%
Sets x VL (%)	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%	3 x 20%

Note: MPV: mean propulsive velocity attained against the intended load (%1RM); VL: Velocity loss.

Statistical analyses

To ensure the statistical significance of the proposed research design (quasi-experimental with pre- and post-intervention data collection), an a priori power analysis was conducted using G*Power 3.1.2 (Kang, 2021). The analysis was based on a two-way repeated-measures ANOVA (within–between interaction) with two groups (TS vs. AS) and two time points (Pre- vs. Post-intervention), considering the primary outcome variables (MPV against submaximal loads for SQ, BP, and PBP, and CMJ height). The input parameters were: effect size f = 0.33 (medium-to-large magnitude) in MPV and vertical jump performance based on previously published VBT training interventions (Pareja-Blanco et al., 2017; Peña et al., 2023), α = 0.05, desired statistical power (1–β) = 0.95, correlation among repeated measures = 0.85, and nonsphericity correction ε = 1.0. This yielded a required total sample size of n = 36 participants (18 per group) to detect statistically significant group × time interaction effects. To account for potential attrition (~20%), the target recruitment range was set at 40–50 strength-trained men. Secondary outcomes will include estimated 1RM values across the three exercises.

Descriptive statistics will be calculated and presented as means or medians (the latter for non-homogeneous distributions), along with standard deviations (SD). To assess normality, the Kolmogorov–Smirnov test will be applied, and Levene's test will evaluate homogeneity of variances between groups. The selection of parametric or non-parametric tests will be predefined according to the expected distribution of each variable based on prior literature and pilot data.

To test for training-related effects, a 2 (group: TS vs. AS) × 2 (time: Pre- vs. Post-) factorial ANOVA with Bonferroni adjustment will be performed. When multiple comparisons are conducted, corrections will be applied to control the Type I error rate. Differences in training variables (MPV, %VL intra-set, and number of repetitions performed across different velocity ranges) between training conditions will be analyzed using a Student's t-test for independent variables. For non-normally distributed data (Berlanga et al., 2012), the non-parametric Mann–Whitney U test will be applied.

Missing data will be addressed using an intention-to-treat approach, with multiple imputation when appropriate (Sterne et al., 2009). Per-protocol analyses (≥85% session adherence) will also be performed for comparison. All protocol deviations will be documented, and their potential influence on results assessed descriptively. Additionally, a planned sensitivity analysis will be conducted by repeating the main analyses only with participants achieving ≥90% adherence to scheduled sessions, to verify the robustness of the findings.

The intra-group effect size will be calculated using Hedge's g based on pooled SD (Lakens, 2013), with values considered small (< 0.20), medium (0.21–0.50), large (0.51–0.80), and very large (0.81–1.30). Additionally, the intra-group percent change for each dependent variable between the two time intervals (Pre- vs. Post-) will be estimated. Statistical significance will be set at $p < .05$ and $p < .001$.

All statistical analyses will be performed using SPSS software version 29.0 (SPSS, Chicago, IL) and the Jamovi Cloud statistical package (online version).

Desired outcomes and discussion

One goal of training methodology should be to develop more efficient strategies, that is, procedures that achieve equal or greater physical performance with less effort per session and/or within a shorter training time. This study provides a detailed description of the preliminary processes and intervention protocol used to examine the effects on muscle strength and physical performance of different RT set configurations (i.e., traditional vs. alternating sets). The research design aims to support future researchers and coaches in analyzing and implementing a time-efficient training strategy without compromising expected strength gains. It is anticipated that alternating sets between different upper- and lower-body exercises, performed while limiting fatigue accumulation within each set (i.e., stopping each set before reaching 50% of the maximum possible repetitions at each load), will yield similar improvements in strength and vertical jump capacity as traditional sets.

In this regard, to the best of our knowledge, only one prior study has analyzed the chronic effects of RT programs using a VBT approach on muscle strength and physical performance variables, focusing on different set configurations (traditional vs. alternating), and using two paired exercises that successively involved lower- and upper-limb muscle groups (Peña et al., 2023). However, limitations of that study include a small sample size, moderate strength levels of the participants, and a relatively short training duration (6 weeks). Moreover, no longitudinal studies have applied our design with a sequence of three lower- and upper-body exercises (i.e., one lower-body exercise followed by two antagonistic upper-body exercises), which could further reduce training time compared to a traditional set configuration that involves only two exercises.

In our view, this new study presents several characteristics and strengths that enable us to address gaps in the existing scientific literature. First, the research includes a sufficiently large and homogeneous sample of strength-trained young men to minimize the risk of a Type II error. Second, our study includes three commonly performed RT exercises that engage both upper- and lower-body muscle groups to analyze the differences in chronic effects produced by identical training programs that utilize different set configurations. Third, the procedure used to control variables related to the training load applied in each session (volume and intensity) is the VBT approach, which allows for a more accurate equalization of the effort level exerted by the different participants in each experimental group and in each training session.

Fourth, the intervention utilizes moderate-to-high relative loads (60–80% of 1RM) and ensures consistent control of velocity loss thresholds (15–20%) to standardize effort. Finally, the duration of the training intervention (8 weeks) is longer than that used in previous studies, potentially allowing for more meaningful and observable adaptations in muscle strength and physical performance.

Study limitations

The implementation of this study may face certain limitations and uncertainties. First, it may encounter logistical challenges, as each training session requires two assistants, two Smith machines, and two linear velocity transducers (along with two computers equipped with the necessary software). While this setup ensures precise control of training variables and enhances internal validity, it also limits applicability in settings with restricted resources. In such cases, the protocol could be adapted by pairing exercises that can be performed on a single Smith machine, allowing longer transition times for manual load adjustments, or replacing continuous velocity monitoring with periodic assessments to reduce equipment demands. In the AS group, the three exercises must be performed consecutively, within a time interval of 45 seconds between exercises. This time frame was determined to be sufficient based on prior experience to allow the

assistants to adjust the loads and reposition equipment efficiently between exercises. This aspect should be addressed during the familiarization sessions.

On the other hand, despite the methodological precautions taken in this study, certain confounding factors and potential biases must be acknowledged, as they may influence the interpretation of the results. The use of a homogeneous sample of strength-trained young men improves internal validity, but findings should be interpreted cautiously when considering other populations or training contexts. Another potential source of bias is interindividual neuromuscular variability, which may influence adaptations to the training protocol. Although participants followed a standardized training regimen and are randomized into groups, individual differences in recovery capacity, muscle fiber composition, or prior training history could affect performance outcomes. Furthermore, external lifestyle factors, such as sleep quality, nutritional intake, and daily physical activity levels, are not strictly controlled. While participants are instructed to maintain their usual habits and refrain from additional structured training, variations in these factors may contribute to differences in adaptation to the training protocols. Finally, although all training sessions are supervised and conducted in a controlled laboratory setting to ensure adherence to the protocol, motivation levels and effort exerted by participants may vary. The use of objective monitoring tools, such as linear velocity transducers, help standardize execution intensity, but psychological factors could still play a role in performance differences. Additionally, no inter-session reliability measures are planned to assess the consistency of training execution over time, although all sessions will be conducted by the same researchers using the same equipment under standardized conditions.

Prospective research

The findings of this study could encourage further research in this field by replicating the same study design under varying training conditions, such as different types of exercises, training loads, and populations, as well as by proposing new hypotheses. For example, a hypothesis worth exploring is whether alternative combinations of exercises, performed with moderate to low fatigue levels per set (<25% velocity loss in the set), might yield outcomes comparable to those found in this study. Such ideas underscore the need for additional research to deepen understanding in this area.

Moreover, future intervention studies could explore the broader applicability of this training strategy in different practical contexts or populations, evaluating whether similar performance improvements can be achieved with other exercise combinations or under different load and rest configurations.

Conclusions

This study provides a detailed description of the preliminary processes and intervention protocol used to examine the effects on muscle strength and physical performance of different RT set configurations (e.g., traditional vs. alternating sets). This research design aims to support future researchers and coaches in analyzing and implementing a time-efficient training strategy without compromising expected strength gains.

However, acknowledging the aforementioned limitations is crucial for a comprehensive interpretation of the findings and underscores the need for further research in more diverse populations (e.g., women and individuals with different strength-training backgrounds), with varying training backgrounds and under different training conditions, before validating this protocol as an optimal strategy.

Practical applications

The main contribution of this study is the detailed description of a protocol for comparing the effects of traditional and alternating sets on physical performance using a velocity-based training approach. Designed according to the scientific method, this protocol ensures reproducibility, validity, and statistical reliability. Its structure may serve as a practical model for implementing time-efficient resistance training programs in both research and applied settings.

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